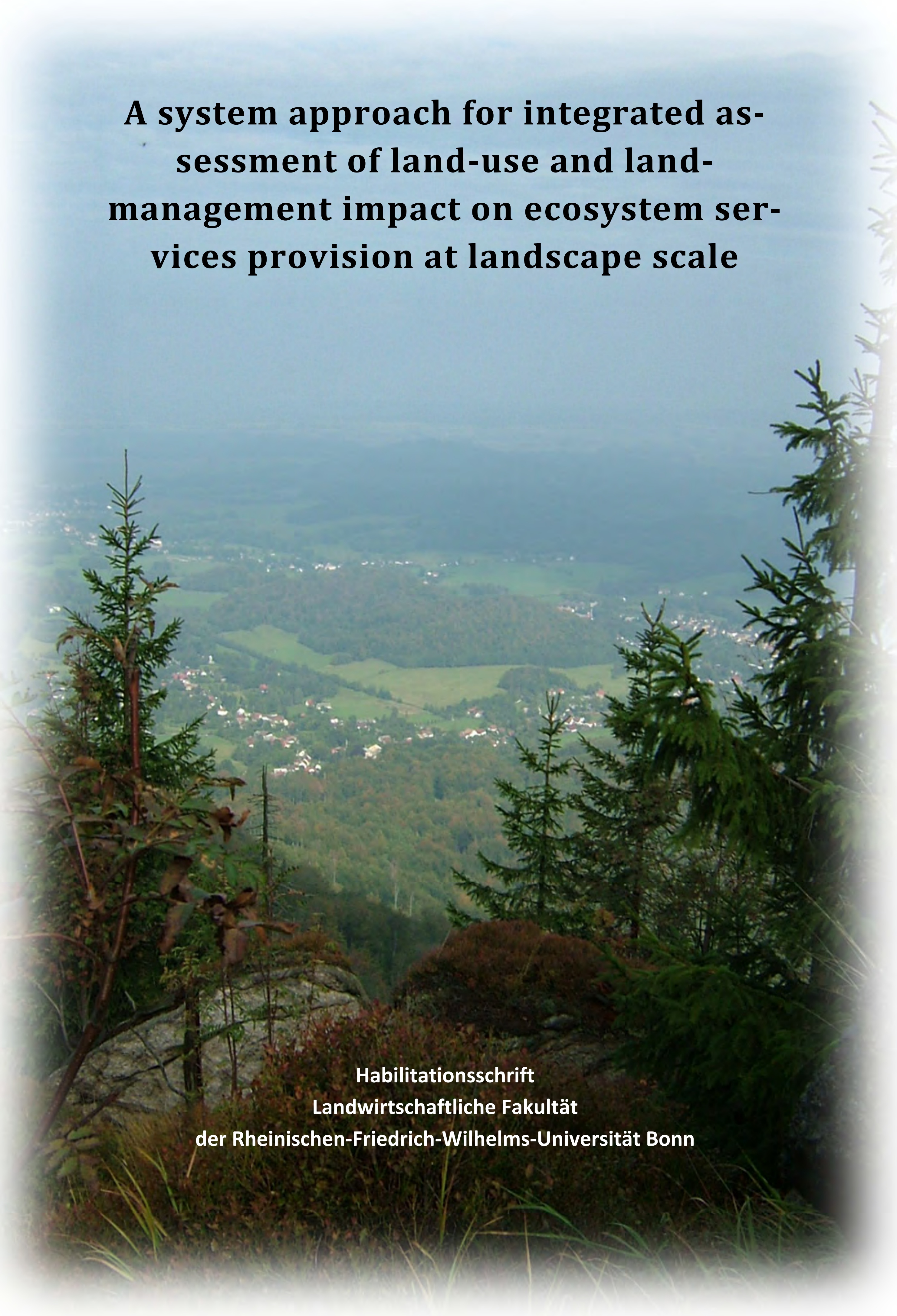
A system approach for integrated assessment of land-use and land-management impact on ecosystem services provision at landscape scale



Habilitationsschrift
Landwirtschaftliche Fakultät
der Rheinischen-Friedrich-Wilhelms-Universität Bonn

Habilitationsschrift

A system approach for integrated assessment of land-use and land-management impact on ecosystem services provision at landscape scale

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"Planning and management of land resources are integral parts of any rural development program as well as many development programs with both rural and urban components.
Land-use does not consider agricultural uses only but also encompasses natural areas, forests, water-courses and urban areas among others.
Land-use planning has often had negative connotations because it was traditionally associated with top-down procedures. [...].
Conventional land-use planning has frequently failed to produce a substantial improvement in land-management, or to satisfy the priority objectives of the land-users. As a result, rural development programs have had mixed success in meeting production and conservation aims."

FAO (1999)

Content and Structure

Table 1: List of publications that form the basis of this habilitation thesis.

#1 Frank, S., *Fürst, C.*, Koschke, L., Makeschin, F. (2011): **Towards the transfer of the ecosystem service concept to landscape planning using landscape metrics**. Ecological Indicators 21:30-38.

#2 Fürst, C., C. Davidsson, K. Pietzsch, M. Abiy, F. Makeschin, C. Lorz, and M. Volk (2008.):"**Pimp your landscape" – interactive land-use planning support tool.** Transactions on the Built Environment (ISSN 1743-3509). Geoenvironment and Landscape Evolution III: 219-232.

#3 Fürst, C., Nepveu, G., Pietzsch, K., Makeschin, F. (2009): **Comment intégrer des considérations multicritères dans la gestion d'un territoire ? "Pimp your landscape" - un essai de planification interactive pour satisfaire les besoins des utilisateurs**, Revue forestière française 1-2009 :21-35.

#4 Fürst, C., Vacik, H., Lorz, C., Potocic, N., Krajter, S., Vuletic, D., Makeschin, F. (2010a): **How to support forest management in a world of change? Results of some regional studies.** Environmental Management 46(6): 941-952.

#5 Fürst, C., Volk, M., Makeschin, F. (2010b): **Squaring the circle - how to combine models, indicators, experts and end-users for integrated land-use management support?** editorial / leading paper, Environmental Management 46(6):829-833.

#6 Fürst, C., König, H., Pietzsch, K., Ende, H.P., Makeschin, F. (2010c): **Pimp your landscape - a generic approach for integrating regional stakeholder needs into land-use scenario design and sustainable management support**. Ecology and Society 15(3): 34, 25 pp.

#7 Fürst, C., Volk, M., Pietzsch, K., Makeschin, F. (2010d): **Pimp your landscape! A tool for qualitative evaluation of the effects of regional planning measures on ecosystem services**. Environmental Management 46(6):953-968.

#8 Fürst, C., Lorz, C., Makeschin, F. (2011): **Integrating land-management aspects into an assessment of the impact of land cover changes on Ecosystem Services**. International Journal of Biodiversity Science, Ecosystem Services Management. 7(3):168 -181.

#9 Fürst, C., Pietzsch, K., Frank, S., Witt, A., Koschke, L., Makeschin, F. (2012): **How to better consider sectoral planning information in regional planning - example afforestation and conversion**. Journal of Environmental Planning and Management 55(7):855-883.

#10 Fürst, C., Frank, S., Witt, A., Koschke, L., Makeschin, F. (in press): **Assessment of the effects of forest land-use strategies on the provision of Ecosystem Services at regional scale**. Journal of Environmental Management, http://dx.doi.org/10.1016/j.jenvman.2012.09.020.

#11 Fürst, C., Helming, K., Lorz, C., Müller, F., Verburg, P. (acc.): **Integrated land-use and regional resource management – A cross-disciplinary dialogue on future perspectives for a sustainable development of regional resources**;. Journal of Environmental Management, Elsevier.

#12 Fürst, C., Flügel, W. (in rev.): **Impact of land-use changes on providing hydrological ecosystem functions (ESF) and services (ESS).** In: Chicharo, L., Müller, F., Fohrer, N., Wolanski, C.: "Ecosystem Services and River Basin Ecohydrology", Springer publisher.

#13 Koschke, L., *Fürst, C.*, Frank, S., Makeschin, F (2012): **A multicriteria approach for an integrated land-cover-based assessment of ecosystem services provision for planning support**. Ecological Indicators 21: 54-66.

#14 Lorenz, M., Thiel, E., *Fürst, C*. (in rev.): **Integration of agricultural practices into regional assessment-systems - combining regional crop sequences with agricultural management and soil protection techniques**. Journal of Environmental Management.

#15 Witt, A., *Fürst, C*., Makeschin, F. (in press): **Regionalization of Climate Change sensitive forest ecosystem types for potential afforestation areas**. Journal of Environmental Management, http://dx.doi.org/10.1016/j.jenvman.2012.08.007.

Table 2: List of research projects in which the development of the system approach was done and assignment of the related publications according to Tab. 1.

Project name, year, funding organization	**Contribution to GISCAME development**	**related to articles**
DynamicDATA EU25+, 2006, cooperation with MOEL/SOEL countries, German Federal Ministry of Education and Research	Start of the user requirements analysis	2, 4
ENFORCHANGE, 2005 – 2009, FONA program, German Federal Ministry of Education and Research, Germany www.enforchange.de	User requirements analysis and adaptation of the first version in the Upper Lusatian part of the case study "Euro-Region Neisse"	5, 6, 7
IT-Reg-EU, 2007, Interreg-III-A / EU http://boku.forst.tu-dresden.de/IT_Reg_EU/	User requirements analysis, development of the GISCAME prototypes for Euro-Region Neisse	3, 6, 7
IWAS – Internationale Wasserallianz Sachsen, 2009 - ongoing, German Federal Ministry of Education and Research www.ufz.de/iwas-sachsen/	Technological adaptation of the software to river basins with irregular shapes of the model region	--
KIDS, 2009 – 2010, Deutsche Bundesstiftung Umwelt http://kids.letsmap.de/index.php	Development of an environmental education application of GISCAME	2
REFORMAN, 2007 – 2008, SEE ERA Net, EU www.reforman.de	User requirements analysis	2, 4
REGIOPOWER, 2012 – ongoing, joint call WoodWisdom / BioEnergy ERA Net www.eli-web.com/RegioPower/	Coupling with production, growth and yield models and linking with a regional feed-stock market model	1, 10, 11, 12, 13, 14, 15
REGKLAM 2009 – now, KLIMZUG program, German Federal Ministry of Education and Research www.regklam.de	Adaptation of GISCAME for regional planning and assessment of regional climate change land-use adaptation strategies	1, 5, 8, 9, 10, 13, 14, 15
REG-TRANSEKT, 2007 – 2008, Marketing of Research Results in MOE/SOE countries, German Federal Ministry of Education and Research http://boku.forst.tu-dresden.de/Reg_Transekt/	User requirements analysis	2, 4
TrainForEducation, 2008 - 2010, Leonardo da Vinci, EU www.foreducation.nlcsk.sk/de/novinky.html	Development of an eLearning application of GISCAME	2

Synopsis

The publications presented here describe the way to develop a system approach for integrated assessment of land-use and land-management impact on ecosystem services provision at regional scale.

“System approach” means in this context a methodological and analytical framework in which supporting software components, analytical methods from landscape ecology, multicriteria evaluation and support of participation mechanism in regional planning are brought together.

The structure of this extended explanation, of how the different publications contribute to the cumulative habilitation thesis according to §6(4) of the “Habilitationsordnung der Landwirtschaftlichen Fakultät der Rheinischen Friedrich-Wilhelms-Universität Bonn, 4.12.2000”, is as follows:

- section 0 “Introduction” starts from challenges in land-use and management planning that led to the system idea and formulated the research questions that underlay the system development,
- section 1 “User requirements analysis” derives the development profile of the system approach based on a bottom-up (user requirements based) approach,
- section 2 “Methodological approach” documents the system development, implementation, iterative improvement and the widening of the approach,
- section 3 “Application” demonstrates some application cases in case studies and the lessons learnt from them,
- section 4 “Discussion and conclusions” discusses implications on the applicability and transferability of the approach and concludes on how to further evolve the approach,
- section 5 “Summary” resumes the development process and further application of the approach.

Publications that form the basis of this habilitation thesis are listed in Tab. 1. Tab. 2 provides an overview on the different research projects in whose context system development and articles were generated.

0. Introduction

0.1 Development background and history

The idea to develop a system approach for integrated assessment of land-use and land-management impact on ecosystem services provision at regional scale was born in 2006/2007 in the context of several joint research projects (DynamicDATA EU 25+, ENFORCHANGE, IT-REG-EU, REG-TRANSEKT and REFORMAN). These projects dealt with the question of how to adapt and improve basics for land-use planning with an original focus on forestry in a transnational context.

As a result, the development of the software system“ GISCAME” was initialized to better involve stakeholders in a way that offers them the opportunity to announce, describe and assess their planning objectives and to enter into exchange with other planning actors (#2 – Fürst et al., 2008; #4 – Fürst et al., 2010a). The original system concept was based on approaches that have been developed for decision support, decision making, and management support (#4 – Fürst et al., 2010a; #5 Fürst et al., 2010b). As a lesson learnt from its application, the focus of GISCAME was soon put more on accompanying regional and land-use planning processes and reflection on the impact of planning actor preferences instead of on providing decisions or decision alternatives (#6 Fürst et al. - 2010c; #7 – Fürst et al., 2010d; #11 Fürst et al., acc.; #12 Fürst et al., in rev.).

In the further development and implementation of GISCAME, new users – especially from regional planning and development – came up and increasing demands on analytical features had to be satisfied (#8 Fürst et al., 2011; #9 – Fürst et al., 2012; #10 – Fürst et al., in press).
In the joint research projects REGKLAM and RegioPower, GISCAME was adapted to the analytical, evaluation and participation needs in regional planning, was used for the identification of land-use adaptation strategies to climate change, and was developed to provide interfaces to regional resource management (#1 – Frank et al., 2011; #13 – Koschke et al., 2012; #14 Lorenz et al., in rev.; #15 Witt et al., in press). As an application area, which will not be expanded upon in this synthesis, GISCAME was also modified and adapted for environmental education and e-Learning in the projects KIDS and TrainForEducation in Austria, Czech Republic, Germany, Slovakia and Poland, which lead to simplification of some analytical features in the core of the system.

Currently, GISCAME is being tested and further developed for a set of model regions in Europe (Finland, Germany, Slovenia, Sweden) with a focus on regional planning regarding regional timber resource management, in South-America (Brazil, project IWAS; Chile) for application in integrated water management (Lorz et al., in press; Lorz et al., 2010) and territorial planning, and in the context of the West African Science Service Center for Climate Change and Adapted Land-use (WASCAL) for application in land-use planning in West Africa.

0.2 Requests for integrated land-use and land-management planning

Planning instruments and among them software tools that intend to support land-use and land-management planning and – in this context – an integrated assessment of land-use change impacts on ecosystem services have to deal with a number of problems.

First, ecosystem functioning and processes, ecosystem interactions and how these contribute to performance of land-(use) systems in providing natural resources and services for society are greatly dependent upon the scale of interest (Müller, 1992; Steinhardt and Volk, 2003; Volk et al., 2008; Rossing et al., 2007).
For integrated assessment of land-use and land-management impact, the meso scale turned out to be most appropriate for delivering sufficient interfaces to micro and macro scale aspects (#11 - Fürst et al., acc.). For instance, land-use and its spatial constellation at catchment scale play an important role for improving flood-plain ecology, soil protection, and river as well as groundwater quality (Steinhardt and Volk 2003; Gaiser et al., 2008; Volk et al., 2008). Also, impact of land-use and land-management practices is mostly assessed at the level of the management planning entity (micro scale to meso scale), taking water and nutrient balance, hydrological processes or reactions of species communities as an example for typically assessed parameters. Therefore, studies at the micro and meso scale are of high relevance as they provide the data needed to parameterize larger scale modeling exercises, to understand relevant biophysical processes and to provide the basis for assessing the impact of land-use and land-management changes.
Yet, process-based models and simulators, such as forest growth simulators, are mostly applied at micro scale (e.g. Crookston and Dixon, 2005; Pretzsch et al., 2002). Most of these models do not provide sufficient interfaces to the meso or macro scale, which impedes an evaluation of the environmental impact of land systems (Bragg et al., 2004). Only a few models are compatible in their temporal and spatial resolution, an aspect which complicates, for instance, the impact assessment of land-use changes if several models and model types are used in parallel (#5 - Fürst et al., 2010b). Also, even though environmental data for initialization and parameterization of such models should be officially available from monitoring or public data bases, access is difficult and even accessible data need to be harmonized in spatial and temporal scale, projection and format.
On the other hand, macro scale models might miss the integration of land-use aspects in sufficient detail as their focus is more often laid on impact assessments of policies and large-scale development strategies in the context of global change (Le et al., 2008; Helming et al., 2008).

Second, and probably even more relevant, are interdependencies between scales. Processes at micro and meso scale interact with processes at global scale, taking global warming and greenhouse gas (GHG) emission from permafrost soils as an example (VijayaVenkataRaman et al., 2012). Abundance of rare species and species diversity is dependent not only upon the existence and quality of specific habitats, but also upon their spatial context and connectivity at landscape scale (Nagendra et al., in press). Hydrological processes at regional scale are impacted by land-use and vegetation cover at the management planning unit level, but at the same time also by the share of land-use types, their spatial distribution and pattern in a regional context (Giertz et al., 2005).

Third, land-use planning is being confronted with specific and often completely different temporal dynamics in ecosystems or land-use types that form part of a land system. Taking forests as an example, forest management planning foresees a division into strategic (long term = at least one rotation period) planning, tactical (mid-term = up to 30 years) planning and operational (short term = up to 10 years) planning (Baskent and Keles, 2005). Strategic planning in forestry must respect political and societal aims addressing, for instance, sustainable biomass provision or nature conservation. Once a strategic decision is made, such as conversion of coniferous into deciduous forest stands, tactical and operational planning are forced to translate this decision into concrete silvicultural measures and management operations. In the event that a strategic decision must be revised due to new, complementary or competing regulations, managing the tree species composition and stand structure according to a new strategy is difficult or takes at least several decades (#5 - Fürst et al., 2010b). In contrast, agricultural land-use – especially arable farming – can react intra-annually to altered conditions that force the farmer to switch, for instance, to other cropping systems (Olesen et al., 2011). Sealing of open areas or waste land in the vicinity of urban systems can even happen daily (EC, 2012). Different temporal and spatial dynamics in land-use, scale interactions, incomplete knowledge, taking ecosystem responses to climate change as an example, result in high uncertainties in land-use and landscape modeling (Hou et al., in press; Verburg et al., in press).

This leads to the issue of how to make scientific knowledge regarding eco- and land system responses to land-use and land-management changes operational for planning processes. Available knowledge is often scattered among manifold knowledge holders, so that a more holistic view on ecological effects of planning decisions and how these interact again with economic and societal parameters is not so easily available. Also, the provision of natural resources cannot be changed by looking exclusively at single ecosystems or land systems without understanding their interplay in a specific cultural and societal context. A precondition for sustainability is therefore a highly integrative viewpoint regarding land-use and land-use planning.

Concepts such as ecosystem services (MEA, 2005), land-use functions (Perez-Soba et al., 2008) or landscape services (Temorshuizen and Opdam, 2009) provide a framework for integrative land-use planning. They necessitate a translation of biophysical findings into more aggregated terms that can be communicated and used in planning processes. Furthermore, benefits might arise from using these concepts as they help to identify and consider also those services and potential future threats in their provision which are not of current interest for the planning actors. Examples therefore are regulating or cultural ecosystem services that are often neglected in planning due to more urgent pressures such as ensuring food-security or enabling economic development (see e.g. Gómez-Baggethun and Barton, in press).

A problem when referring to the ecosystem services concept or comparable approaches is, however, that existing monitoring or survey networks are not prepared to deliver information that is requested to assess and monitor the provision of services (Chapman, 2012). Related is the question of the selection and interpretation of suitable criteria and indicators which enable an integrated assessment of ecosystem and land system processes and their impact on services provision. The high number and variety of criteria and indicators to assess the impact of human activities on the environment at different scales impedes interpretation and harmonization of indicator-based assessment approaches and might limit their usefulness in supporting land-use decisions (#13 – Koschke et al., 2012). To make ecosystem services, land-use functions and/or landscape services applicable to land-use planning practice, these concepts need to be kept open to modifications by planning actors and to allow the introduction of planning objectives that are relevant and assessable (#13 – Koschke et al., 2012; Koschke et al., 2010).

A central objective of land-use and land-management planning is that the vision of sustainable development is brought down to spatially differentiated objectives and standards that have to be (a) made assessable by concepts such as ecosystem services and (b) disputed in participatory decision processes (Costanza et al. 1997; Petry 2001; Mendoza and Martins, 2006; Hein et al., 2006).
A problem in this context is the lack of actor involvement often due to language barriers, a lack of mutual understanding between actors and sectors, and quasi non-existent inter- and trans-disciplinary communication (e.g. Reed, 2008). However, the formulation of planning and management objectives at meso scale is no longer the preserve of a few specialized experts, rather is it the outcome of discussions among planners, politicians, land-users and the concerned public who form a heterogeneous group of stakeholders with different interests and demands (Petry 2001; Hirschfeld et al., 2005; Newham et al., 2006; Volk et al., 2008; Rosa 2008; Volk et al., 2009).
Land-use and land-management planning processes have to consider that concerned land owners argue from a local, micro-economic point of view. Other actors in planning, such as water providers, are more likely to address catchments as spatial entities that are somehow located between micro and meso scale. Actors such as nature conservation organizations might have both scales in their target system, the protection of the rare habitat at micro scale or maintaining the unique character of a region at meso scale. In all cases, the prior use or protection interest of a party limits the success of each other party to accomplish their land-use interests (e.g. Pravat and Humphreys, in press).
Also, the degree of freedom to change the land-use pattern or to intensify land-use by innovative land-use strategies that increase the provision of natural resources without consuming more land and provoking land-use conflicts, is limited by legal and administrative regulations, land-ownership rights, socio-cultural concepts, or natural restrictions arriving from climate or edaphic conditions (Irwin and Geoghegan, 2001; Krausmann et al., 2003).
Planning requires therefore approaches that support moderation between stakeholders with conflicting or even incompatible land-use interests and the inclusion of expert knowledge in consensus building (Higgs et al., 2008; Lennertz et al., 2008).

In a society that is characterized by globalization effects, interactions between agencies and institutions at an international level impact additionally land-use planning at regional scale. Cross-sectoral policy making processes in agriculture and forestry as they are requested in realizing the renewable energy provision targets in Europe might serve as an example, where macro scale objectives provoke land-use conflicts at meso to micro scale.
Increasing demands for public goods from citizens that are more and more scrutinizing the impact of land-use on their private interests in recreation, scenic beauty and experiencing nature add additional conflicts in achieving acceptance on land-use planning decisions (see e.g. Rakodi, 2001).
All these aspects make it difficult to answer even simple questions, such as “whose and which demands to consider primarily at the different and at the same time interwoven spatial scale levels?”.

0.3 Research and development questions

Support in spatially explicit land-use and land-management planning can be provided by management support systems (MSS) such as CropRota (Schönhart et al., 2011a) or MANUELA (v. Haaren et al., 2012) and Spatial Decision Support Systems (SDSS) such as CLUE (Verburg et al., 2002), or LUDAS (Le et al., 2008).

Such systems found their entrance in participatory planning processes, but they should have previously proved to be useful for solving complex, strategic problems and should not build completely on analytical solutions (Janse and Konijnendijk, 2007; Volk et al., 2007). MSS and SDSS can contribute partially or to the complete planning process chain by (a) providing an overview of the problem area, (b) assessing the impact of each possible planning alternative, (c) comparing the alternatives, and (d) estimating the preferences of different stakeholders or stakeholder groups (Booltink et al. 2001; Hurni, 2000; Rauscher et al., 2005).

Because MSS and SDSS are based on formalized knowledge, their application can facilitate decisions and make them reproducible and as rational as possible.

However, when comparing different solutions and searching for application examples beyond their original development context, it turned out that many of them were not further developed or used (Uran and Janssen, 2003). A reason is that the use of such tools or instruments requires acceptance by the user, who thinks in his regional context, who should be familiar with the system and who does not want to spend too much time in being trained in solutions and methods beyond those that he already applies (#4 - Fürst et al., 2010a). Systems which deal with complex questions address often only scientists and run the risk of becoming too complicated (Uran and Janssen 2003). Simple methods which follow a qualitative approach to the evaluation of land-use and land planning measures might be a bridge between science, policy, the interested public and planning practice and a basis for later more detailed, quantitative analysis (McIntosh et al., 2011).

Rationale in the GISCAME development was therefore to identify strengths and weaknesses of available tools, methods, and models and to develop together with the later end-user an idea for how to build a methodological framework that answers user questions in an easily-interpretable manner.

For the development of GISCAME, the following questions were formulated which are reflected by the structure of this synthesis:

1. Can we define generic user demands for supporting integrated land-use and land-management planning? (section 1)

2. How should a methodological framework be conceived that supports the impact assessment of land-use and land-management strategies on ecosystem services provision? (section 2)

3. How should we adapt the framework to different use cases and which modifications are requested for transfer into practice? (section 3)

4. How can we extend the framework to further application areas and which analytical or modeling features should be added? (section 4)

Fig. 1 provides an overview of the development process related to the subsequent text sections and the projects in which the different development steps were realized.

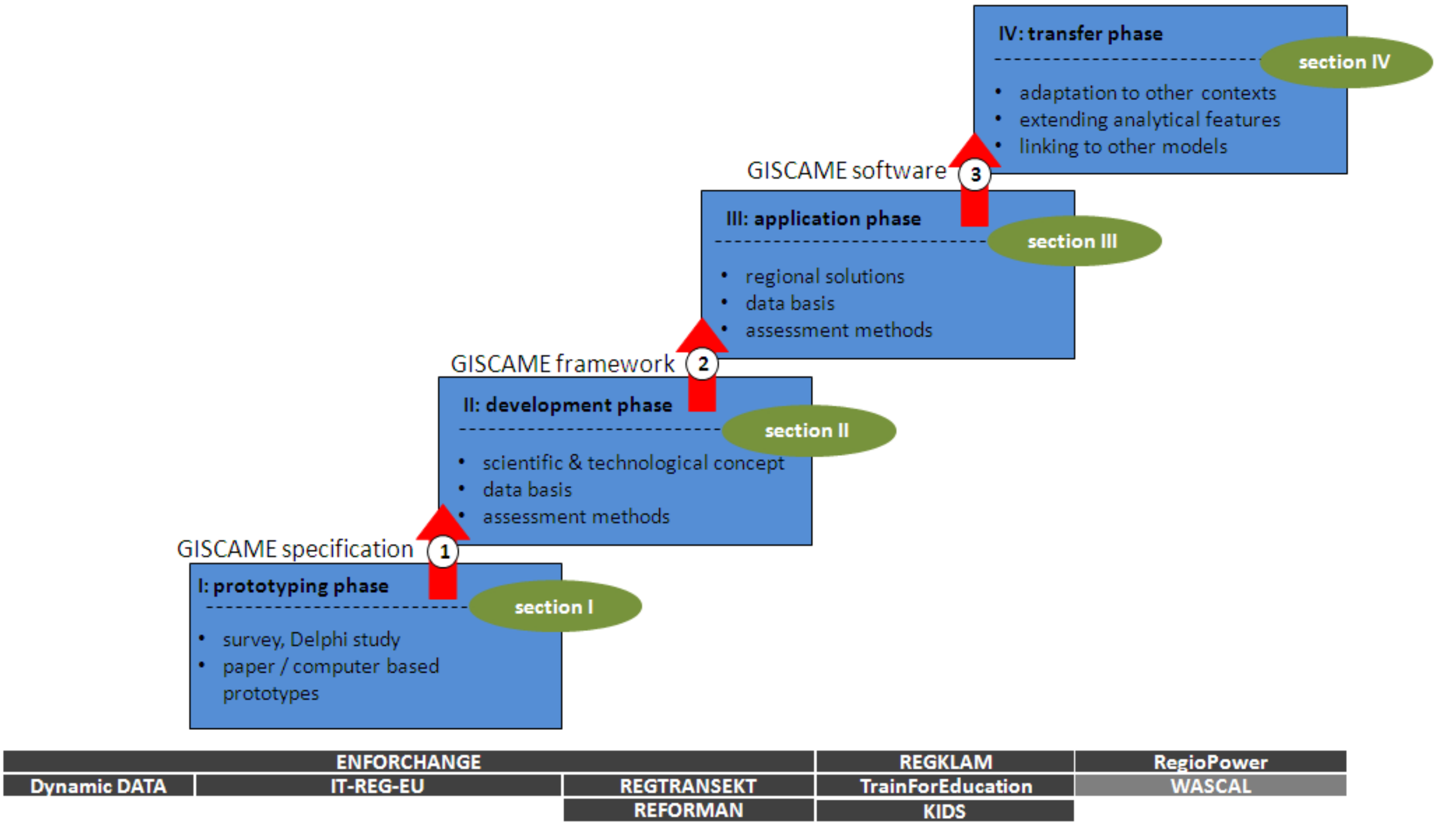

Fig. 1: GISCAME development process related to the phases addressed by the underlying projects (see also section 0 “Synopsis”; adaptation and transfer within WASCAL have most recently started).

1. User requirements analysis

The development of GISCAME started with a user requirements analysis and was accompanied and supported by parallel in-depth analysis of existing and available tools and methods for supporting land-use and land-management planning. The user requirements analysis was carried out in five projects, namely DynamicDATA EU 25+ (BMBF), ENFORCHANGE (BMBF), IT-REG-EU (Interreg IIIa), REG-TRANSEKT (BMBF), REFORMAN (ERA SEE) with participants from forest and environmental planning, nature conservation, tourism, and water management in Austria (1), Bosnia and Herzegovina (3), Croatia (5), Czech Republic (10), Germany (12), Poland (10), Serbia (4), Slovakia (8), Slovenia (5), and The Netherlands (1).

The user requirements analysis was organized in a two-step approach (#2 – Fürst et al., 2008; #4 – Fürst et al., 2009; #6 – Fürst et al., 2010c).

In a one-time survey based on mind-mapping techniques, the participants were asked to express where they see a need for improved planning instruments or planning support now and in the future. This was done on a workshop basis. Before the workshop, the participants were given the opportunity to examine some exemplary tools and to conclude from them on desirable design features that were then discussed in the workshop. These tools were CardoGIS as an example for user-friendly GIS-based solutions (www.cardogis.com), Lenné 3 D (www.lenne3d.com) as an example for visualization tools, MeaScope (www.mea-scope.eu) as an example for landscape management support in agriculture, and SIAT as an example for a complex impact assessment and management support system (www.ip-sensor.org). Tools and information on the underlying methods were made available online. The participants were asked to indicate in the workshop on which scale levels - local/regional or national/EU level – they would most appreciate improved support now and in the future. Subsequently, the findings were clustered to more generic terms for planning applications to identify trends for present and future, local/regional and national/EU scale.

As a result, a need for highly integrative tools was identified for the later GISCAME specification that leaves the scale of sectoral planning (forest management planning, agricultural planning in their more narrow sense) in favor of tools that address explicitly the meso or landscape scale. Participants pointed out a need for tools that better support dealing with uncertainty considering large scale drivers such as climate change, newly emerging needs from society or policy making, and socio-ecological system dynamics as such.
Considering uncertainty provoked by future policies, support was expected in assessing better ways for how to introduce complex legal regulations in planning that come especially from EU scale, referring to the problems in implementing NATURA 2000 (incl. species protection directive 79/409/EWG and habitat protection directive 92/43/EWG) and EU Water Framework Directive (2000/60/EG).
Taking classic forest management planning as an example, participants defined a need to replace it with “landscape planning”, using this term in an understanding that addresses cooperation with other sectors, increased stakeholder participation, improved interfaces to policy support and adaptive land system management. Explicitly, support in communication and conflict negotiation was specified as a further expectation.

In a second step, focus was laid on participants in Czech Republic, Germany and Poland with whom a two-stage Delphi study was carried out to specify more concrete user needs. Based on a pre-defined selection of possible alternatives which had to be ranked on a scale from 1 (= always / most desirable) to 6 (= never / most undesirable), we asked the participants to give their opinion on (a) what kind of information sources they use in general to prepare interdisciplinary planning decisions, (b) which tools they use to visualize the planning process and to support their decisions, and (c) what an optimal support system should look like. References were again the already mentioned tools CardoGIS, Lenné 3D, MeaScope and SIAT.

The Delphi study showed that various kinds of information sources were used for knowledge mining without particular preference for a specific source (question A). Information from publications and the consultation of colleagues or experts were used as intensively as web-based information and personal or institutional experiences, which are collected in sectoral information systems.
For the planning and decision finding process, computer-based tools were clearly preferred (question B). Standardized office applications, geographical information systems and interactive database applications were the most preferred instruments, followed by planning materials such as maps and monitoring data and institution specific planning software. Collections of key figures were still in use for orientation, while handbooks and written guidelines were clearly ranked in last place.
Considering question C, preference was expressed for online portals and expert systems, while other alternatives such as collection of spreadsheets and key figures, software or decision schemes and handbooks were ranked lower.

Based on the results of the user requirements analysis and some free-lanced ideas provided by the participants, a paper-based prototype was designed to learn more about usage and hidden user demands. Subsequently, the paper prototype was transformed into a first computer-based tool with very small and simple features for testing land-use planning scenarios (#6 – Fürst et al., 2010c; #7 – Fürst et al., 2010d). Both prototypes were again tested and refined by user feedback in a number of workshops with the Delphi study participants and an iteratively increased number of test persons from the projects DynamicDATA EU 25+, ENFORCHANGE, IT-REG-EU, REGTRANSEKT and REFORMAN.

The final GISCAME specification ended in "a system in which different actors involved in planning decisions can share and exchange their planning propositions and are supported by easily interpretable information on the effects of the planning alternatives for regionally important ecosystem services."
This demand included features such as broad accessibility for users at any time and any place (web-offer) and the possibility to iteratively integrate experience from case studies, regional experts and upcoming scientific results into the knowledge base (learning system). Furthermore, an interactive and self-explanatory user interface was demanded to support also those users who are not very familiar with the use of computers and electronics.

Based on the experiences from testing different tools and from testing the prototype of GISCAME, the following more specific features were formulated by the test participants:

- high ability to "design" the landscape and to introduce and modify planning rules,
- easy handling of landscape changes in the system "by mouse click" without the necessity to learn a special programming language, and
- transparency of the evaluation results and possibility to modify the evaluation basis.

These user requirements were finally completed by analyzing scientists' viewpoints and demands in the context of the cooperation projects that underlay the GISCAME development. More generally, an integrated system solution for supporting land-use and land-management planning that is able to cope with the present and future multifaceted challenges should (#5 - Fürst et al., 2010, adapted from: Alkemade et al., 1998; De Kok et al., 2009; Giupponi, 2007, Harremoës et al., 2001; Hewett et al., 2009; McCown 2002; Parker et al., 2002; Uran and Janssen 2003; Van Delden et al., 2007; Van der Sluijs, 2007; Voinov and Gaddis, 2008):

- be able to deal with discontinuity in information and datasets and bridge information gaps through active integration of scale-appropriate (local, regional) experience from experts and stakeholders;
- create a standardized list of indicators, which supports customizable indicators applicable on local to regional level that are consistent with the generic list in the sense of a nested approach;
- support the user in structuring the decision-making process and apply an appropriate conceptual approach (modeling vs. expert systems);
- support participation processes in generating decisions, management options and system understanding by means of user-friendly communication approaches such as visualization instead of simply presenting tables or parameter values;
- help to develop, compare and evaluate alternative management options (on the basis of a pool of options);
- help to assess the efficiency and trade-offs of possible management strategies on the basis of available information (data and experience);
- assist different stakeholders or stakeholder groups to balance and estimate their preferences.

The above research findings were mainly published in two peer-reviewed articles (cf.- #4 - Fürst et al., 2010a; #5 – Fürst et al., 2010b), the summaries of which follow.

Extended abstract #4

Fürst, C., Vacik, H., Lorz, C., Potocic, N., Krajter, S., Vuletic, D., Makeschin, F. (2010a): **How to support forest management in a world of change? Results of some regional studies.** Environmental Management 46(6), p.941-952.

This article summarized results from the survey and user requirements analysis which was done in the projects ENFORCHANGE, IT-REG-EU, REFORMAN, and REGTRANSEKT. The article focuses on needs and application areas, and desirable attributes for the GISCAME system and includes also an analysis of marketing potentials for support tools, which went beyond the GISCAME development needs specification as such.

Core results were that by comparing present and future application areas a trend from sectoral planning towards landscape planning and integration of multiple stakeholder needs is emerging. In terms of conflicts, where support tools might provide benefit no clear tendencies were found, neither on local nor on regional level. In contrast, on national and European level support of the implementation of laws, directives, and regulations was found to be of highest importance. Following the user-requirements analysis, electronic tools supporting communication were preferred. The users identified most important attributes of optimized management support tools: (i) a broad accessibility for all users at any time should be guaranteed, (ii) the possibility to integrate iteratively experiences from case studies and from regional experts into the knowledge base (learning system) should be given, and (iii) a self-explanatory user interface is demanded, which is also suitable for users rather inexperienced with electronic tools.

The market potential analysis revealed that the willingness to pay for support tools is very limited, although the participants specified realistic ranges of maximal amounts of money, which would be invested if the products are suitable and payment is inevitable. To bridge the discrepancy between unwillingness to pay and the need to use management support tools, we concluded that there is a demand for optimized financing or cooperation models between practice and science.

Extended abstract #5

Fürst, C., Volk, M., Makeschin, F. (2010b): **Squaring the circle - how to combine models, indicators, experts and end-users for integrated land-use management support?** editorial / lead paper, Environmental Management 46(6), p. 829-833.

In this lead article for the homonymous special issue, we analyzed and discussed most important challenges in the field of integrated land-use and management tools. These were i) harmonizing and integrating different datasets, ii) selecting appropriate indicators and (iii) fitting suitable models to adequate scales, and finally iv) integrating data, indicators and models into systems that allow both a high level of participation and flexibility with the adaptation to a variety of questions and applications.

Based on the outcomes of the papers involved in the special issue and on extended literature analysis we arrived at seven features for successfully applicable integrated land-use management support systems, namely (1) ability to deal with discontinuity in information and datasets, (2) contribution to solve the problem of indicator diversity, (3) structuring the decision-making process, (4) support of participation processes in generating decisions, (5) development, comparison and evaluation of land-use alternatives, (6) assessment of the efficiency and trade-offs of management options, and (7) assistance of stakeholders in group communication processes.

2. Methodological approach – building a system for integrated assessment of land-use and land-management impact on ecosystem services provision at landscape scale

2.1 GISCAME framework

2.1.1 GISCAME philosophy

Based on the outcomes for profiling the GISCAME system, a scientific and technological development approach was conceived. First, an analysis was done regarding how to define and describe interactions at landscape scale in a manner that (a) allows simulating land-use and land-use pattern changes in a realistic way and (b) provides information to assess the impact of land-use and land-use pattern changes on ecosystem services provision (#1 – Frank et al., 2011; Frank et al., 2010; #2 – Fürst et al., 2008).
Therefore, not only environmental parameters had to be integrated, but also information on social aspects such as land ownership and population density, and on administrative or political aspects, such as county or municipal boundaries and legally binding planning restrictions (protected areas, priority and preference areas in regional planning, restrictions derived from the landscape plan). On the other hand, the data hunger of GISCAME should not grow too large so that interactions that play a role at landscape scale can be chosen optionally to not endanger the transferability of the approach (#2 Fürst et al., 2008; #6 – Fürst et al., 2010c; #7 – Fürst et al., 2010d).

Taking the landscape as reference scale (meso scale), the interfaces between land-use, landscape composition and configuration and spatial interactions between neighbored land-use types and larger response units (e.g. patches) were put into the focus of the GISCAME analysis.

Land-use is considered to be the basic assessment topic in our multicriteria assessment approach (see section 2.2) and is assessed together with environmental and other parameters taken from information layers that modify locally (a) the impact of a specific land-use on the provision of ecosystem services, or (b) the eligibility of a land-use type as interface to restrictions for land-use change scenarios. Referring to "land-use" instead of land cover supports involvement of more detailed information on management practices or ecosystem characteristics in the assessment of land-use changes (see section 2.3). This better reflects opportunities for modification of ecosystem services provision beyond land cover changes. Linear elements such as hedge-rows, roads, and watercourses are handled as additional attributes that can increase or decrease the land-use impact on ecosystem services provision.

Composition and spatial configuration of the land-use form a superior integration and analytical level in which the contribution of each single land-use type to ecosystem services provision is up-scaled.
Both, land-use, and landscape composition and configuration are subsequently used for the uppermost analytical level, which accounts for spatial interactions. These are analyzed (a) at the local scale as interactions between "cells", which form the smallest indivisible assessment unit with homogeneous land-use type. Interactions are considered following the Moore neighborhood taking a distance of one cell as standard (Pan et al., 2010; see section 2.1.2). (b) At regional scale a set of landscape metrics (see section 2.2) is applied that analyzes additionally the homogeneity or heterogeneity of the landscape and the connection or fragmentation of near-to-nature areas as a means to involve more information on ecological integrity of a landscape and on its scenic beauty. Assessment of the

impact of land-use, landscape composition and configuration and spatial interactions on the underlying environmental (e.g. impact of a land-use type on soil quality) and other parameters is outside the system's analytical focus.

Taking the user requests from the system profiling, a central interest of GISCAME is to enable fast and simple simulation of land-use changes. Therefore, the back-end holds all analytical and assessment routines and provides interfaces for feeding the system with information by the administration (admin) center.
The front-end serves to simulate land-use change scenarios and to provide feedback. Feedback is given in visualized form (land-use maps, ecosystem service provision capability maps, water erosion risk maps) and in the form of qualitative assessment results (ecosystem service balance, trends in ecosystem service provision, trends in the percentage distribution of land-use types). The Graphical User Interface at the front-end provides a number of land-use change-scenario design features that support (a) active design (drawing) scenarios, (b) formulation of conditions under which land-use changes should be done or not done by using the parameter layers or (c) specification of transition probabilities for land-use changes depending on parameter layers and / or freely formulated assumptions as interface to agent-based land-use change modeling.

Fig. 2 provides an overview on the system in its current status.

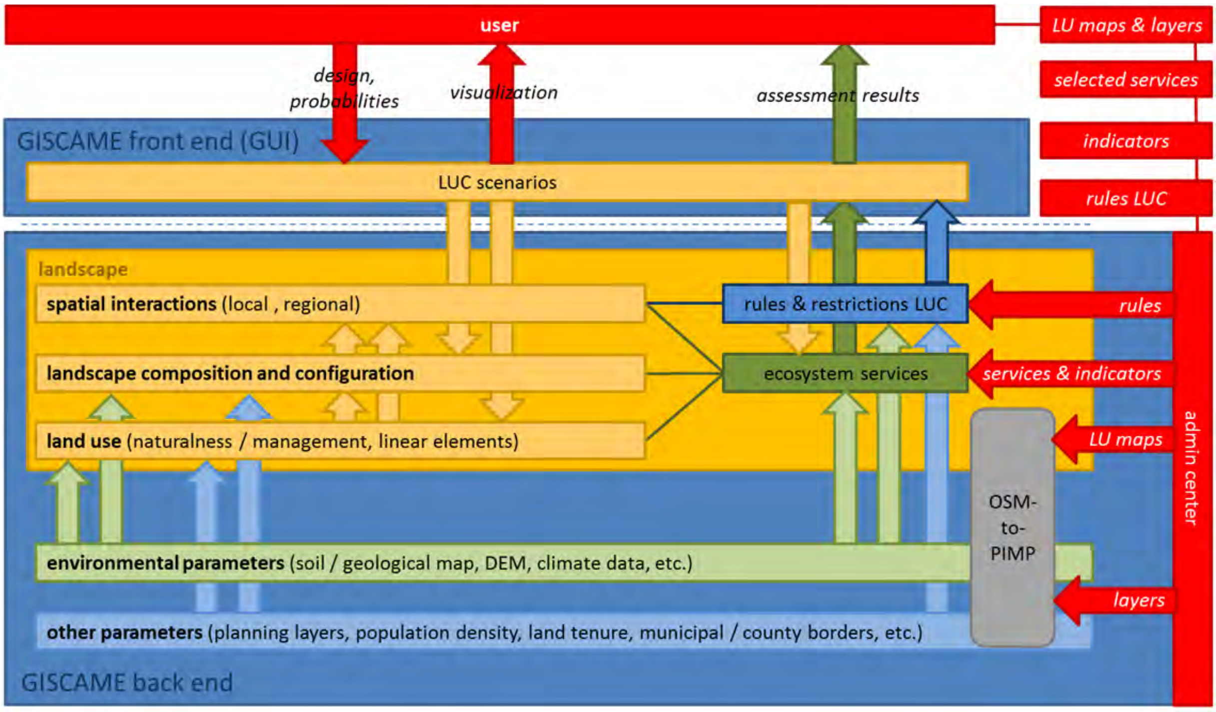

Fig. 2: Overview GISCAME system. LU: land-use; LUC: land-use change. OSM-to-PIMP: alone standing software tool that supports to merge geo-referenced environmental and other information layers, land-use maps and infrastructural data from OSM (OpenStreetMap, www.openstreetmap.org) in WG 84 projection and prepares them for parameter sensitive up-load (click-on / click-off) in GISCAME, © PiSolution GmbH.

In GISCAME, we are currently working with maximum 10,000 km² large regions and break these down to simulate land-use changes to 100 km² large working windows to facilitate the work progress.
For these working windows, land-use change rules can be developed and implemented either in the form of simple rule sets for triggering land-use change actions depending on land-use type, or other cell attributes and neighbored land-use types. In this case, land-use changes will be carried out if such a predefined rule applies, i.e. the transition probability is 100 %.
To make land-use changes more flexible and nearer to reality, land-use type specific transition probabilities between 0 and 100 can be defined which involve cell attributes and neighbored land-use types (not yet published). In this case land-use changes can but must not happen dependent on the transition probability. For a number of model runs and iterations, different land-use pattern situations can be generated that represent possible future trajectories of land-use change.

Both rule sets and transition probabilities can subsequently be transferred from the working windows to the rest of the model region so that scenario testing and transfer of derived recommendations is sped up (see also technical explanations, figure caption Fig. 4).

2.1.2 Scientific and technological approach

To realize the described analytical features in GISCAME, an methodological framework was constructed that is based on three components, a Geographical Information System (GIS) module, a 2-D cellular automaton and a hierarchical multicriteria assessment approach (#10 – Fürst et al., in press; section 2.2 for details).

Figure 3 shows the roles of the three components within the GISCAME assessment approach.

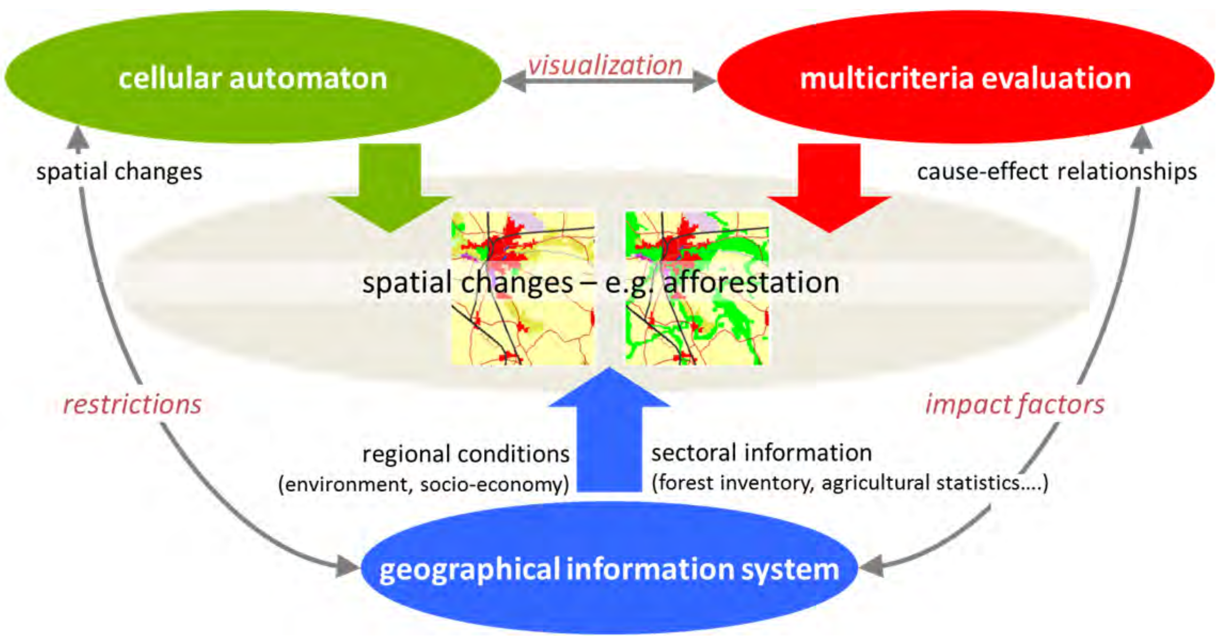

Fig. 3: Interplay of the GISCAME components.

The GIS module involves some standardized routines building on SAGA GIS (www.saga-gis.org) that help to integrate, handle and merge the parameter layers with the land-use maps and that support some analytical routines such as the calculation of the water erosion and mass movement risk.

The cellular automaton forms the core of the GISCAME system that links land-use and parameter layers with the multicriteria assessment routine and enables the simulation of cell-wise or larger scale land-use changes in landscape context.
A cellular automaton is originally a discrete dynamic system where each point in a regular spatial lattice, called "cell", can have any of a finite number of states. The states of the cells are updated according to rules depending on the state of the cell one time step previously, and the states of its nearby neighbors at the previous time step. All cells in the lattice are updated synchronously. The state of the lattice advances in discrete time steps (Cochinos 2000).

For GISCAME, we made use of this approach by defining the cell to be the smallest indivisible simulation and assessment unit that is characterized by one specific land-use type as the central attribute. Currently, cell sizes of 100x100 m² or 25x25 m² are in use, depending on the spatial and thematic resolution of the land-use maps (section 2.3).

In contrast to the classic cellular automaton approach, we skipped the automatic updating of the cell states. In GISCAME, a cell can be changed actively by using one of the scenario design features in which one or a number of cells with a specific land-use type are changed into another land-use type as far as no previously-defined rules or restrictions come up against this change. Also, cell attributes derived from the parameters and land-use type can be used to trigger a land-use change action (AAMS – attribute action management system).
More recently, the original approach was extended, allowing land-use changes based on transition probabilities that drive the process and that can be specified for a freely definable number of states – or land-use types in our case – that can be adopted by a cell (not yet published). This number of states can be specified by the user as those which are considered to be interesting, relevant or realistic for scenario simulation. The probabilities can further be modified by involving information provided by the parameter layers, such as site quality, age or development status (age class in case of forests), and climate parameters ("integrated transition probabilities").

Each cell interacts rule-based with its neighboring cells. With regard to proximity effects, a Moore neighborhood (nine-cell neighborhood with range r = 1, see, for example, Georgoudas et al., 2007; Pan et al., 2010) is used. It is one of the two most commonly used neighborhood types, the other one being the 4-cell von Neumann neighborhood. The Moore neighborhood type was selected as it enables the consideration of the impact of each neighboring cell, even of the corner cells.

The multicriteria assessment approach builds in hierarchical manner on the different analytical levels in GISCAME shown in Fig. 2, namely land-use, landscape composition and configuration, and spatial interactions. More details are given in section 2.2.

Figure 4 provides complementary information on the software architecture of GISCAME.
The Graphical User Interface holds a workflow manager which currently supports the workflow in two major applications, GISCAME on the one hand and some derived versions that are in use for environmental education ("letsmap" applications).
The GISCAME Kernel is the main component that creates a bridge between the applications and the data processing, which is done by the GISCAME Engine.
To hold and export information and to provide interfaces to different data base formats and the OSM-to-PIMP routine, a log manager (for handling the internet protocols), a data base manager

which enables one to embed Oracle, MySQL (current standard), PostgreSQL and Sybase as well as an object manager are installed.

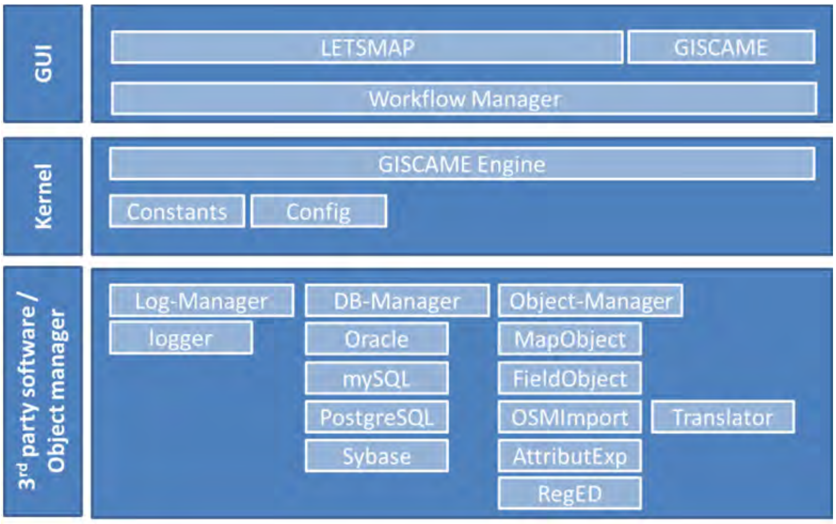

Fig. 4: GISCAME software architecture.

GUI: Graphical User Interface. Constants: link source code parameters with variable states they can adopt in the simulation. Config: for use of configuration files. AttribExp: Attribute (Layer) Export. RegED: Regional Editor – GISCAME handles regions up to 10,000 km², which are divided into working windows for user friendliness in scenario simulation. The Regional Editor helps to handle working windows within a region, scales the assessment results from scenario simulation in single working windows up to regional scale, and supports transferability of rule sets for land-use changes from working window to regional scale.

2.2 Multicriteria assessment approach

The multicriteria assessment approach (Fig. 5) bundles, in hierarchical manner, information on the impact of the land-use as such and its spatial pattern (landscape configuration) on the provision of ecosystem services (#3 – Fürst et al., 2009; Fürst et al., 2010e; #8 – Fürst et al., 2011; #13 – Koschke et al., 2012; Koschke et al., 2010). A unique aspect of our assessment approach is that it manages to combine information obtained from modeling, literature references and measuring or monitoring with expert opinion, and that each step in the evaluation procedure is done in participatory manner (#3 – Fürst et al., 2009; #7 – Fürst et al., 2010d; #8 – Fürst et al., 2011; #13 – Koschke et al., 2012).

In a first step, we compile a regionally specific value matrix that describes the impact of each land-use type on each ecosystem service. The assessment of the land-use type impact is done based on criteria and indicators. These are specifically selected for each regional application depending on the set of selected services and available information from prevailing studies, literature references or expert knowledge.

To enable a comparison of the impact of planning alternatives on the ecosystem services, where different indicators with different measurement units have to be applied, a qualitative assessment approach was introduced: all indicator values are transformed by mathematical normalization to a relative scale from 0 (minimum value) to 100 (maximum value; #2 – Fürst et al., 2008; #3 - Fürst et al., 2009). If several indicators are used for calculating a service, they are accounted with equal weight (#13 - Koschke et al., 2012; Koschke et al., 2010). The value between 0 and 100 which an eco-system service can adopt on landscape scale is subsequently calculated as the mean value of all cells.

In a subsequent step, the cell specific (local) value of a land-use type for each ecosystem service is calculated. Knowledge on how site factors (environmental parameters) and neighborhood constellations (proximity effects) decrease or increase the provision of ecosystem services by a cell can be used as far as respective model or monitoring information is available or assumptions can be made.

In a third step, the impact of the land-use pattern on the potential of the model region to provide ecosystem services is assessed in GISCAME by a set of landscape metrics and is also expressed in a qualitative way. The landscape metrics are applied to adjust the results achieved for services related to the "ecological integrity" of a landscape as a supporting service and its "aesthetic value" as a cultural service (#1 - Frank et al., 2011; Frank et al., 2010).

Currently, we implement in GISCAME (a) the proportion of functionally connected habitats (Zebisch et al., 2004), (b) the proportion of natural land-use types (Augenstein, 2002; Steinhardt et al., 1999; Tasser et al., 2008), (c) the average of unfragmented open areas (Gao and Li, 2011; Girvetz et al., 2008; Jaeger, et al., 2008), (d) the shape index (Augenstein et al., 2002; Baessler and Klotz, 2006; Renetzeder et al., 2010), (e) the Shannon-Wiener diversity index (Yeh and Huang, 2009; Kim and Pauleit, 2007) and (f) the patch density per km² (Hein et al., 2004).

The single landscape metrics are aggregated in so-called ecological connection matrices (Bastian and Schreiber, 1999) and – as an evaluation convention – the aggregation process results in 0 - 30 points to which the result for our two services "ecological integrity" and "aesthetical value" can be increased or decreased at the level of the model region, while the lower (0) and upper (100) limit of our relative scale cannot be exceeded.

For the aggregation in the ecological connection matrices, first the "typical" range of values that can be adopted by each of the landscape metrics for the total region is calculated and then this range is segmented into "sub-ranges". Subsequently, the sub-ranges of the landscape metrics are aggregated pairwise to three assessment criteria for ecological integrity and aesthetics, namely “landscape fragmentation”, “habitat connectivity” and “landscape diversity” and these pair combinations are evaluated on a scale from minus 10 to plus 10 points. The final aggregation result is achieved by adding the number of points in each of the criteria. The landscape metrics assessment approach and how it is adapted to the cellular automaton in GISCAME is described in detail by #1 - Frank et al., 2011.

Additionally, regulations or restrictions that are imported from regional planning (layers with preference or priority areas for a specific planning objective) or defined by using the GISCAME rule building options are involved insofar as they do not only contribute to forbid land-use changes, but can also be used to “punish” undesired land-use changes by reducing the value of a land-use type for ecosystem services provision at an unwanted place (#6 – Fürst et al., 2010c).

The resulting evaluation system allows for assessing the impact of land-use changes on ecosystem services at a not-further-specified time point t_n. Not-further-specified means that due to the different temporal dynamics of the land-use types and due to different management intervals, it is so far not possible to predict changes for specific time slots, such as 5-year intervals or decades. Thus, it is assumed that each land-use change establishes immediately a new land-use type in a cell. By doing this we ignore the fact that, for instance, in forest ecosystems the establishment of the full functioning and ecosystem services provision of the forest takes at least several decades. This shortcoming is currently being solved by coupling the cells over their land-use type with growth, yield and production models in the project RegioPower.

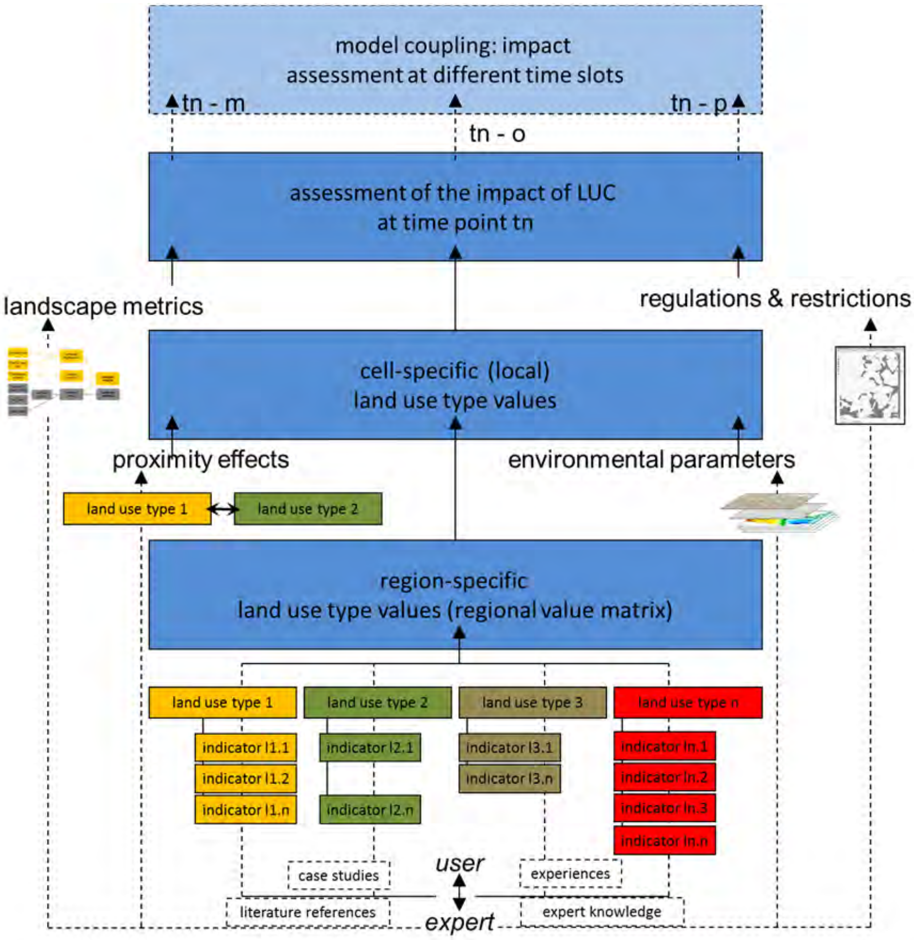

Fig. 5: Overview on the hierarchical multicriteria assessment approach in GISCAME.

2.3 Land-use classification approach

An essential part of adapting the GISCAME and making the best use of its analytical features was the question of how to better describe and classify "land-use" in contrast to "land cover".
While Corine Land Cover (www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version) forms mostly the standard for ecosystem service assessment approaches, a criticism on land cover data is that their spatial and thematic resolution does not allow for the consideration of management practices whose impact on changes in ecosystem services provision might be equal or even larger compared to land cover changes (Verburg et al., 2009; Dale and Polasky, 2007).

In the context of the projects REGKLAM and RegioPower, we started the development of a more functional land-use classification for a model region in Middle Saxony, Germany. Functional stands for better accounting for the relation between land-use on the one hand, and ecosystem processes and functions on the other, that trigger the provision of ecosystem services.
With Euromap GmbH, a combination of remote sensing information and terrestrial inventory was applied to achieve a more detailed land-use classification (Euromap Land Cover Classification, EMLC).

For forestry, terrestrial data came from forest inventory in governmental forests, and from biotope and land-use mapping for non-governmental forests.
For introducing scenarios of choice for forest management (conversion) and for afforestation, the concept of forest ecosystem types (Eisenhauer and Sonnemann, 2009) was involved in the form of an additional information layer in GISCAME which triggers spatially explicit the eligibility of the forest land-use types. Here, a regionalization model was developed that builds on the forest site classification (Kopp and Schwanecke, 1994), soil classification (Sponagel et al., 2005) and the digital elevation model (DEM, 1:25,000) considering the local suitability of the forest ecosystem types within existing forests and at agricultural sites (#15 - Witt et al., in press).

In agriculture, land-use data were not easily available and especially not in the form of raster or vector data that could have been imported in GISCAME. Besides, having the different temporal dynamics of land-use types in mind, information on single crops would not have been helpful for assessing the impact of agricultural practices in a landscape context. Therefore, the concept of regionally typical crop sequences was developed as a thematic reference that allows for better comparing ecosystem services provision between agricultural and other land-use classes and especially between agricultural and forest land-use. These crop sequences were designed to represent best regionally typical practices of different arable or mixed farm types including conventional and organic farming practices (#14 – Lorenz et al., in rev.).
The basis for these crop sequences was statistical data on cultivated crops from 2005 – 2010 to identify typical pre- and post-crops to key crops in Saxony. The crop sequences were furthermore differentiated for diluvial sites ("D"), loess sites ("L"), and deeply weathered bedrock sites ("V") which are the most important mother material types in the model region. For spatial transfer, the medium-scale agricultural soil mapping (1:25 000) and statistical data on cultivated key crops at the level of so-called "field blocks" were used. These field blocks are the smallest spatial entity for which agricultural practices are reported as a basis for agricultural funding in the frame of the European Agricultural Fund for Rural Development (EAFRD, see e.g. Heinrich et al., 2009). Additionally, different soil management techniques (conventional, conservation till, no-till farming) were introduced as an eligible attribute to the crop sequences which modifies the water erosion risk as an interface to the GIS analysis and productivity indicators.

Fig. 6 shows exemplarily a comparison between the CLC and the EMLC maps for the model region.

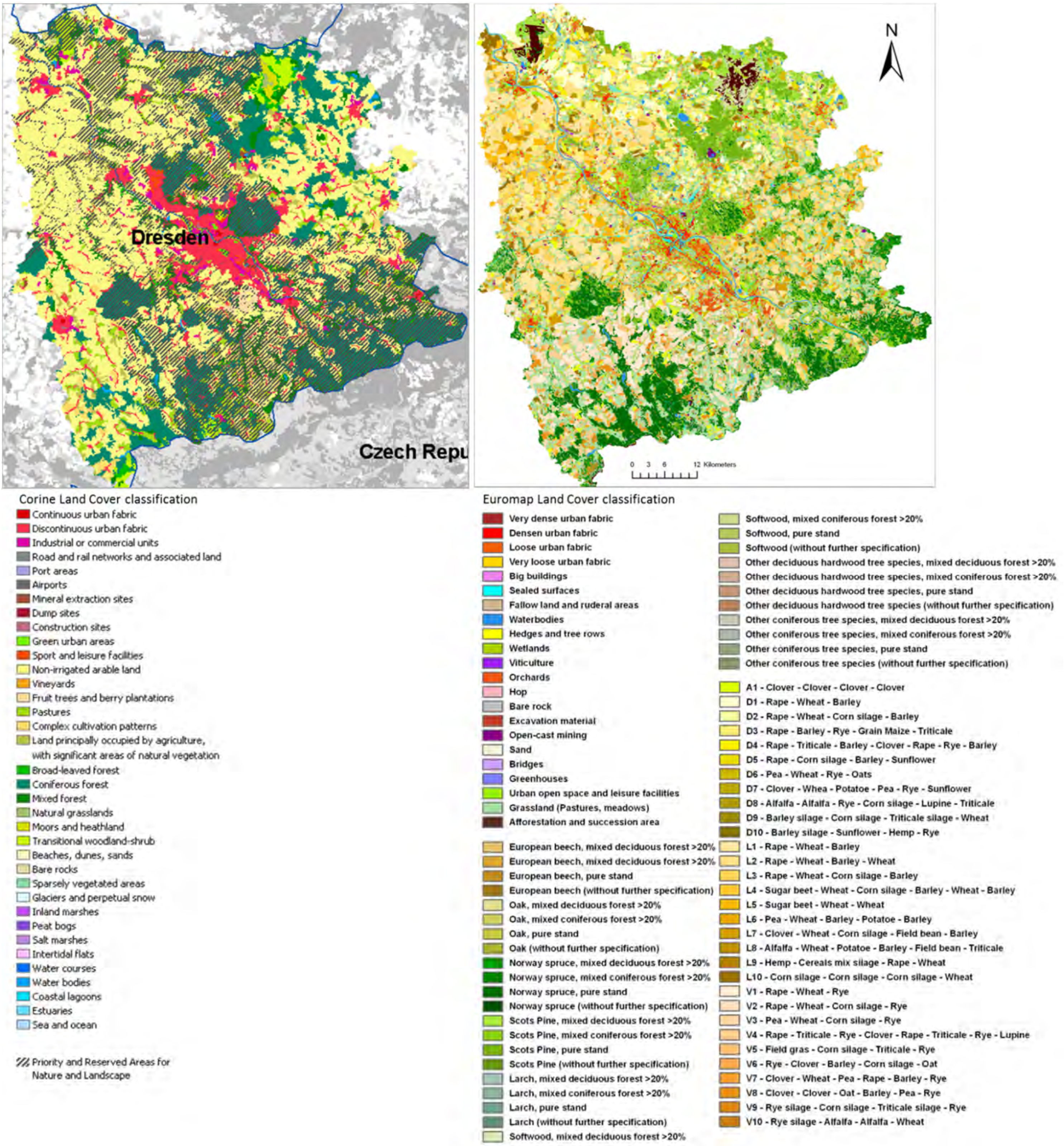

Fig. 6: Comparison of thematic and spatial resolution between Corine Land Cover (CLC) classification (left) and Euromap Land Cover (EMLC) classification (right) for the model region Middle Saxony.

Considering the relation between land-use classification and the multicriteria assessment approach, the problem emerged that models and/or monitoring data accounting for such a high level of detail in land-use classification were not or only partially available.
Taking the forest land-use classes, most forest models focus only on few tree species and describe mainly pure and single layered stands behavior (e.g. Papst et al., 2008; Pretzsch et al., 2002) at micro scale. Information on mixed and multi-layered stands could also not be taken from forest yield tables (e.g. Schober, 1995).
In agriculture, crop rotations are already applied in bio-physical process models and/or economic models on farm level to derive different environmental impacts (e.g. Janssen and van Ittersum, 2007; Schönhart et al., 2011a; van Ittersum et al., 2008), but empirical data are mostly missing (Schönhart et al. 2011b).

Coming to the transferability of such a land-use classification to other case studies the problem of data availability gains in importance. Terrestrial information for training the interpretation of remote sensing data for land-use classification might not be accessible and only a few remote sensing techniques provide data that are detailed enough for drawing conclusions regarding land-use types (e.g. Colditz et al., 2011). Also, clear delineation of land-use types as such might not always be possible, taking land-use practices such as mixed cropping, grazing and/or agro-forestry systems, and diversity of seasonally driven vegetation dynamics into account.

However, this phase of the work has provided greater insight in the type of data that are likely to be needed in the future if meaningful multicriteria analysis is intended to play its role in designing resilient landscapes. The principle papers in which this knowledge has been published are summarized below.
Articles#2 – Fürst et al., 2008, #6 – Fürst et al., 2010c, and #7 – Fürst et al., 2010d introduce the GISCAME approach.
Articles #3 – Fürst et al., 2009 and #13 – Koschke et al. 2012 present the multicriteria assessment framework and article #1 – Frank et al., 2011 introduces the landscape metrics application within this framework.
Finally, the approaches for implementing a functional land-use classification in forestry (cf. #15 - Witt et al., in press) and in agriculture (cf. #14 – Lorenz et al., in rev.) are shown.

Extended abstract #2

Fürst, C., C. Davidsson, K. Pietzsch, M. Abiy, F. Makeschin, C. Lorz, and M. Volk (2008.):"**Pimp your landscape" – interactive land-use planning support tool.** Transactions on the Built Environment (ISSN 1743-3509). Geoenvironment and Landscape Evolution III, p. 219-232.

This article presented the very beginning of the development of GISCAME mainly in the context of the INTERREG IIIA project IT-Reg-EU. The software was originally named „Pimp your landscape" (P.Y.L) to express its focus on actor involvement and actor based scenario building. Only later on, the name GISCAME was introduced (**G**eographical **I**nformation **S**ystem, **C**ellular **A**utomaton, **M**ulticriteria **E**valuation).

The original software application was developed for solving land-use conflicts in the Euro-Region Neisse. It was conceived as a very simple web-based tool with focus on visualizing and evaluating changes in the land-use pattern without involving information on environmental or social aspects.

Information on the land-use pattern in this version was based on Corine Land Cover 2000. We started with the idea to assess the impact of land-use on a relative scale from 0 (worst) to 100 (best), but in this version, we did not yet differentiate between the concepts of ecosystem services (MEA, 2005), land-use functions (Perez-Soba et al., 2008) or landscape services (Temorshuizen and Opdam, 2009).

Also the indicator based approach was not yet further developed; at this stage, the ranking of land-use type impacts was mostly based on expert knowledge.

We introduced also two different applications, one for consensus building in regional planning and one for environmental education.

Extended abstract #6

Fürst, C., König, H., Pietzsch, K., Ende, H.P., Makeschin, F. (2010): **Pimp your landscape - a generic approach for integrating regional stakeholder needs into land-use scenario design and sustainable management support**, Ecology and Society 15(3): 34, 25 pp.

The article introduces a further developed version of GISCAME for the case study "Euro-Region Neisse" with focus on consensus building in transnational land-use planning (Czech Republic, Germany and Poland).

In this version, the interactions between the three components GIS, cellular automaton and multicriteria evaluation were further developed and we could already simulate and visualize different land-use pattern alternatives in real time including their impact on a set of land-use functions adopted from Perez-Soba et al., 2008, namely ecology, economy, water quality and aesthetics.

In this article, we introduced mainly how to make use of – in this case still – reduced functionalities of the cellular automaton, how to base upon this approach the indicator based multicriteria evaluation, and how to involve more environmental information in the cell based land-use impact assessment.

Finally the constraints and limits of this GISCAME version were discussed for its application field – regional planning – and compared to other approaches.

Extended abstract #7

Fürst, C., Volk, M., Pietzsch, K., Makeschin, F. (2010): **Pimp your landscape! A tool for qualitative evaluation of the effects of regional planning measures on ecosystem services**, Environmental Management 46(6), p. 953-968.

This article presents an already higher developed version of GISCAME, which started at this time to be applied in the context of the project REGKLAM (Regional Climate Change Adaptation Program) for testing the impact of forest management options in regional planning in the model region Middle Saxony.

We present how to combine the 2-D cellular automaton more intensively with GIS features. Some extended opportunities for scenario design including the delineation of non-cellular infrastructural elements, such as roads or watercourses are shown. Also, an extended version of the qualitative evaluation approach is introduced, where we left the concept of land-use functions (Perez-Soba et al., 2008) and started to integrate and modify the ecosystem services concept (MEA, 2005).
We developed and presented an approach for participatory evaluation of land-use impacts on eco-system services provision to close the knowledge gap between data based assessment of land-use type impacts for well-known and described land-uses and those, for which no models or monitoring data exist.

Finally, we concluded on some shortcomings in this version of the software, addressing mainly the question how to better account for landscape structural aspects that were involved later on based on landscape metrics assessment (#1 - Frank et al., 2011).

Extended abstract #3

Fürst, C., Nepveu, G., Pietzsch, K., Makeschin, F. (2009): **Comment intégrer des considérations multicritères dans la gestion d'un territoire ? "Pimp your landscape" - un essai de planification interactive pour satisfaire les besoins des utilisateurs**, Revue forestière française 1-2009, p. 21-35.

In this paper, focus was laid on the question of the multicriteria assessment of land-use changes, here presented mainly for forest land-use opportunities. We applied a reduced set of services and land-use types. The article gives a preliminary idea how to combine different indicators and criteria and translate them on a relative evaluation scale from “0” (negative / no impact) up to “100” (highest impact) to assess the impact of land-use changes on ecosystem services (MEA, 2005) and/or land-use functions (Perez-Soba et al., 2008). We presented how different knowledge sources from literature and expert knowledge can be combined to achieve an integrated evaluation of land-use type impacts on the provision of regionally relevant services.

Also, two GISCAME applications were presented, a so-called expert application, which was created to support and train professionals in land-use planning decisions, and a game application, where anyone had the possibility to test visions for optimizing a landscape. The expert application provided advanced possibilities to adapt the evaluation system to regional characteristics and to test and introduce planning restrictions, which can be derived from EU directives or regional regulations. The game application helped to introduce both expert knowledge and citizens’ concerns in participatory planning processes.

The end of the paper was devoted to an introduction of some usage examples addressing especially forest planning at landscape scale and to a discussion of further development of the software. Meanwhile, the split between the expert and game applications was discontinued and the involvement of different knowledge sources in the evaluation was more standardized.

Extended abstract #13

Koschke, L., Fürst, C., Frank, S., Makeschin, F (2012): **A multicriteria approach for an integrated land-cover-based assessment of ecosystem services provision for planning support.** Ecological Indicators 21, 54-66.

This article forms part of a PhD thesis in the context of the GISCAME development whose objective is to further develop and extend the multicriteria assessment of land-use changes based on the cellular automaton and GIS functionalities of the software.

The article demonstrates an extended multicriteria assessment framework for the qualitative estimation of regional potentials to provide ecosystem services as a prerequisite to support regional development planning. The assessment framework was developed and applied in the context of the REGKLAM project for a model region in Middle Saxony, Eastern Germany.

For an estimation of the potentials of the model region to provide ecosystem services, we employed a benefit transfer and an expert-opinion-based approach, which were both applied for a modified version of the ecosystem services concept compared to MEA 2005, where in our case the understanding of the involved services was drafted together with regional stakeholders. We could show that the different data gathering methods “benefit transfer” and “expert-based assessment” have a considerable impact on the evaluation outcomes.

Based upon our new more extended assessment approach, we analyzed the performance of the model region to provide ecosystem services, and generated maps showing how the ecosystem services provision is regionally distributed.

The results of our study show that the combination of selected services and – in this case – Corine Land Cover data - can contribute to regional planning by better communicating the impact of land-use changes.

Finally, we discussed the limitations of our approach that are related to the use of the Corine Land Cover data and the difficulties involved in introducing the ecosystem services concept in regional planning processes.

Extended abstract #1

Frank, S., Fürst, C., Koschke, L., Makeschin, F. (2011): **Towards the transfer of the ecosystem service concept to landscape planning using landscape metrics.** Ecological Indicators 21, 30-38.

A shortcoming identified in the GISCAME versions thus far was that landscape structural aspects could not be involved in the assessment of land-use changes on ecosystem services provision. Therefore, a PhD thesis was started to analyze and involve a set of standardized landscape metrics into ecosystem services assessment.

This article introduces the conceptual approach for the landscape metrics based assessment within the multicriteria assessment framework of GISCAME. Using the example of the service "ecological functioning", we tested the potential of our approach to improve the understanding of how landscape structure contributes to the provision of ecosystem services. As a test case, we simulated different afforestation scenarios in the model region "Middle Saxony", Germany.

A major finding was that, without the inclusion of landscape metrics, the actual ecosystem services provision potential of this poorly structured model region with a large proportion of agricultural areas would be overestimated. In contrast, benefits gained from afforestation strategies, which aim at improving aspects such as biotope connectivity at the landscape level, would become less obvious.

We concluded that the involvement of landscape metrics contributes to a more realistic appraisal of the potential for landscapes to provide ecosystem services beyond the contribution of single land-use types or—in this case—land cover classes.

This initial assessment concept formed the basis for extending later on the number of landscape metrics. Currently, the application for different landscape structure dependent ecosystem services is ongoing.

Extended abstract #15

Witt, A., Fürst, C., Makeschin, F. (in press): **Regionalization of Climate Change sensitive forest ecosystem types for potential afforestation areas**, Journal of Environmental Management, http://dx.doi.org/10.1016/j.jenvman.2012.08.007.

A problem in the application of the GISCAME software thus far was the use of land cover data, which limited the analytical features of the software to a low spatial and thematic resolution of land-use information. Therefore, in the context of a third PhD thesis, algorithms are developed for how to better connect and transfer terrestrial mapping information with remote sensing data, and how to make use of this information also for regionalization of choice opportunities for land-use changes.

In this article, we introduce an approach for how to make use of forest inventory and forest management planning information to predict and up-scale Climate Change sensitive forest ecosystem types for forest conversion and potential afforestation areas.

The method was developed and applied in the project RegioPower with focus on the case study region 'Middle Saxony. Data were taken from forest inventory and forest management planning at forest district level, and biotope and land-use mapping as well as silvicultural planning at the level of the Federal State of Saxony. Subsequently, silvicultural planning was introduced because it describes trajectories for how to develop current forest ecosystem types into climate change adapted forests including the selection of optimally drought-resistant tree species, a broad range of mixed tree species, and the hereon dependent tending, harvesting and regeneration strategies to be applied (Eisenhauer and Sonnemann, 2009).

The eligibility of each of these climate change adapted forest ecosystem types within existing forest areas depends on site information such as nutrient potential, exposition and hydrological soil parameters, so that forest land-use mapping and future choice opportunities could be directly lined.
Outside existing forests, the regionalization of the eligible forest types had to be based on topographical parameters from the digital elevation model and hydrological soil parameters from soil mapping. This was done because the nutrient balance of agricultural sites was greatly impacted by fertilization practices and would therefore not have been assessed in an appropriate way to draw conclusions regarding forest type suitability.

As a result, we could provide maps for regional planning and decision making with spatially explicit information on eligible forest types for simulating and assessing the impact of alternative conversion and afforestation scenarios.

Extended abstract #14

Lorenz, M., Thiel, E., Fürst, C. (in rev.): **Integration of agricultural practices into regional assessment-systems - combining regional crop sequences with agricultural management and soil protection techniques**, Journal of Environmental Management.

Based on our experiences regarding how to extend the land-use classification for forestry, we started in the context of the REGKLAM project a cooperation with the Saxon State Office for Environment, Agriculture and Geology (LfULG) to transfer our forest classification approach (#15 – Witt et al., in press) to agriculture.

This article presents again for the model region "Middle Saxony" an approach regarding how to introduce the concept of regionally typical crop sequences in agricultural land-use classification to better account for inter-annual aspects in agricultural management that cannot be expressed when focusing the classification on single crops.

A procedure was developed to (i) derive representative regional crop sequences by combining different data sources and expert knowledge, (ii) integrate innovative aspects such as no-till techniques, energy crops or organic farming, and (iii) regionalize crop sequences and corresponding tillage systems on the basis of a variety of field data.

3. Application of the system approach and lessons learnt from case studies

Having developed GISCAME to a status where manifold analytical features were involved, we started to apply the software to regional planning questions and to test and further develop our extended land-use classification approach (#8 – Fürst et al., 2011; #9 – Fürst et al., 2012; #10 – Fürst et al., in press).

Tests were focused on the model region "Middle Saxony", Germany in the context of the projects REGKLAM and RegioPower and were concentrated on strategies for conversion, afforestation, or alternatively establishing short rotation coppice.
Parallel to spatially explicit testing, we applied and implemented in GISCAME also an opportunity for spatially inexplicit testing that forms an interface to state regional planning, where policy aims are broken down to roughly formulated land-use change targets that are then transferred in a spatially explicit manner by regional planning (#10 – Fürst et al., in press).

In testing how to best integrate forest management planning knowledge in regional planning, we could demonstrate that conversion as a strategy that is highly appreciated as a means for improving ecosystem services provision did not result in the expected impact in the model region. One reason was that the share of forest land with an average of 26 % in this model region was very low. Also, conversion could only realistic be done in state forests, which amount to an average of one third of the total forest area in our model region. Furthermore, regional distribution of forests was quite unequal. While in the Western part of the region, forest cover did amount to 12 % maximum, including situations where no forest land cover occurred, forests concentrated in the Southern part in the Ore Mts. and the Saxon Switzerland. The latter, however, did not provide any potential for conversion as it forms part of a Czech Republic – Germany border-crossing National Park "Saxon-Bohemian Switzerland" in which even not-well-adapted forest stands will not be actively converted.

Thus, we concentrated our efforts more on deriving afforestation strategies, concluding on optimal shares and corridors for afforestation and involving different forest types to overcome potential trade-offs from afforestation, namely in the provision of regional biomass and generation of regional income.

For our model region, we selected three working windows (Fig. 7) which represent best typical regional situations considering the combination of land-use pattern, soil type and topographical aspects.
The working window 4/3 in the western part of the model region represents weakly-structured and agriculturally-dominated Loess areas in our model region. In the Loess areas, high-water erosion risk has been observed and is even expected to increase if no better structuring of the land-use pattern can be achieved by afforestation or strategic allocation of short rotation coppices. Our test involved in this section also addressed the question of spatial prioritization of afforestation projects.
Working window 4/7 is representative of a more intensively structured hilly area in the north-east of the model region, which is highly impacted by increased drought risk. This part of the region is expected to suffer in the future from higher uncertainties in agricultural productivity and was therefore considered to be prone to afforestation at least in part of the current agricultural areas.

Working window 8/4 is representative of the agriculturally dominated Ore Mts. plateau with a higher share of forest land, but still with poor structure due to spatial segregation of forest and agricultural sites. A need for more forests in this part of the region is identified to reduce the risk of flooding events (LfULG, 2009; SMUL 2008).

Through these three working windows, we explored land requirements for afforestation or short rotation coppices to achieve an improvement in ecosystem services provision that involved acceptable trade-offs for some services from the viewpoint of the regional actors. Regional actors were in this case institutional representatives from the regional planning authority and stakeholders that were organized in working groups on forestry, agriculture, water management and nature protection at the level of the ILE (Integrated Rural Development) and LEADER regions within our model region. With them, we developed step-by-step in a series of workshops a testing matrix for combined afforestation and conversion strategies, and ended up in scenarios that represented the maximum tolerable amount of areas for afforestation or short rotation coppices (#10 – Fürst et al., in press).

The exercise came up with recommendations for the updating of the regional plan that foresee for the agricultural areas in the western part a share of 29.7 % to be dedicated to afforestation and/or alternatively short rotation coppices. This corresponds well to the general planning targets of the Saxon Federal State regional planning where an average share for forest land cover of 30 % is foreseen. Our recommendation involved spatially explicit indication of areas, where maximum impact of the newly established forests or short rotation coppices could be achieved for lowering the water erosion risk and linking existing near-to-nature areas (biotope connection corridors).

Our recommendations involved also considerations for avoiding trade-offs for agricultural production that would have been provoked by unjustified splitting of agricultural parcels. This aspect was brought in by our actors, but could not really be supported by the landscape metrics based analysis, as spatially explicit information on land ownership could only partially be obtained for the model region. Considering spatial prioritization of afforestation projects, we could conclude by a number of tested scenarios the highest benefits for structural change near settlements, whereas afforestation in the neighborhood of existing forests resulted in the lowest structural impact (Fürst et al., 2011b).
In our other working windows in the loess-hill region (4/7) and in the Ore Mts. (8/4), we were able to identify optimal afforestation targets of 14.4 % and 23.6 %, respectively.

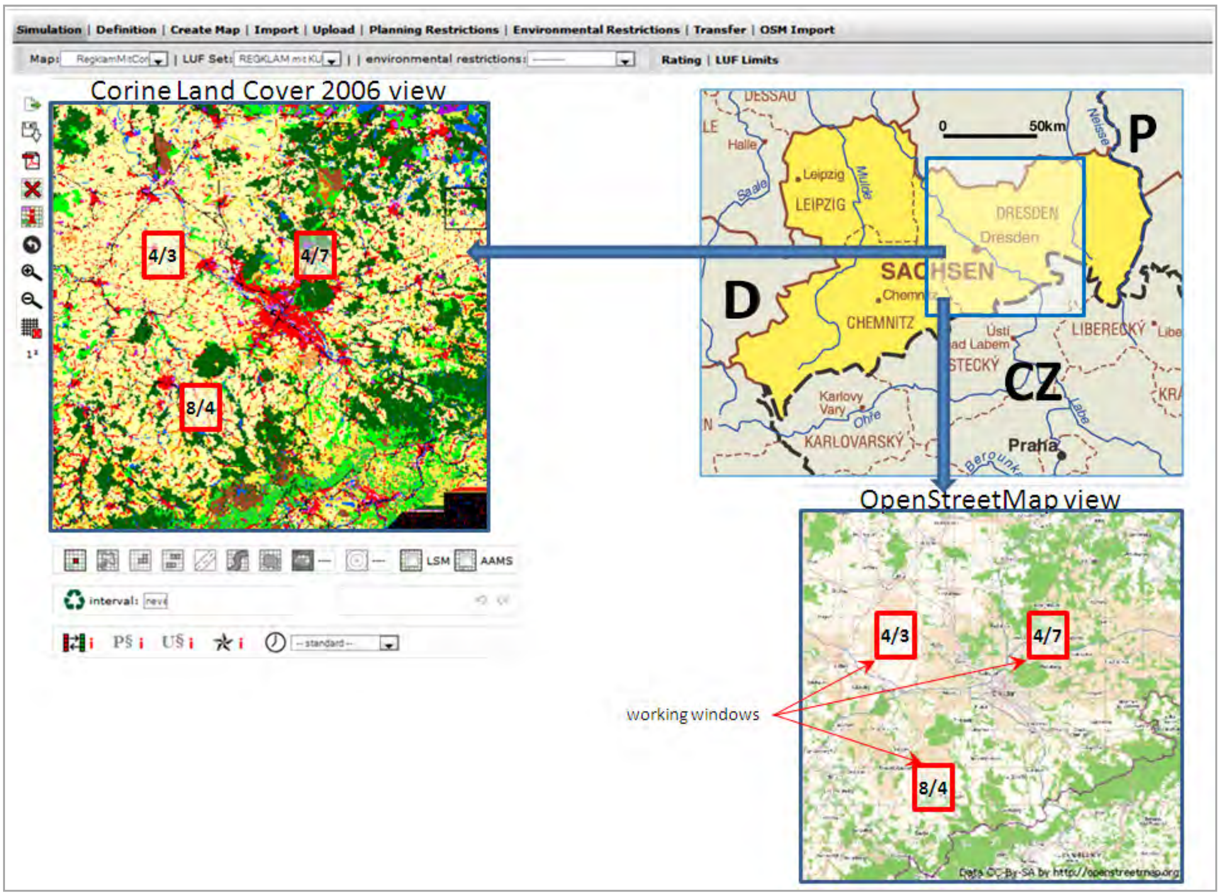

Fig. 7: Model region Middle Saxony and working windows for the GISCAME application test. The model region is divided into a number of 100 working windows, which are numbered according to row (first number) and column (second number) for identification. In this case, we applied the Corine Land Cover classification extended by our forest types, since information on the agricultural land-use types was not involved in this application test.

In all cases, we involved choice opportunities for different eligible forest types taken from the EMLC classification (see section 2.3; #15 Witt et al., in press) as a discussion basis to overcome trade-offs in biomass provision and impact on regional economy. We could show that short rotation coppice would be a preferable alternative to afforestation if trade-offs for these two services are intended to be the lowest.
Afforestation with forest types that include fast growing tree species such as Douglas fir or American Oak could also minimize, in the long run, losses in biomass productivity. However, they would provide a lower contribution to generate income from land-based production due to the longer rotation periods compared to short rotation coppice.
We recommended including in the updated regional plan preference areas for “lignocellulosic resources” instead of afforestation, in order to increase the acceptance and probability of land-use changes in accordance with our actors, and in order to give them more space for decision-making.

As an outcome, we exported our spatially explicit recommendations for “lignocellulosic resources” preference areas from GISCAME as shape files for regional planning and combined them with an information layer for the eligible forest types (#15 - Witt et al., in press).

Lessons learnt from the application of GISCAME in regional planning were that the opportunity to easily test conversion and afforestation scenarios was very motivating for most of our actors and that they felt responsible for providing recommendations and building consensus on them in the workshops.

On the other hand, the initialization and parameterization of the software became more and more time-consuming. First, manifold geo-information layers were involved, whose impact on the ability of each land-use type to provide ecosystem services had to be analyzed based on existing research. Second, to close knowledge gaps in case no prevailing studies or literature references were available, participatory evaluation was applied. The process to achieve consensus among the participants on the impact of different land-use types under different site conditions and in different neighborhood on the provision of ecosystem services took considerably long time (#6 – Fürst et al., 2010c; #7 - Fürst et al., 2010d; #8 – Fürst et al., 2011)

Also, although we realized in our software development a bottom-up approach and involved exclusively analytical features that were considered to be relevant and necessary by the actors, it turned out in the application tests that the software became too complex for easy comprehension by all planning actors. Regional planners appreciated the range of analytical features and made use of them to develop and test even very differentiated and complicated land-use scenarios. Other actors that were not so accustomed to working with such systems could not get the full advantage from the system and concentrated their scenario building on the simplest instruments.

As a consequence, we started again to introduce different applications in the workflow manager (Fig. 4). We split most recently into a scientific application that involves attribute and transition probability driven scenario design, landscape metrics analysis, and risk analysis in the form of apps. For participatory regional planning processes, we provide an application in which we turned off these apps and provide simple routines with which the user can initiate land-use changes by clicking on the cells.

The experience gained in our test applications has provided insights into the complexity of land-use planning with GISCAME, but it also has started to show ways and means of finding practical ways of improving the software. The papers related to this work are summarized below (cf. #8 – Fürst et al., 2011; cf. #9 – Fürst et al., 2012; cf. #10 – Fürst et al., in press).

Extended abstract #8

Fürst, C., Lorz, C., Makeschin, F. (2011): **Integrating land-management aspects into an assessment of the impact of land cover changes on Ecosystem Services**, International Journal of Biodiversity Science, Ecosystem Services Management. 7(3):168-181.

In this paper we assessed the impact of forest land-use strategies to mitigate climate change effects in the context of the REGKLAM study for the model region Middle Saxony, Germany.

In this model region, the degree of freedom to respond to climate change with land cover changes is very small so that adapted land-use in agriculture and forestry could play a major role for ensuring and enhancing ecosystem services provision in the future.

We tested different afforestation scenarios based on information layers from the prevailing regional plan for the model region and we analyzed their impact on ecosystem service provision to provide recommendations for regional planning. At this stage, our landscape metrics-based analysis was at its very initial status so that we could not come up with optimization algorithms but gave feedback on possible trade-offs for different afforestation strategies that built on the regional plan and made use of spatially explicit eligible forest types.

Extended abstract #9

Fürst, C., Pietzsch, K., Frank, S., Witt, A., Koschke, L., Makeschin, F. (2012): **How to better consider sectoral planning information in regional planning - example afforestation and conversion**. Journal of Environmental Planning and Management 55(7):855-883.

This paper builds on the analysis of how to integrate forest management opportunities into regional planning presented previously, again for our model region Middle Saxony, German. Here, we introduced results which were produced in the context of the project REGKLAM, but were extended and adopted for the updating of the current regional plan.

Issues addressed in this study were, how to evaluate conversion of existing forests and afforestation on agricultural sites regarding the impact of these strategies on the provision of ecosystem services at a regional scale. At this stage, we were able employ our landscape metrics analysis which enhanced our capability to improve landscape structural aspects by afforestation.

We could demonstrate that the conversion scenarios planned by the Saxon state forest administration have only a minor impact at the regional scale because the share of additional forest cover remains too small.

As a consequence, recommendations for regional planning were to (a) considerably increase the planned afforestation areas under consideration of the locally suitable future forest ecosystem types and (b) concentrate preference areas for afforestation along corridors, which most augment the additional benefits provided by connecting the biotopes at the landscape level.

Extended abstract #10

Fürst, C., Frank, S., Witt, A., Koschke, L., Makeschin, F. (in press): **Assessment of the effects of forest land-use strategies on the provision of Ecosystem Services at regional scale**, Journal of Environmental Management, http://dx.doi.org/10.1016/j.jenvman.2012.09.020.

In this paper, we developed and compared a spatially inexplicit and a spatially explicit testing strategy to derive recommendations for conversion, afforestation and the establishment of short rotation coppices in the model region Middle Saxony, Germany at the interface to state regional planning (spatially inexplicit) and regional planning (spatially explicit).

We were able to demonstrate that spatially inexplicit planning that cannot consider structural aspects and can only make limited use of knowledge on conversion strategies would result in recommendations that cannot be easily applied. Spatially explicit testing with GISCAME resulted in strategies that could be diversified for different representative working windows in the region.

We were able to show that potential losses in the biomass provision service and the regional economy can be considerably reduced by replacing afforestation areas with short rotation coppices.

In summary, we found that the spatially explicit analysis of land-use scenarios in combination with more detailed land-use classification plus an assessment of changes in land-use pattern gave us an improved basis for assessing different possible planning strategies and enhanced communication between forest management planners and regional planners.

4. Discussion and conclusions

At the interface between sectoral (forest and agricultural) land-use planning and regional planning, the spatially explicit testing method in GISCAME intends to reveal benefits from adapted land-use and land-management practices on the one hand and from their optimal spatial allocation on the other. Starting from a very simple paper-based prototype, we developed iteratively an IT-based approach that makes use of GIS features and combines them with a cellular automaton and a hierarchical multicriteria assessment approach. The software is currently applied in a number of model regions in Brazil (Pipiripau watershed), Finland (Central Finland), Germany (Upper Elbe Valley / Eastern Ore Mts.; Western Mecklenburg-Schwerin; Municipality of Leipzig, Luppe catchment), Sweden (Southern Sweden), and Slovenia (Metropolitan Area Ljubljana). Adaptation for some larger scale applications in West-Africa (WASCAL project) and Chile (linking territorial planning with strategic environmental assessment and ecosystem services) are in the works.

The support of communication between planning actors was the leitmotif and central motivation in the GISCAME development. By improving communication processes, we intended to overcome the problem of top-down processes in land-use planning that was criticized by FAO (1999) as one of the major aspects for failure of rural development programs.
The concept of the software and its analytical features were therefore conceived and developed completely in a bottom-up approach together with actors in regional planning. We asked them about their needs, experiences in working with other tools and expectations to be supported in their current and future work. We experienced that spatially explicit working systems such as GISCAME can contribute, in an easily understandable way to an assessment of the impact of land-use changes and the additional impact of changes in the land-use pattern on the provision of ecosystem services.

The bottom-up development approach enabled an intensive analysis and consideration of user requirements that were identified in our projects and were subsequently more specifically adapted to the model regions Euro-Region Neisse and Middle Saxony. Based on this development background, we intended to introduce generic and flexibly selectable land-use change scenario design and impact assessment features that cover different professional or educational skills of planning actors in using software support for planning.
As a “success example”, in the REGKLAM case study, we arrived at a relatively broad participation process with more than 70 institutional actors in drafting a regional climate change adaptation program and in translating parts of it in the updating of the Saxon Federal State regional plan and the regional plan for the planning region “Upper Elbe Valley – Eastern Ore Mts.” (= model region “Middle Saxony”; #8 – Fürst et al., 2008).
Also, the implementation of the software in the projects IWAS in Brazil and RegioPower at EU scale shows so far that only minor technical modifications of the original concept are needed for transfer to different regional conditions or thematic foci.

Nevertheless, the application of the software platform in land-use, territorial or regional planning procedures might be not transferable from the original development and current application context to others in every respect. Our bottom-up approach did so far not involve an analysis of typical working steps and processes in deriving or updating a regional or land-use plan and especially not of typical actor interactions that could or should be supported in participatory planning processes.

A reason was that requests for supporting regional or spatial planning approaches, their addressed scale and consequently the involved actors or actor groups cannot be standardized (e.g. Cabanillas et al., 2013). The resulting diversity of possible regional or spatial planning systems impedes a process analysis which would be requested for broadly applicable or even marketable software solutions (Higgins, 2008). As a lesson learnt, for further adaptation of GISCAME, we start in most recent application cases first with a planning system and planning process analysis. In a revised GUI (Graphical User Interface) we intend to come up with a more systematic and process-oriented presentation of the analytical features related to consecutive working steps in spatial analysis and formulation of a regional or land-use plan.

A critical aspect for the applicability and transferability of our approach was the identification, selection and handling of reference systems for land-use change impact assessment. In our case studies, we mostly referred to the ecosystem services approach (MEA, 2005) and made initially use of the Corine Land Cover (CLC) classes. We had to learn that a modification of both was often needed and should be easily possible in the system adaptation to application case specific requirements. In case of the ecosystem services approach, its introduction into planning practice did still not succeed in many cases so that modified or alternative planning target systems had to be introduced. For the application of CLC, we could show that its thematic and spatial resolution is not sufficient to really support land-use change impact assessment.
Admittedly, we experienced that we arrived with our analytical features and our reference to a very detailed land-use classification at limitations of complexity that were understood by all planning actors. Regional planners were pleased to be provided with manifold scenario design instruments together with a broad information basis on eligible land-use and land-management alternatives. Especially the latter helped them to more readily account for land-use opportunities to which they previously had no knowledge based access. On the other hand, actors that worked closer to land-use practice were often not so used to applying complex scenario building opportunities and could not take full advantage of all features the software provides in its current status.

A leitmotif in the GISCAME development was therefore to conceive an open platform which supports an in depth analysis of land-use change impact, but which can also be applied under conditions where data scarcity or limited user skills might impede land-use change scenario impact assessment.
Consequently, our user interface was conceived from the beginning on to allow for case specific definition and nomination of the desired set of land-use classes, ecosystem services, landscape services or land-use functions. Also, even though the combination of GIS and cellular automaton supports assessing the impact of variable environmental or social attributes which can be imported as information layers, this analytical function can, but must not be applied. Only some of our extended analytical features such as the water erosion risk and mass movement assessment or the so called attribute action management system (AAMS) cannot be applied without a minimum set of environmental (DEM) or other information layers (e.g. priority or preference areas from the regional plan; cadastral maps). Most recently, we involved them therefore in the Graphical User Interface (GUI) in form of applications (apps) that can be activated on demand, but are not part of the basic analytical features that are provided by default.

Furthermore, in the context of the WASCAL project and as part of the cooperation in the Ecosystem Service Partnership (www.fsd.nl/esp) working group 9 “Management, planning and restoration” we intend to broaden our user requirements analysis to different regional or spatial planning concepts and to further elaborate, adapt and improve the manageability and comprehensibility of the software platform.

We learned that the development of approaches such as GISCAME is a bit like tightrope walking between the intentions of aggregating information and reducing complexity on the one hand and the need to provide valid results and to face the complexity of ecological-economics systems in land-use on the other. Even in our well described and researched model regions Euro-Region Neisse and Middle Saxony, where the system was originally born and adapted, the information base for assessing the impact of land-use was not so comprehensive that we could increase the quality of our assessment by adding more detailed land-use classes. We had to learn, through the application of our system, that approaching reality in land-use changes is fairly limited by missing land-use class specific models, missing knowledge about measured data for model calibration, or about applicable model parameters. Consequently, detailed knowledge on the impact of some well described land-use classes had to be used as reference for expert opinion or stakeholder experience based assessment on the impact of all other classes.

To facilitate the involvement of expert opinion and stakeholder experience in the sense of a participatory evaluation approach, some simplifications were necessary, among them the transformation of indicator values for the impact of a land-use type on ecosystem services provision on a relative scale from 0 – 100. This simplification was the result of a mutual learning process with regional planning experts and practitioners with different disciplinary and professional background which often failed to understand and interpret single indicators. They requested to develop a consensus system which supports communication between them and assists them in understanding to what extent land-use changes might impact the provision of a bundle of ecosystem services. Also other systems such as MANUELA (von Haaren et al., 2012), MODAM (Zander and Kächele, 1999; adapted e.g. by Sattler et al., 2012) or DEXiPM (Pelzer et al., 2012), which are used for assessing farming practices, work with such simplifications. They succeed in addressing the land-user because they make the consequences of decision alternatives more comprehensible.
Comparable simplifications were made in our multicriteria assessment approach considering the use of the landscape metrics based assessment (#10 - Fürst et al., in press; #1 - Frank et al. 2011), which faced the problem of a lack of reference studies that would help to parameterize and validate our approach.

Together with our actors we learned that such simplifications in the evaluation system and assumptions regarding the manner in which land-use and its spatial pattern impact the provision of ecosystem services are accepted even though transparency of the evaluation background is lost and might have negative impact on the trustability of the provided results (Janssen, 2010; Uran and Janssen, 2003).

To overcome problems in transparency and to avoid a “black-box” approach, we intend therefore to improve the accessibility and visibility of indicator values by diagrams and show how they are iteratively merged to arrive at the results
From prevailing and current applications of our software platform, some further demands for development of the software can be concluded.
A weakness so far is that temporal dynamics in land-use types cannot be included and that the simulated land-use changes are done under the assumption that each land-use fulfills its full contribution

to ecosystem services provision in the moment it is installed in the simulation. This assumption was made to harmonize the diverse temporal dynamics of different land-use types, taking urban systems and forest ecosystems as most extreme examples. We knew when making this assumption that we are ignoring basic principles in ecosystem modeling (#11 – Fürst et al., acc.).
Therefore, in RegioPower we are currently combining GISCAME with forest growth and yield, and agricultural production models at cell level in form of a nested modeling approach. Growth, yield and production model runs are initiated before land-use change simulation to produce a data base for a set of pre-defined scenarios. Scenarios are understood as a combination of environmental conditions (site factors), climate change scenarios and scenarios for altered resource demands due to fluctuations in the regional human population. Modifications of such scenarios by restarting a model can then be triggered exclusively by the concerned cells in the process of land-use change simulation if the pre-modeled scenario conditions are not met.

A demand of our regional planning professionals from the very beginning of the GISCAME development on was to "automatize" scenario building and to give feedback on how assumptions on changes in drivers such as climate change, world market trends or so called "payments for ecosystem services" would impact landscape composition and configuration (Fig. 2).

Focus of GISCAME has so far been put on user-driven land-use changes, where a bundle of scenario design instruments was offered to facilitate the building of such scenarios. This includes scenario design routines that trigger changes by mouse click and more complex routines that make use of cell attributes and / or transition probabilities. The formulation of the latter is so far based on expert opinion or results obtained from time series analysis on land-cover changes.

For regional planning professionals, these instruments turned out to be not always sufficient or time efficient. As a consequence, we started in the RegioPower and WASCAL projects to further evolve the functionalities of the cellular automaton in the GUI. This involves the opportunity to define not only land-use change transition probabilities dependent on current land-use, site conditions, neighbored land-uses and age (in the case of forest land-use classes), but to introduce as well spatially explicit decision criteria and some fuzzy logic algorithms on where these land-use changes start and stop to better reflect the haphazardness of land owner decisions in socio-ecological systems. Intention was in this case not the prediction of likely land-use change situations, but the support of pretesting potential effects of policy and planning measures and involving stochastic processes in the simulation and assessment of land-use change scenarios.

Moreover, we are attempting to improve and standardize the "mouse click" scenario design instruments of the software at the front-end (Fig. 2) of GISCAME. We work on facilitating land-use change scenario building by using moderating routines that facilitate the translation of user assumptions or experiences in spatially explicit land-use change scenarios instead forcing the user to actively change the land-use pattern by mouse click.

As an add-on, too overcome the problem of availability of thematically sufficiently resolved land-use data, we have started to reprogram the cellular automaton to make use of its functions in form of a "land-use structure generator" that brings together land cover data and statistical data on the share of different land-uses within the land cover classes.

Especially in participation processes with users that lack in knowledge on how to interpret maps, a pre-request for successful application of tools such as GISCAME is a realistic representation of the landscapes. In applying our software, we came to realize that reference to and use of land-use maps was not in any case comprehensive to our actors and that not all of them are used to projecting their idea of a landscape on 2-D perspective. Especially when intending to transfer the system to applications where the targeted persons are not trained in mapping and map interpretation, this is still an essential hurdle (Arciniegas et al., 2013).

As a consequence, 3-D visualization features complemented by methods taken from social sciences to support actor involvement in land-use change scenario development such as role play games need to be involved in the further GISCAME development (e.g. Burgoin et al., 2012; Villamor, 2012). Currently, in cooperation with CIRAD/BIOS UMR AMAP GreenLab project (France), we intend to arrive at a combination of the land-use map based graphical presentation of GISCAME with the 3-D visualization features provided by LandSim 3D, www.bionatics.com/Site/product/landsim3d.php to allow for an easy, but comprehensive representation of landscape characteristics and land-use dynamics.
A problem is the issue regarding, on the one hand, how realistic 3-D simulations must be to create the impression of standing in a well-known region and avoiding, on the other hand, simulation of too many individual aspects that would boost the modeling effort (Paar, 2006). So far, approaches such as Lenné-3-D (www.lenne3d.com) or LandSim 3D achieve the simulation of real world features of a landscape, but miss broader transferability for reasons of model performance and modeling effort (e.g. Tress and Tress, 2003). Approaches such as these which make use of mathematical algorithms like LandSim 3D to switch between different scales are promising, but the test of their potential connection to land-use change impact assessment models such as GISCAME and their appraisal by planning actors is still a matter of future research.

Alternatives for improving the visualization features of GISCAME that we currently discuss with regard to a meaningful modeling effort and comprehensibility to our actors are support of the scenario building by photorealistic visualization (Tress and Tress, 2003) or a 2-D presentation that translates the land-use maps into artificially created satellite maps in "Google-Earth-style" (see e.g. Shepard and Cizek, 2009). In ongoing projects, we hope to collect experience on the pro´s and con´s related to each of these alternatives (see also van Lammeren et al., 2010).

So far, a criticism can be passed on our approach considering the fact that a sensitivity or uncertainty analysis of the outcomes is not possible. A reason therefore is that comparable models for validation involving both, the impact of single land-use classes and landscape metrics to estimate the provision of ecosystem services at meso scale are rare. Also, monitoring schemes that reflect the impact of land-use and land-use changes on ecosystem services provision are so far not yet realized (Chapman, 2012).
As an example, uncertainty provoked by the combination of cells as smallest assessment entity instead of pixels with the landscape metrics analysis could not be quantified. We started a comparative test series with FRAGSTATS versions 3 (Mc Garigal et al., 2002) and 4 (Mc Garigal et al., 2012), but in contrast to FRAGSTATS, our software includes linear landscape elements in the landscape metrics analysis, so that our calculated results cannot fully be compared and validated by the FRAGSTATS results.

Another aspect is uncertainty on socio-ecological system component interactions when drafting and assessing land-use scenarios under consideration of numerous environmental and social factors. By use of the cellular automaton approach and introducing “integrated transition probabilities” and random selection of starting points for land-use changes, we tried to involve knowledge about environmental impact factors, scenarios of how these can be altered, for instance, in the context of climate change, and the haphazardness of actor-driven land-use change decisions.

The aspect of actor influence on land-use changes could be supported by improving interfaces to or including algorithms of specialized tools such as LUDAS (Le et al., 2008). So far, a test of the advantage or disadvantage of our approach compared to other methods such as agent-based modeling or Bayesian Belief Networks (BBN) (Ma et al., 2007) or how to combine GISCAME with respective routines for lowering the level of uncertainty is outstanding and part of our future research and development plan. Especially by using agent-based routines and leaving the pure focus on land-use types in favor of a more integrative view including land tenure, our land-use change scenario building based upon transition probabilities could be made more employable in regional planning processes.

Both, extended visualization opportunities and linking with agent-based approaches will be part of the research work and further system adaptation in the WASCAL project.

Concluding from the experiences gained in applying the software in our case studies, we still have to work on the applicability of GISCAME as community-based or multi-actor planning instrument in participatory regional or land-use planning processes.
An opportunity to correspond to the variability of planning approaches and systems and the related user requirements without blowing up our approach in abdicable manner is to extend GISCAME by complementary approaches in the sense of an analytical tools framework. Such a framework should allow for integrating in harmonized manner existing model systems or software platforms with specialized application area in regional or land-use planning (#11 - Fürst et al., acc.). The tools combination should particularly consider the linking with different scale levels (see e.g. Castella et al., 2007).

As an example, GISCAME cannot well address aspects at farm scale or forest ownership scale. Farms and forests – the latter under consideration of their different ownership types and sizes - are important spatial reference entities where management actions impact notably ecosystem services provision in a regional context. Here, tools such as MANUELA in agriculture (Von Haaren et al., 2012) or forest growth simulators (Lupp et al., in press) provide a valuable interface between land-management and land-use change at landscape scale, whose results can be embedded in the meso scale approach of GISCAME.

Also, the GISCAME assessment features are so far tested and run well for regions up to 10,000 km². However, they would provoke a considerable modeling time effort when being transferred to a larger scale. The latter might be needed as a previous step before transferring policy aims into regional planning. At macro scale, land-use policy impact assessment tools such as the CLUE model family (Verburg et al., in press) could therefore be addressed in a form of a nested approach.

Moreover, we are missing thus far a link to hydrological process models at a meso scale (#12 – Fürst and Flügel, in rev.). Our software algorithms support linking with ecosystem process models at cell level and involve the simulation of water erosion risk and mass movement at regional level. However, so far we cannot account for hydrological processes below the earth surface such as groundwater recharge or nitrate leaching through the unsaturated zone into the groundwater aquifer. Especially such hydrological processes, however, are relevant for so called “blue” services taking maintenance of the regional water balance and drinking water provision or as examples.

In the projects IWAS and REGKLAM, GISCAME was already adapted to also work on catchment scale (Lorz et al., in press; Lorz et al., 2010) although this produced some problems in the application of the landscape metrics approach which was originally programmed and tested for square-shaped contours and not for irregular shapes of the test regions. What we missed was an approach to define modeling entities that better correspond to hydrological processes at meso scale. A model development request is therefore the introduction of algorithms that allow the definition of a spatially connected and for hydrological processes relevant compound of cells with comparable topographical and geological / soil information.

As a consequence, linking with the ILMS platform (Kralisch et al., 2012) and involvement of the concept of HRU (hydrological response units, Flügel et al., 1996a, b) or EHRU (eco-hydrological response units, Hörmann et al., 2005) in a way that combines landscape ecological assessment methods and hydrological modeling (#12 - Fürst and Flügel et al., in rev.) is an essential aspect of some currently applied European and national research projects for the further GISCAME development.

A permanently continued participation of planning actors in the up-building and evolution of each single component in the analytical tools framework and of the framework concept as such is hereby indispensable.

The above discussion on improvement needs and on opportunities for how to realize them in GISCAME is part of a lead paper and a book chapter, the extended summaries of which follow.

Paper # 11 – Fürst et al., acc. draws conclusions on requests for how to conceive an analytical tools framework for land-use change modeling as outcome of a European wide cooperation process on integrated land-use that was initiated in 2010 under the title “European Land-use Institute (ELI, www.eli-web.com).

Paper #12 – Fürst and Flügel, in rev. discusses how to bring approaches in hydrological modeling together with land-use change modeling and impact assessment on the provision of ecosystem services.

Extended abstract #11

Fürst, C., Helming, K., Lorz, C., Müller, F., Verburg, P. (acc.). **Integrated land-use and regional resource management – A cross-disciplinary dialogue on future perspectives for a sustainable development of regional resources**. Lead paper of the Special Issue RegioResources, Environmental Management.

In this lead paper to the special issue "RegioResources 21", we put the focus on the identification of general requirements for tools and approaches related to supporting integrated land-use planning and we came up with a profile for an analytical tools framework for integrated land-use planning in whose frame the GISCAME development is and will be done.

We identified (a) a need for a platform which supports bundling in comprehensive manner knowledge and methodological approaches from different land-use sectors, from landscape ecology and from social sciences to ensure a holistic point of view. This includes in our understanding (i) definition of the meso scale as reference for modeling (ii) ability to harmonize and integrate different data sets and data formats into this reference scale, and (iii) instruments to account for land-use interactions and processes that go across the meso scale.

(b) Knowledge provided by such a framework, should then be transformed in a way that enables planning actors to make use of it to test their own planning ideas and communicate them with other actors in a consensus building process.
This includes in our understanding (i) provision of standardized assessment concepts such as ecosystem services, land-use functions or landscape services and involves the underlying assessment criteria, indicators and methods. (ii) This should also include the opportunity to combine, modify and adapt such approaches and give support for integration of factual knowledge and expert opinion. Finally, we should involve (iii) tools that help to design land-use planning scenarios which can range from multiple drivers dependent land system transformation processes, agent-based land-use changes in cultural landscapes to scenarios where actors actively design their landscape.
The therefore necessary interaction between the planning actors, the assessment concepts and the scenario building itself should be supported by visualization features and simple entry and feed-back mechanisms.

Extended abstract #12

Fürst, C., Flügel, W. (in rev.): **How to assess the impact of land-use changes on providing hydrological ecosystem functions (ESF) and services (ESS) – a conceptual framework.** In: Chicharo, L., Müller, F., Fohrer, N., Wolanski, C. (eds.): “Ecosystem Services and River Basin Ecohydrology”, Springer publisher.

This paper intends to conceive an idea how one of the shortcomings in GISCAME, the coupling with meso scale hydrological processes could be overcome and how to make use therefore by the concept of Hydrological Response Units (HRU, Flügel et al., 1996 a, b).

Main objective of this paper was to contribute to the book an approach that supports the assessment of so called hydrological ecosystem functions and services and that brings together the different scales in ecosystem services assessment, namely the regional scale in planning and the scale of catchments or river basins in hydrological modeling.

Core of the chapter is a conceptual framework approach that builds on the HRU concept and merges the latter with the cellular automaton based land-use change assessment framework GISCAME. The concept is discussed with respect to its potential application in eco-hydrology.
A benefit of the framework could be that it supports a much more detailed consideration of land-use dynamics within the HRU as modeling entities. Also, the framework can contribute to link hydrological modeling with land-use modeling and landscape ecological assessment methods such as landscape metrics. Finally, it provides an improved basis for integrating hydrological ESF and ESS in regional planning decisions and for sustainable ILWRM (Integrated Land and Water Resource Management).

Future research is needed to test the framework in well-equipped test basins to explore its potential for land-use change impact assessment and to give feed-back on data demands and the adaptation of environmental and hydrological institutional monitoring networks.

5. Summary

The habilitation thesis is built on 10 research projects from 2006/2007 up to now which focused on the scientific and technological development of a system approach for integrated impact assessment of land-use and land-management on the provision of ecosystem services. In a number of 15 articles that include outcomes of three running PhD theses we describe the development, test and application of the software platform GISCAME and discuss its limits and further development needs.

GISCAME was originally developed as a very simple support tool for exchange, communication, knowledge sharing and participation in land-use planning. In an initial step, generic user needs were derived from a European case study in Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Germany, Poland, Serbia, Slovenia, Slovakia, and The Netherlands. Deeper going system specifications were subsequently made with experts from Czech Republic, Germany and Poland in the Euro-Region Neisse.

In this initial prototyping phase, we referred to approaches coming from decision support and management support systems in a more sectoral (forest management) understanding. We had to learn that such instruments are still in use and accepted for supporting current land-use and land-management planning processes. Nevertheless, our study participants expected the delivery of a more holistic instrument because they faced increasing complexity in planning processes and decision making.

In the underlying projects Dynamic-DATA EU 25+, ENFORCHANGE, IT-REG-EU, REGTRANSEKT and REFORMAN, we were confronted with the problem that the drafting and development of an integrated system solution cannot simply be based on the analysis and adaptation of existing tools. The latter were used as reference and testing basis for our study participants.

We had to adapt methods from social sciences and IT-development for arriving at a sufficient number and regional / thematic representativeness of the participants, for obtaining qualified information on user requirements and for transforming the latter into a system profile. Hereon based, we improved iteratively along a large number of user tests and over a several years lasting feed-back process the structure and analytical features of GISCAME. This adaptation is still ongoing in current projects such as IWAS, REGKLAM, RegioPower or, most recently, in WASCAL. The projects KIDS and TrainForEducation contributed to this adaptation by experiences in facilitating the GISCAME structure and some analytical and visualization features for enabling an application in environmental education and eLearning.

Along the software adaptation process, we experienced that our original understanding of “land-use planning” was far too much unspecific and therefore not operable for profiling and developing an integrated support system. As a consequence, we focused the development on supporting “regional planning” as a process of breaking down policy aims at national or Federal State level (in Germany) into the mapping of concrete land requirements.

To support scenario design and participation in regional planning processes, we developed a technical platform that combines a cellular automaton with GIS features. This technical development was done together with a software company, PiSolution GmbH, to ensure a high quality in the object-oriented code programming and of sustainability in the adaptation and application support.

The software development is organized in a close feed-back process which involves the software architecture drafting, pseudo-code programming, transfer into operational code, testing and final integration into the core system.

By the combination of cellular automaton and GIS, we obtained an instrument for flexible design and assessment of land-use change scenarios with high level of independence on the case-study specific data availability. Cellular automaton and GIS enable to involve manifold environmental and other information layers in the drafting of land-use change scenarios and related rules, but do not necessarily request for a specific information layer set.

As a third component, we added a hierarchical multicriteria evaluation system that transforms land-use change scenarios in a qualitative response on how the balance of a selected set of planning objectives (e.g. ecosystem services) is modified.
This multicriteria evaluation framework involves two aspects which are currently part of two PhD theses. Both PhD theses were initiated two years after the start of the GISCAME development and were a result of the ongoing user requirements analysis. Users representing state agencies for environmental and water management, and regional planning authorities criticized the originally simpler land-use change impact assessment procedure and highlighted the importance of accounting for the land-use pattern in ecosystem services assessment.
The first PhD thesis aims at the further development of the hierarchical, indicator and criteria based evaluation approach as such. In this approach we aggregate stepwise literature references, modeled or measured indicator values that express quantitatively the ability of a land-use type to provide ecosystem services with expert estimation on those land-use classes for which only few or no quantitative information is available. The approach includes the consideration of local environmental or social attributes that might modify the ecosystem services provision capability of a land-use type.
Focus of the second PhD thesis is to add a corrigendum considering the impact of the landscape structure and of linear elements on the capacity of a landscape to provide ecosystem services.
Both PhD theses referred originally to the ecosystem service concept in the understanding of the Millenium Ecosystem Service Assessment (MEA). As a result from focusing on regional planning and based on requests of our study participants, we started to modify this concept. Currently, we make use of a terminology that refers still to the ecosystem service concept, but includes also aspects of the land-use function (LUF) and the landscape service concept. Also, we started to standardize and harmonize the evaluation process as such, and came to a concept that allows for a flexible combination of different evaluation components so that we are again able to run our approach under conditions of data scarcity.

In the case studies REGKLAM and RegioPower and as part of a third running PhD thesis we tested and developed different land-use classification schemes to explore a recommendable level of spatial and thematic detailedness for land-use change impact assessment. We assumed that a land-use classification which reflects regionally typical agricultural and silvicultural practices would help to identify best practices for adapting the land-use to societal demands on ecosystem services provision and to external impact factors such as climate change. Referring to the model region Middle Saxony, we came up with a regionalization approach for eligible land-use classes in forestry and agriculture. These enabled the study participants to formulate and test spatially explicit a broader range of land-use change scenarios compared to scenarios that built upon less detailed information provided, for instance, by Corine Land Cover (CLC).

Nevertheless, the effort to adapt the multicriteria evaluation approach and to obtain all requested information or expert opinion to assess the impact of each single land-use class became notably higher. Also, the adaptation of the landscape metrics corrigendum to a thematically more detailed land-use classification turned out to be demanding as some of the selected metrics were directly dependent from the number of land-use classes and produced consequently results that were difficult to interpret. We had to learn in the end that accounting for the full diversity of land-use practices is supported neither by available measuring data nor by contemporary land-use type specific models.

In the test applications REGKLAM and RegioPower, mainly in the model region Middle Saxony, we could successfully apply GISCAME for testing alternative land-use strategies for climate change adaptation and we could make use of GISCAME to derive spatially explicit recommendations for regional planning. We experienced that GISCAME in its current development status was helpful to support communication between actors in regional planning, even though we had to revise the way how and to whom our analytical features are made available to cover different professional and disciplinary backgrounds of the users. In the software application, also some limitations and missing components of GISCAME were identified. GISCAME as a meso scale system necessitates a better linking with models or tools that cover analytical demands at the micro and macro scale. In RegioPower, we started a test how to couple our cellular automaton approach with forest growth and yield, and with agricultural production models. So far, we could not gain enough experience on the resulting slowing down of simulating land-use change scenarios to explore how this approach must be improved.

In parallel, we began to draft different approaches for complementary analytical tools frameworks in which instruments that address different modeling topics and scales or that provide alternative features for visualization and results processing are involved.
Weaknesses that we hope to compensate in a fourth, most recently started PhD thesis in the context of the WASCAL project address an improved analysis of so called “blue” services because subsurface hydrological processes can so far not be modeled within GISCAME.
Also, we started to figure out how to improve the so far 2-D land-use map based visualization of land-use change scenarios and how to involve agent-based aspects in land-use change scenario building. Here, a fifth PhD thesis which is currently in the application process in Chile is intended to consider such aspects, and make GISCAME compatible to territorial planning systems in a different socio-cultural context compared to its original development background.

The support of multi-actor or community based planning processes will be the great challenge of the GISCAME adaptation in the context of the WASCAL project and of other international cooperation initiatives, as the so far underlying understanding of how land-use change impact assessment in regional planning processes should be supported cannot easily be transferred from the originally European development context to other world regions.

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Other sources: doctoral theses that are supervised by the author

- Frank, Susanne, (started in 2009): Development of mathematical approaches for evaluating the impact of landscape structure on non-marketable ecosystem services on landscape level (REGKLAM, RegioPower, TU Dresden).

In this cumulative thesis, one article is already published and one is in revision. The thesis is planned to be finished in 2013/14.

- Koschke, Lars (started in 2009): Development of integrated evaluation approaches for the impact of forestry and agriculture on landscape related ecosystem services (REGKLAM; TU Dresden).

In this cumulative thesis, one article is already published and another one is accepted. The thesis is planned to be finished in 2013/14.

- Witt, Anke (started in 2010): Development of approaches for integrating models for water and wind erosion and drought in GISCAME (REGKLAM, RegioPower, TU Dresden).

In this cumulative thesis, one article is in press. The thesis is planned to be finished in 2014/15.

Declaration authorship of the publications that form the basis of the habilitation thesis

This habilitation thesis builds on 15 articles which have been published since 2008.

In case of articles #2 -#12, I was lead author with full responsibility for the intellectual conception and writing. I co-authored articles #1, #13, and #15 because they were written in the course of three PhD theses that I am currently supervising. To support the lead authors in their first publication projects, I have spent considerable time effort for each of the articles, not only for guiding and supervising the methodological development and the respective application with and in GISCAME, but also for revising carefully (and in all cases several times) the articles before their submission to well approved journals with comparably high impact factor in the research area land-use / environmental management.
Article #14 was co-authored because it resulted from a cooperation with the Saxon State Office for Environment, Agriculture and Geology in the REGKLAM project were I originally developed the idea and concept of the crop-sequences based agricultural land-use classification, but where the analysis of the statistical data in Saxony and the finalization of the concept was done by the responsible scientific co-worker, Marco Lorenz under my coordination in the module 3.3 “land-use strategies”. However, to get this article through the first review step (currently acceptable after revision), I spent a notable time effort for restructuring the text and making the classification process, the underlying analysis and the applicability of the concept clear to the reviewers.

All articles were written in a multi-authorship because a leitmotif of GISCAME is team-work. Common publishing was therefore done together with representatives of the software company PiSolution GmbH in appreciation of the technological component in the system development and with the PhD students accounting for their intellectual contribution in the discursive development of the system concept. Also, a central concern for the multi-authorship was also to exchange with approved colleagues on potentially critical aspects and involve a broader viewpoint especially in the discussion of the methods and results before the review process as such.

Declaration support received from other persons

The development of GISCAME is done in cooperation with the Small and Medium Enterprise (SME) PiSolution GmbH. Responsibility of PiSolution GmbH is to do the software programming as such. Software structure and pseudo-code (= instructions what the program code as such should do and how it is linked with other elements in the object-oriented structure of the software, here in the sense of a specification of the later program code) are developed by me and the PhD students, respectively, in a discursive process with Katrin and Frank Pietzsch and are subsequently programmed mainly in PHP, JAVA and C++.

This task sharing was done to ensure that software architecture and program code correspond to professional demands and are well documented in standardized manner. Furthermore, task sharing was necessary to ensure that the application of the software in other projects and by other users can be supported in case of bugs or purely technical adaptation needs.

Scientific concept and full intellectual property rights in GISCAME were hold from the beginning on by me and are part of the IPR declaration with the software company PiSolution GmbH, while the SME is holding the source code.

Land-use classification was done in cooperation with the SME Euromap GmbH who did the thematic interpretation of the remote sensing data and the delineation and spatial correction of the land-use pixels based on terrestrial (inventory) data that were provided by the Saxon State Office for Agriculture, Environment and Geology (LfULG) and Saxon state forest enterprise “Sachsenforst”. The conception of the classification scheme as such and the concept how to correct spatial inhomogeneity between the different involved data sets was part of my work.

Curriculum vitae

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Project coordination

- ELI – European Land-use Institute (coordination), joint research project German Federal Ministry of Education and Research (BMBF) (since 5/2011), head European Nodal Office des Global Land Project, (since 7/12)
- RegioPower - IT-A regional IT-based platform for bringing resource needs and land-based resource production together, joint research project ERA WoodWisdom / Bio-Energy (since 2/2012)

Project contribution and networks

- WASCAL, BMBF, WP. 6 Integrated Assessment (since 1/12)
- ForSys - Cost action FP0804 (partner since 2010)
- ESP – Ecosystem service partnership (Individual Member, TWG 8 lead team ES in planning, management and restoration, partner since 2010)
- Working group "Croissance-Amélioration-Qualité", LERFoB, UMR INRA-AgroParisTech, Nancy (since 2003)

04/04 – 12/11

Scientific co-worker, Chair of Soil Science and Soil Protection, Dresden University of Technology

Project coordination

- WP 3.3 land-use strategies, joint research project REGKLAM, BMBF (until 12/11)
- ELI – European Land-use Institute, joint research project BMBF (since 5/2011)
- KIDS – (joint research project Deutsche Bundesstiftung Umwelt (DBU2009 - 2010)
- ENFORCHANGE – joint research project BMBF (2005 - 2009)
- REFORMAN - SEE-ERA-Net project (2007 – 2008)
- REG-TRANSEKT - joint research project BMBF (2007 - 2008)
- IT-REG-EU Interreg-III a - project (2007)
- DynamicDATA EU25+ - joint research project BMBF (2006)
- a.t.l.a.n.t-IS – independent network on adaptive land-use planning systems (2004 - 2006)

Project contribution and networks

- TrainForEducation – joint research project Leonardo da Vinci (partner, 2008 - 2010)
- Mobility@forest, joint research project German Federal Ministry of Economics and Technology (BMWi, 2007 - 2010)
- MORE - IST EC (FP 6) (transfer partner, 2006 - 2009)
- ECHOES - Cost action FP0703 (partner since 2010)
- ForSys - Cost action FP0804 (partner since 2010)
- ESP – Ecosystem service partnership (partner since 2010)
- Netzwerk Umweltbildung Sachsen (2010 - 2012)
- CONFOREST - EFI project center (2004 - 2009)
- Working group "Croissance-Amélioration-Qualité" LERFoB, UMR INRA-AgroParisTech, Nancy (member since 2003)
- Erasmus-Agreement (9/11) with TU Gheorghe Asachi Iasi, Faculty of Chemistry and Environmental Protection, Dept. Environmental Engineering

03/10
PhD thesis (cumulative)
Fly ash impact in forest ecosystems in Northeastern Germany – an assessment and regionalization approach (summa cum laude, 0.56)

11/00 - 03/04
Scientific co-worker, Chair of Soil Science and Soil Protection and Chair of Forest Management Planning, Dresden University of Technology

Project coordination

- Sustainable Methods and Ecological Processes of a Conversion of Norway Spruce and Scots Pine Stands into Mixed Forests, joint research project BMBF (2000 - 2004)

Project contribution and networks

- Value inventory and value control (part of Sustainable methods), BMBF (2000 - 2004)
- adHOQ – young scientist network wood-quality modeling (2003 – 2005)

06/98 - 10/00 Internship II Bayerische Staatsforstverwaltung (Second state examination 7/00)

04/94 - 04/98 Studies in forest sciences, Ludwig-Maximilian University München

- Diplom-Forstwirt Univ. 04/98 (1.7; diploma thesis 1.1; Certificate „Applied Informatics“ 6/98)
- Funded by Studienstiftung des Deutschen Volkes 04/94 - 04/98

10/93 - 03/94 Internship I Bayerische Staatsforstverwaltung

09/84 - 06/93 Leibniz-Gymnasium Altdorf bei Nürnberg

- 06/93 Baccalaureate (1.1)

09/80 - 08/84 Elementary School Feucht bei Nürnberg

Funding acquisition (since 2003)

National programs

• German Federal Ministry of Education and Research (BMBF)	2.55 Mio €
• German Federal Ministry of Economy and Technology (BMWi)	200,000 €
• Deutsche Bundesstiftung Umwelt	125,000 €

EU programs

• INTERREG	45,000 €
• SEE ERA	20,000 €
• ERA WoodWisdom / Bioenergy (handled in Germany by BMELV)	1.625 Mio €
• FP 6	56,000 €
• Leonardo da Vinci	47,000 €

Other

• Freistaat Sachsen / Sachsen-Anhalt / TU Dresden	52,000 €
• Stifterverband für die deutsche Wissenschaft	8,000 €

Reviewer activities

Scientific Journals

- African Journal of Agricultural Research – 1
- African Journal of Business Management – 1
- African Journal of Biotechnology – 1
- Atmospheric Environment - 1
- Ecological Indicators (editorial board since 2013) – 31
- Environmental Impact Assessment Review – 1
- European Journal of Forest Research – 2
- Environmental Management, Springer – 11 (SI guest editor 2010)
- Environmental Management, Elsevier – 6 (SI guest editor 2012/13)
- Environmental Modelling and Software – 3
- Environmental Engineering and Management Journal – 1
- Forest Ecology and Management (SI guest editor 2007) – 10
- International Journal of Biodiversity Science, Ecosystem Services & Management – 2
- International Journal of Geographical Information Science – 2
- Journal of Ecosystem & Ecography – 1
- Journal of Forest Science – 3
- Landscape Ecology – 3
- Landscape and Urban Planning – 1
- Regional Environmental Change – 1
- Sustainability – 1
- Scandinavian Journal of Forest Research - 1
- Spanish Journal of Rural Development (scientific board since 2010) – 1
- Soil and Tillage Research – 1
- Open Journal of Forestry (editorial board since 2011) – 2

Research programs

- CONSOLIDER program, Spanish Ministry for Science and Innovation
- National Research Foundation, South-Africa
- Expert participation COP Biodiversity (Forestry)

Workshops and Conferences (member sc. Board / organization)

- FORSYS 2013 – International conference on Decision support systems 4/13 (www-conference.slu.se/forsys2013/index.html)
- IUFRO Landscape Ecology Conference „Sustaining humans and forests in changing landscapes" Symposium "Ecosystem functions and services in changing landscapes / Spatial patterns and ecological processes", 11/2012 (www.iufrole2012.cl/)
- Ecosummit 2012 symposium "Structure matters – the potential of land-use pattern to contribute to ecosystem services provision, 10/2012 (www.ecosummit2012.org/)
- IALE symposium "New frontiers in landscape economy - assessment and up-scaling of the impacts of land-use practices on ecosystem services" Beijing, 8/2011 (www.iale2011.org)
- Air Pollution 2012 Coruna 5/2012 (www.wessex.ac.uk)
- RegioResources 2012 Dresden, 5/2012 (http://eli-web.com/)
- RegioResources 2011 Dresden, 5/2011 (http://eli-web.com/)
- LandMod 2010 Montpellier, 2/2010 (www.umr-lisah.fr/rtra-projects/landmod2010)
- Air Pollution 2010 Kos 6/2010 (www.wessex.ac.uk)
- Forestry in Achieving Millenium Goals, Novi Sad, 11/2008 (www.ilfe.org)
- ForwardForests, 04 – 12/2005 (http://forwardforests.czu.cz)

Lectures and supervision of scientific work

Lectures (up to now)

- Master courses "Forstwissenschaften" und "Raumentwicklung and Naturressourcenmanagement", TU Dresden - Module FOMF 37 "From land-use to land-management - integrating soil and land management aspects in landscape development" WS 2010/11 and 2011/12; since WS 2011/12 obligatory and evaluated;
- Master course „Forstwissenschaften", TU Dresden - Module FOMF 34 section „Forschungsmanagement Waldlandschaften" WS 2010/11 and 2011/12
- Specialization area "Raumentwicklung" of the master course "Raumentwicklung und Naturressourcenmanagement", TU Dresden – Guest lecture on "Opportunities of agricultural land-use for the adaptation to Climate Change - focus crop production"
- Master course „Geoinformatik", Uni Jena - Module GEO 404: Angewandte Geoinformatik, Realisierung: Integrierte Landnutzung und Landschaftsplanung, WS 2012/13
- UNEP/UNESCO Course "Environmental Management for Developing and Emerging Countries", CIPSEM - lecture „Integrated land use", 2011
- UNEP/UNESCO short course Climate change adaptation: Water and Soil, CIPSEM - Lectures "Land-use and land management impacts" und " Land-use planning and decision support", WS 2010/11 und 2011/12

- International Graduate School Cottbus, Brandenburgische Technische Universität Cottbus, Course “Applied ecosystem research and landscape change”, Gastvorlesung “A mesoscale system for supporting integrated land-use”

Diploma, master and bachelor theses

- Kartierung von Bodenmerkmalen an sechs Bodenprofilen entlang eines Flugaschegradienten in der Dübener Heide (diploma thesis)
- Detection of Black Carbon in fly-ash impacted forest soils (master thesis)
- Comparison of methods for Black Carbon detection (diploma thesis)
- Bewertung der Relevanz und der Umsetzbarkeit von Anpassungsstrategien an den Klimawandel aus der Sicht sächsischer Acker-, Ost-, und Weinbauunternehmen (diploma thesis)
- Entwicklung einer Datenbankanwendung zur Erfassung von Holzabnehmeranforderungen an den Holzproduzenten (diploma thesis)
- Analyse der Korrelation bodenchemischer Eigenschaften mit der Ferrimagnetischen Suszeptibilität (bachelor thesis)
- Analyse der Schwermetallgehalte in forstlichen Böden entlang eines Flugaschegradienten (scholarship thesis)
- Kartierung der ferrimagnetischen Suszeptibilität in einem regelmäßigen Raster zur Erfassung historischer Flugascheeinträge (graduation thesis in cooperation with Technical School of Forestry, Lohr am Main)
- Erhebung des Einflusses der Veränderung landwirtschaftlicher Nutzungspraktiken auf den N-Austrag auf Landschaftsebene (student thesis)

Doctoral theses

- Ecosystem services of wetlands and Agricultural land use under climate change: case study of a semi-arid watershed, North Benin (WASCAL, in work)
- The potentials of Pennisetum purpureum as a biological geotextile and the application of different plant growth media in reclaiming a disturbed mine site (KNUST, in work)
- Development of integrated evaluation approaches for the impact of forestry and agriculture on landscape related ecosystem services (TUD, in work)
- Development of mathematical approaches for evaluating the impact of landscape structure on non-marketable ecosystem services on landscape level (TUD, in work)
- Development of approaches for integrating models for water and wind erosion and drought in GISCAME (TUD, in work)
- Nähr- und Schadstoffdynamik flugaschebeeinflusster Waldböden der Dübener Heide: Ist-Zustand und Prognosen (TUD, 2011)
- Biodiversité potentielle dans les forêts du Vercors : une approche hiérarchique pour la conservation des espaces forestiers (IRSTEA / Univ. De Grenoble ; rapporteur de thèse, 2012)
- Spatial preferences in forest planning (Swedish University of Agricultural Sciences, Member of the Evaluation committee, 2013)

Annex – Publications that form the basis of this habilitation thesis

#1 Frank, S., *Fürst, C.*, Koschke, L., Makeschin, F. (2011): **Towards the transfer of the ecosystem service concept to landscape planning using landscape metrics**. Ecological Indicators 21:30-38.

Ecological Indicators 21 (2012) 30–38

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Original article

A contribution towards a transfer of the ecosystem service concept to landscape planning using landscape metrics

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ABSTRACT

The article introduces a conceptual approach for how to enhance the assessment of ecosystem services with regard to landscape structural aspects. Therefore, we have implemented landscape metrics in the cellular automaton based software "Pimp Your Landscape". Using the example of the service "ecological functioning", we tested the potential of our approach to improve the understanding of how landscape structure contributes to the provision of ecosystem services. As a test case, we simulated different afforestation scenarios in a model region in North-Eastern Germany.

A major finding for landscape planning was that, without the inclusion of landscape metrics, the actual potential of our poorly structured model region with a large proportion of agricultural areas would be overestimated. In contrast, the benefits gained from afforestation strategies, which aim at improving aspects such as biotope connectivity at the landscape level, would become less obvious.

We conclude that our approach can contribute to a more realistic appraisal of the potential for landscapes to provide ecosystem services beyond the contribution of single ecosystem services or—in our case—land cover classes. We therefore plan to expand our approach to other ecosystem services as well, where landscape structural aspects, such as cultural services (for aesthetic value), are essential.

1. Introduction

In the international debate on Climate Change impact assessment, landscape management, and biodiversity conservation, the concept of ecosystem services has become a central issue. Many studies focus on the natural resources of the environment for providing ecosystem services and on the relationship between ecosystem services and their value for human well being (de Groot et al., 2010). The progressively rising demand on these natural resources makes protection of ecosystems and biodiversity essential (MA, 2005). Thus, nature conservationists and environmental scientists hope to communicate the importance of ecosystems and the worthiness of maintaining their present condition and function by translating their value into ecosystem services.

Usually, only marketable and tradable ecosystem services are taken into account in decision-making concerning planning and management of resources (MA, 2005). Consequently, the consideration of provisioning services is satisfying, but the consideration of regulating services is not satisfying. Cultural services are almost not taken into account, as they are difficult to translate into financial values. Also, the contribution of ecosystems to national economy is supposed to be significantly higher than the measurable monetary value (Beck et al., 2006). Furthermore, environmental management has mostly focused on individual ecosystems (Potschin and Haines-Young, 2001). Nowadays, environmental management is increasingly confronted with the problem of managing and planning entire landscapes which often consist of complex, interacting mosaics of different habitat patches and ecosystems (Lindenmayer et al., 2008). For a more realistic and holistic appraisal of ecosystem services provision, both provision of ecosystem services by specific ecosystems and the additional benefit from the pattern of various ecosystems/land cover types on landscape scale (i.e. landscape structure) must be taken into account (Burkhard et al., 2010). For example, high heterogeneity of land cover types in a region might have a positive impact on services such as aesthetics, which are difficult to assess. However, currently it is not possible to consider such aspects in a standardized way in landscape planning. The here presented method could contribute to a better transfer of knowledge on how and why ecosystem services are provided and which impacts might result from changing the landscape structure in landscape and regional development planning.

A possible approach to account for spatial patterns and their impact on landscape structure related ecosystem services might be the use of landscape metrics (LMs) (Feld et al., 2007). LMs help to mathematically assess landscape structures and can give valuable information to improve the assessment of the ecological functioning, economic wealth, and aesthetic value of a region (Frank et al., 2010c; Fürst et al., in preparation; Uuemaa et al., 2009). LMs can

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be classified into eight groups (Blaschke, 1999), area metrics, patch metrics, edge metrics, shape metrics, core area metrics, nearest-neighbor metrics, diversity metrics, and contagion/interspersion metrics. The main application fields are, for example, biodiversity and habitat quality analysis, estimation of water quality, urban landscape pattern, landscape aesthetics, management, planning, and monitoring (Uuemaa et al., 2009).

LMs are available at different scale levels: at the patch level (e.g. within a forest), at the class level (e.g. all forests in a specific region) and at the landscape level (all land cover classes of a region) (Lang and Blaschke, 2007; McGarigal et al., 2002). Regarding the aesthetic value for example, Shannon's Diversity Index considers all land cover types, whereas the presence of water can be described using class-level metrics such as number of patches. In largely agricultural landscapes naturalness, land cover diversity, and heterogeneity also contribute to the aesthetic perception (Dramstad et al., 2006; Herbst et al., 2009). Therefore, the Shape Index, Shannon's Diversity Index, and the Hemeroby Index can be applied for both the assessment of the ecological functioning and the aesthetic value. The presence of water bodies carries special significance in terms of landscape aesthetics (Franco et al., 2003; Palmer, 2004). It might be measured using LMs, such as the number of water bodies or their total area. To assess economic services at the landscape level, land cover types, their localization in relation to existing infrastructure and their form and compactness must be taken into account (Dieleman and Wegener, 2004). Here, LMs such as the Shape Index and the Effective Mesh Size can be used, for instance, to estimate patch form and size and respective costs for cultivation and harvesting at agricultural sites.

In this study, we consider three ecosystem services to be assessable by LMs: ecological functioning, aesthetic value and economic wealth of a landscape. These ecosystem services are modified compared to the Millennium Ecosystem Assessment (MA, 2005) because they represent a regional adaptation, which was developed in a participatory approach (Fürst et al., 2010a,b; Koschke et al., submitted for publication).

Till date, only a few studies have combined in a cross-sectoral approach the concepts of ecosystem services and LMs for complete landscapes. For instance, Sherrouse et al. (2011) are looking at several services and LMs, but they have focused only on forest ecosystems. Other recent studies have dealt with several ecosystem services and ecosystems at the landscape level, but neglect spatial aspects (Yapp et al., 2010). So far, a combination of the conceptual approaches, serving the practical application in landscape planning, is missing (Burkhard et al., 2010).

The assessment of ecosystem services aims at the quantification of benefits derived from ecosystems for planners and politicians, who develop plans and strategies for the protection of the environment and the provision of socially requested services (BMU, 2007; BNatSchG, 2010; Farley and Costanza, 2010; RP, 2009). In order to transfer the concept of ecosystem services to landscape planning, integrated and easily applicable assessment approaches are needed (Burkhard et al., 2010; de Groot, 2006; Frank et al., 2010b; Lautenbach et al., 2010; Rannow et al., 2010). The aim of the presented study is to develop such an integrated assessment approach for a case study REGKLAM in Saxony, North-Eastern Germany. An objective of the REGKLAM project is to involve regional actors who are much better in planning and to bridge the gap between sectoral management planning approaches in agriculture and forestry on the one hand and regional development planning on the other. Therefore, we developed and applied our method by using concrete afforestation scenarios taken from regional development planning in the REGKLAM model region.

The article introduces a framework for how to make use of LMs for an improved appraisal of ecosystem services at the landscape level. A set of LMs was selected for three exemplarily selected services and was implemented into the software platform Pimp Your Landscape (PYL) (Frank et al., 2010b; Fürst et al., in preparation). In this article, we focus on the ecosystem service ecological functioning. The test application in assessing afforestation scenarios compares an assessment of the ecosystem service with and without LMs. Some conclusions are drawn on the applicability of the presented framework for other ecosystem services and on possible ways to improve our approach.

2. Methods

2.1. Application of the concept of ecosystem services

In our study, we applied a modified set of ecosystem services (Fürst et al., 2010a; Koschke et al., submitted for publication) compared to the definitions and terms used in the Millennium Ecosystem Assessment (MA, 2005) and the most recent study on the Economics of Ecosystems and Biodiversity (TEEB, 2010). In comparison to the MA and the TEEB study, our set of ecosystem services was adapted in a participatory process to the concrete needs of the regional planning actors in the REGKLAM model region (Fürst et al., 2010b). The ecosystem services in our study belong to the following classes of ecosystem services: provisioning services (bio-resource provision and contribution to human health and well being), regulating services (mitigation of Climate Change impact), cultural services (aesthetic value), and supporting services (contribution to the ecological functioning). Additionally, regional economic wealth was added as a most important regional "service" (Fürst et al., 2010b; Menzel and Teng, 2010). The terminology was chosen on the basis of participatory developed processes (Fürst et al., 2010a). As the transfer of the complex ecosystem services concept to practice remains a challenge, regional stakeholders were asked to find expressions, which are easily understandable and describe regionally highly relevant services.

2.1.1. Theoretical background and framework for linking ecosystem services and LMs

In the REGKLAM case study, the software PYL is used to assess the impact of Climate Change and possible adaptation strategies in forestry and agriculture on our six ecosystem services (Fürst et al., 2009, 2010a,b). The software is a combination of three different modules, (a) a cellular automaton, (b) a Geographical Information System (GIS) and (c) a multi-criteria evaluation approach (Fürst et al., 2010a,b). The cellular automaton is used to enable a flexible handling of different scenarios: how to change and develop the landscape, how to account for environmental attributes, planning information (=cell attributes), and proximity effects (=inter-cell interactions). The GIS supports holding the cell attributes and linking them to the multi-criteria evaluation approach. This evaluation approach combines an assessment of the impact of land cover on the ecosystem services, the additional impact of landscape structures and restrictions, which are given by planning or, for example, other information such as the ownership type (Fürst et al., in preparation; Koschke et al., submitted for publication). The impact of the land cover and other cell attributes on the provisioning of the ecosystem services is projected on a relative scale from 0 (worst) to 100 (best). In a second step, spatial characteristics such as fragmentation, biotope connectivity, etc., are taken into account to increase or decrease the values achieved for the ecosystem services.

Considering landscape structure, we focused on LMs, which are applicable at the class- and landscape-level. Before integrating the most appropriate mathematical approaches into PYL, we tested them in FRAGSTATS 3.3 software (Frank et al., 2010a).

To enable the pathway from LMs to an improved assessment of ecosystem services, we introduced a number of evaluation criteria

Table 1
Potential LMs for the assessment of the ecosystem services ecological functioning, aesthetic value and regional economy.

Ecosystem service	Corresponding ecosystem service according to de Groot et al. (2002) and the Millennium Ecosystem Assessment (MA, 2005)	
Evaluation criterion	Potential Landscape metric	Reference
Ecological functioning	Habitat or supporting functions	
Landscape fragmentation	Effective mesh size	Gao and Li (2011), Girvetz et al. (2008), Jaeger et al. (2008)
Naturalness	Hemeroby index	Steinhardt et al. (1999), Tasser et al. (2008)
Habitat connectivity[a]	Cost-distance-analysis	Zebisch et al. (2004)
Land cover	Shannon's diversity index	Kim and Pauleit (2007), Yeh and Huang (2009)
diversity	Edge contrast index	Watling and Orrock (2010)
Compactness of (semi-) natural	Core area index	von Haaren and Reich (2006)
land cover types	Shape index	Baessler and Klotz (2006), Renetzeder et al. (2010)
Aesthetic Value	Information functions (natural scenery, recreation)	
Landscape complexity	Shape index	Augenstein (2002)
Land cover contrast	Edge contrast index	Augenstein (2002)
Land cover diversity	Shannon's diversity index	Augenstein (2002), Dramstad et al. (2006), Herbst et al. (2009), Hunziker and Kienast (1999), Palmer (2004)
Naturalness	Hemeroby Index	Augenstein (2002)
Presence of water	Total Area, Number of Patches	Dramstad et al. (2006), Franco et al. (2003), Herbst et al. (2009), Palmer (2004)
Economic wealth[b]		
Economic efficiency of urban area	Degree of compactness	Haase et al. (2007), Thinh (2004)
Machinability of agricultural areas	Shape index	Huang et al. (2007)
Infrastructure provision	Effective mesh size	Gao and Li (2011), Girvetz et al. (2008), Jaeger et al. (2008)

[a] Extension of the LM concept.
[b] Extension of the concept of ecosystem services, as described in Fürst et al. (in preparation).

such as land use intensity, habitat connectivity, and ecosystem diversity, which in our case were applied to the ecosystem service ecological functioning. These evaluation criteria support assessing ecological functioning and help to reflect typical ecological problems in cultural landscapes in Central Europe (BMU, 2007; BNatSchG, 2010). Relationships between LMs and these evaluation criteria were described in several studies ((Feld et al., 2007), see Table 1). The choice of our three criteria addresses the potential of a landscape to provide services related to the integrity of the natural environment such as genepool protection or nursery habitat (de Groot et al., 2010). Therefore, the stakeholder-vote based term "ecological functioning" should be understood as a case study specific aggregation of supporting and regulating services.

As an example, the above mentioned evaluation criteria can be described by LMs such as Effective Mesh Size, Hemeroby Index, Shannon's Diversity Index and Shape Index of natural land cover types. Fig. 1 demonstrates exemplarily the service ecological functioning in the chain from LMs to assessment of the ecosystem services.

The LMs were chosen on the basis of outcomes from several studies. For instance, the Effective Mesh Size was found to be well suited for a comparison of the degree of landscape fragmentation of various regions by Jaeger (2000). Additionally, the Core Area Index was implemented. This LM works as weighting factor in order to focus on the fragmentation of core areas of for ecological functioning valuable land cover types. The buffer-width was set by 100 m. Steinhardt et al. (1999) found the Hemeroby Index to be ecologically well-founded and easily applicable. A pre-study showed that this LM reflects the degree of naturalness well (Frank et al., 2010c). The here applied Cost Distance Analysis is based on a methodology developed by Zebisch et al. (2004) and Zebisch (2004), which allows to assess the structurally and functionally connected potential habitat area. The approach is based on "ecological costs", which are assigned to land cover types according to their degree of hemeroby: near-to-nature land cover types can easily be passed by animals, i.e. the effort (ecological costs) of moving from one habitat area to another is low. In contrast, land cover types with high anthropogenic impact such as settlements or industrial area are "costly" to be passed and therefore do not contribute to habitat connectivity. Based on the methodology of Zebisch, we use a moving-window approach to assess the accessibility of core habitat areas from smaller natural areas (stepping stones). The assessment of functional connectivity plays a special role in our assessment framework, because it is not directly based on LMs. Shannon's Diversity Index is used as an indicator for diversity of the land cover based on the ration of two components, (a) a compositional and (b) a structural one (Eiden et al., 2000). The number of different patch types (compositional component: richness) and the proportional area distribution among patch types (structural component: evenness) additionally indicate biodiversity as described by Wrbka et al. (2004). Originally, Shannon's Diversity Index, which often is used to assess the heterogeneity of landscape pattern (Li et al., 2005), refers to all land cover types. This implies that also land cover types such as continuous and discontinuous urban fabric, industrial areas, airports, etc. are considered in calculating diversity at landscape level. In our case, this would be a falsification as "structural landscape diversity" is assessed to conclude on the ecological functioning. Therefore, we aggregated meta- and poly-hemerobe land cover types to one class to better assess the impact of natural and semi-natural land cover types.

Besides ecological functioning, two other ecosystem services are actually assessed. The aesthetic value of a landscape strongly depends on configuration, composition and form of land cover types (Hunziker and Kienast, 1999; Jessel, 2006). Fry et al. (2009) found that there is a common ground of visual and ecological landscape indicators. Regional economy represents one of the most important planning issues and can be measured by various LMs (Fürst et al., 2010b). Table 1 gives an overview of LMs, which are partially already applied in PYL or in a test for later integration.

To come from LMs to an improved assessment of the ecosystem services within the cellular automaton based assessment approach in PYL (Fürst et al., 2010b), a two-step procedure was applied. First, the LM values were assigned to five classes from low to high, which express in a numerical way the extent to which the ecosystem service values in PYL achieved without LMs have to be increased or decreased. Absolute values of LMs cannot directly be

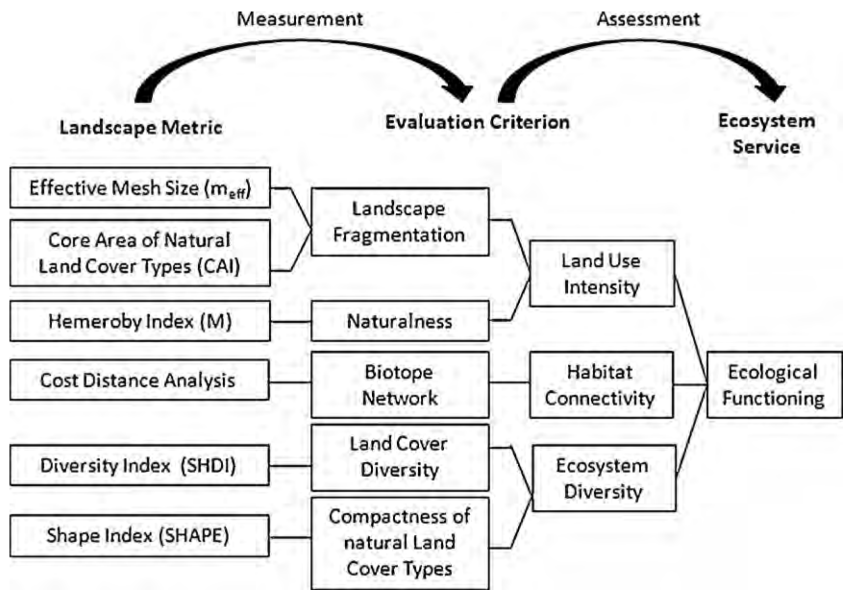

Fig. 1. Conceptual framework for the assessment of the ecological functioning of a landscape: chain from LMs to an ecosystem service. "Ecological functioning" here stands for ecological integrity and therefore the integrity of ecosystems in the landscape of interest.

mathematically linked with the qualitative evaluation approach in PYL. As a convention, our five classes range from −10 to +10 points. Thresholds of these classes are based on laws and strategies (e.g. BMU, 2007; BNatSchG, 2010) and on discussions with experts and regional stakeholders. An example is the Federal Act for the Protection of Nature of Germany, which says that the minimum area of connected ecological valuable (i.e. natural or semi-natural) area must be 10% in each federal state (§ 20(1), BNatSchG, 2010). As many scientists consider 10% as too less (Krüsemann, 2006; SRU, 2000), we assigned zero assessment points for a share of 10–15% of well-connected, valuable area as it meets the minimum requirements. The classification works in five-point steps. Hence, in this example the steps are shares of 0–5% (−10 points), 5–10% (−5 points), 10–15% (zero points), 15–20% (+5 points), and finally 20–25% (+10 assessment points).

In some cases, two LMs contribute to one evaluation criterion. In the ecosystem service ecological functioning this appears twice: the LMs Effective Mesh Size and Hemeroby Index are combined in the evaluation criterion "land use intensity"; Shannon's Diversity Index and the Shape Index are combined in the evaluation criterion "ecosystem diversity". Therefore, ecological connection matrices were used to express the mutual interactions between the LMs (Bastian and Schreiber, 1999; Rannow et al., 2010). The schematic procedure is illustrated in Table 2.

In the next step, an additive connection of the evaluation criteria is used to calculate the final value to which the ecosystem service has to be reduced or increased. As an example for the ecosystem service ecological functioning, for which three criteria are applied, this decrease or increase can range between −30 and +30 points.

Table 2
Combined assessment of two LMs using an ecological connection matrix.

Evaluation Criterion 1		LM 1				
		Low	–	–	–	High
	Low	−10	−10	−10	−5	0
	–	−10	−5	−5	0	5
LM 2	–	−10	−5	0	5	10
	–	−5	0	5	5	10
	High	0	5	10	10	10

2.1.2. *Test case afforestation*

The application of LMs for improved ecosystem service assessment was tested for a part of the REGKLAM model region (Fig. 2), the so-called "Großenhainer Pflege". This area is highly dominated by agricultural sites. The question to be answered is how to come to a realistic estimate of the possible impact of afforestation as Climate Change mitigation opportunity in the provision of ecosystem services.

The afforestation scenario is based on the regional development plan (Termorshuizen and Opdam, 2009). In our scenario, priority areas for afforestation and priority and reserve areas for nature and landscape were iteratively afforested to simulate a number of scenarios with an increasing share of forests at the landscape level.

3. Results

The results of our study are demonstrated for a minimum and a maximum afforestation scenario (Fig. 3). The minimum afforestation scenario assumed that afforestation is done exclusively on sites that are mapped as priority areas for afforestation in the regional plan. The maximum afforestation scenario also assumed that, additionally, priority areas for nature and environment are completely afforested.

The implementation of LMs had a significant impact on the scoring points: without an integration of landscape metrics, the evaluation results would suggest that even the actual landscape provides a sufficient value for the service ecological functioning. Also for the maximum-scenario the value would hardly increase. The consideration of LMs revealed that the value for ecological functioning is much worse, in the present situation and also in the minimum afforestation scenario, than initially assumed. The reasons for this are the low share of forested area and natural land cover types and their fragmented distribution. In contrast, by applying the LM-based correction in the maximum-scenario, the value for ecological functioning increased considerably. This benefit is caused by higher shares of well-connected forested areas. Table 3 shows exemplarily for the values of the evaluation criteria "ecosystem diversity" and "habitat connectivity" used here, how the original outcomes from PYL are corrected through the use of LMs.

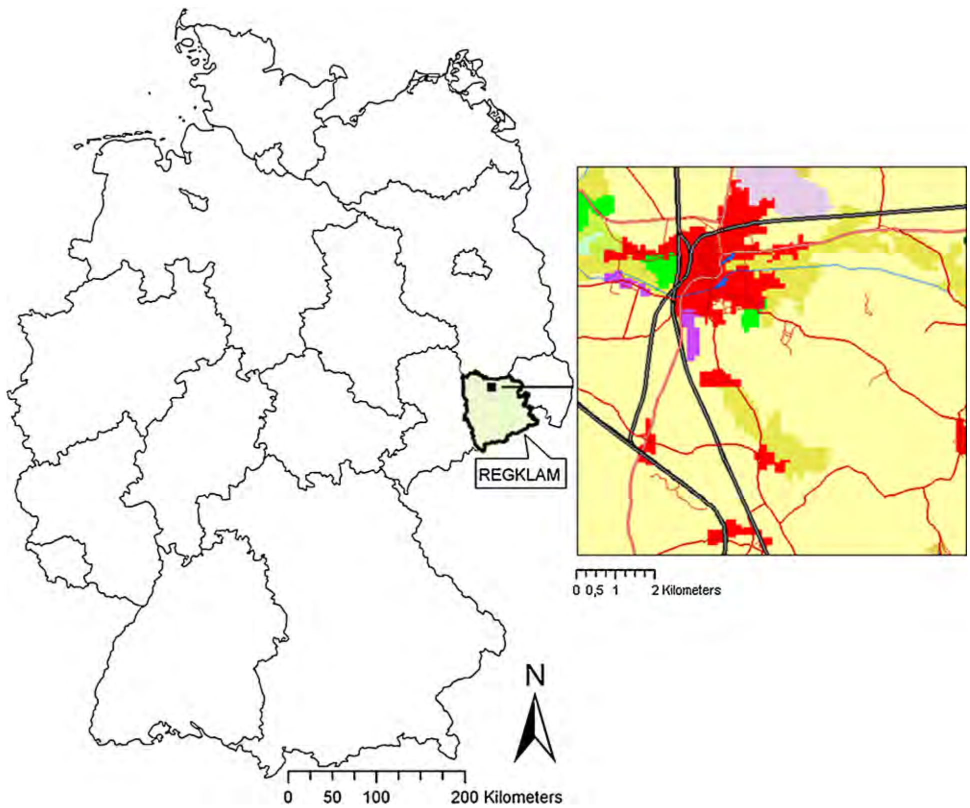

Fig. 2. Test area in the north of the REGKLAM region, Saxony, Germany.

An in-depth analysis of the results revealed that especially habitat connectivity was affected by the land cover change (afforestation). In the maximum-scenario the scoring of habitat connectivity changed from the worst (−10) to the best value (+10). The reason for this significant enhancement is that priority areas for nature and landscape were delineated in the regional development plan (Termorshuizen and Opdam, 2009) with particular focus on the creation of a biotope network. The value of the evaluation criterion land use intensity increased less significantly. Due to the increase in land cover types that are less anthropogenic influenced, the naturalness (one part of the main evaluation criterion land use intensity indicated by the Hemeroby Index) improved slightly, but not enough to enhance the value of the assessment criterion. The degree of landscape fragmentation (the second part of the main evaluation criterion land use intensity, indicated by the Effective Mesh Size and the core area of ecological valuable land cover types) changed due to the establishment of unfragmented core areas, which represent potential habitat area. Finally, the value for land use intensity increased, too.

The results presented here are only preliminary; do not represent all of the criteria. However, the test has shown that the applied approach contributes to an enhanced consideration of landscape structural aspects. So far, the assessment in PYL is based on the individual cells and their attributes and therefore neglects structural aspects. The implementation of the here presented method improves the assessment of the provision of ecosystem services, which are strongly determined by the spatial arrangement of various land cover types.

4. Discussion

The afforestation of priority areas for nature and landscape into forest fulfilled its purpose of establishing a habitat network of

Table 3
Results of the ecosystem service assessment for the ecological functioning without and with consideration of landscape structure. Three situations: present situation, minimum- scenario, and maximum- scenario on the basis of the regional development plan (RP, 2009).

		Present Situation	Minimum- Scenario	Maximum- Scenario
Ecological Functioning without structural Aspect		46	47	53
Linking of “Effective Mesh Size” and “Core Area of ecological valuable land cover types” in a connection matrix gives the value for “Fragmentation”:				
	Effective mesh size	4.15 km^2	4.15 km^2	4.15 km^2
	Core area	0.80%	0.84%	12.12%
Fragmentation		−10	−10	0
	Hemeroby index	81.02	79.21	73.73
Naturalness		−10	−10	−10
Linking of “Fragmentation” and “Naturalness” in a connection matrix gives the value for the evaluation criterion “Land use intensity”:				
Land use intensity		−10	−10	0
	Share of functionally connected ecological valuable area	1.34%	1.48%	21.42%
Habitat connectivity		−10	−10	+10
Ecological functioning with structural aspect		26	27	65

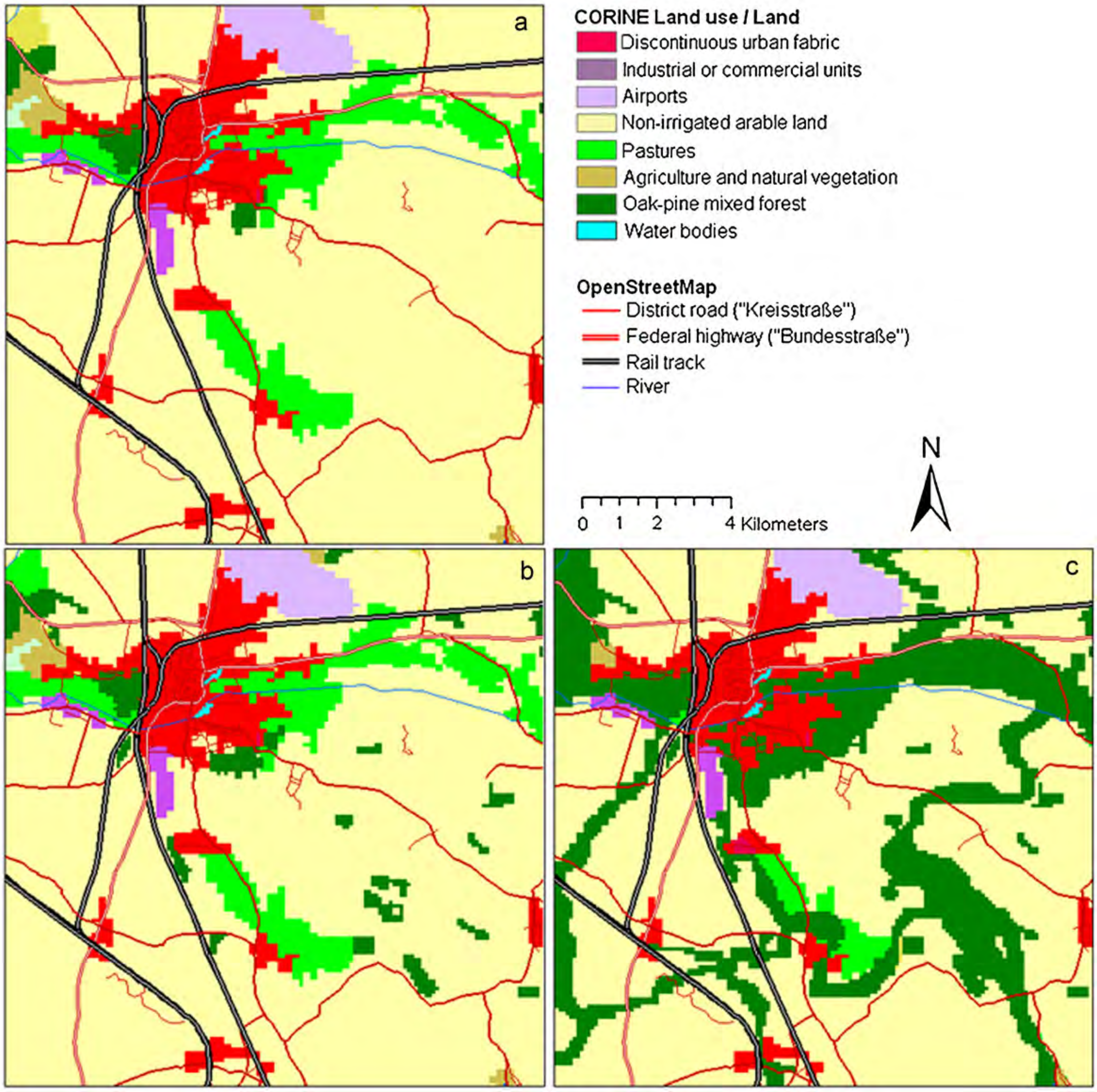

Fig. 3. Present situation and the two scenarios of afforestation in the test area: (a) present situation (agricultural landscape), (b) minimum-scenario (priority areas for afforestation changed into forest), and (c) maximum-scenario (additional afforestation according to the priority areas for nature and landscape).

well-connected, less anthropogenic influenced land cover types. The validation of this planning measure helped us to generate discussion with regional planning actors as to how to improve their afforestation strategies in the future. It was also important to discuss where to execute afforestation to get maximum benefit for provision of the service ecological functioning. In contrast, we could show that afforestation only on priority areas for afforestation does not contribute to an improvement in this service at the landscape level.

The combination of assessing LMs and ecosystem services offers some strength: first, LMs are useful in the framework of standardized landscape assessment. The formalized assessment of LMs provides a fast interpretation of various land cover pattern and the opportunity to easily compare various scenarios is valuable for participatory planning processes. Second, conclusions can be supported on how to optimize the regional pattern of land cover types to enhance the provision of ecosystem services. As an example in our case study, the question of the regional planners was how to improve habitat connectivity by an optimal spatial allocation of afforestation areas.

A weakness however is that LMs cannot be used to appraise all aspects of the suitability of a landscape to provide ecosystem services. In consequence, the approach cannot be used independently from the basic assessment of the potential of single land cover types to contribute to the provision of regional ecosystem services (Fürst et al., 2010a).

Another weakness consists of use restrictions resulting from the application of the LMs in the cellular automaton based software and based on land cover types as reference. However, some assumptions were made to come to a robust assessment standard: first, an adaptation of the basic data (here: re-classification of the land cover classes into hemeroby classes for the use of Shannon's Diversity Index). Second, we had to pay special attention to the spatial resolution of 100 m × 100 m per grid cell and 10 km × 10 km for the working units (here "Großenhainer Pflege"), because the underlying formula of the LMs required a fixed spatial context to deliver robust results (Buyantuyev and Wu, 2007; Castilla et al., 2009). This might limit the applicability of our approach in the event that there is an intention to apply other spatial resolutions. In this case, the mathematical basis has to be adapted, which slightly limits our flexibility in the use of PYL. Problems would also occur if the thematic focus and classification of the land cover would change and if the form of the working area (form of the map) was irregular (Baldwin et al., 2004; Díaz-Varela et al., 2009; Saura and Martíez- Millán, 2001). Therefore, for evaluating the impact of LMs in PYL, the thematic resolution is fixed to 25 land cover types and the form of the working area is fixed to the geometric form of a square. Otherwise, if these preconditions are not fulfilled, the module “landscape metrics” is deactivated in the software, while the use of all other modules is still possible.

A possible threat for the applicability of our approach is the question of the transferability of this concept to other regions. As a basis for providing transferability, we had to define thresholds for the LM values in the assessment procedure. These thresholds are the basis for our qualitative assessment on a relative scale. Our solution for classifying LM values was the use of limits and thresholds defined in German laws and strategies and on expert knowledge (scientific findings from recent studies). When transferring the approach to other regions, these thresholds need to be checked for adequacy according to regional laws and planning restrictions. Also, the performance for regions with differing natural framework conditions (e.g. mainly forested areas of national parks) needs to be tested in further applications of PYL. The thresholds for the classification of LM values might be changed in PLY. Thus, future scientific findings on relationships between landscape structure and ecosystem services can be easily integrated into our assessment framework.

An opportunity of our approach is to improve the understanding and communication base on how regional structures and the spatial distribution of land cover classes contribute to the provision of ecosystem services in regional (participatory) planning processes (Walker et al., 2001). The integration of LMs could help to better estimate the potential how to develop a landscape in a sustainable way by respecting at the same time the need to maintain the benefits from nature that human beings utilize. Some case studies have already taken into account the relationships between horizontal interactions among landscape structure and ecosystem services (Feld et al., 2007). For instance, in the RUBICODE project LMs are even recommended as indicators for the evaluation of ecosystem services. For the assessment of ecological functioning and the aesthetic value of landscapes, LMs are more often used (e.g. Billeter et al., 2008; Palmer, 2004; Renetzeder et al., 2010; Rossi and van Halder, 2010), while their application to estimate the landscape potential to provide other services is quite rare. In many recent studies on ecosystem services, the influence of landscape structure is either neglected or considered only for a singular ecosystem service (e.g. Dale and Polasky, 2007). However, research on how structural landscape aspects affect the numerous ecosystem services is still at the beginning and necessary knowledge is still missing. In consequence, we had to focus on services, such as the ecological functioning, where approved knowledge on the impact of structural landscape aspects is available. Services such as biomass production, biological regulation, or education and service (de Groot et al., 2010) might not be well indicated by LMs. In the REGKLAM application of PYL, the so-called “aesthetic value” is one of the services to be assessed. Although not discussed within this article, also the assessment of this ecosystem service could greatly profit from considering LMs; the appreciation of natural scenery and the value of landscape structure for recreational activities such as hiking or biking could be better expressed by the use of LMs (de Groot et al., 2002; Fürst et al., 2010a). A special role in our case study plays the service “economic wealth”. It is difficult to assess the contribution of a landscape to economic wealth, but aspects such as the accessibility of economically relevant land cover types, their spatial connectivity and the size of agricultural or forest complexes could be assessed and support the consideration of economic aspects in the ecosystem services concept.

5. Conclusions and outlook

On the basis of the software PYL, we compared the potential of a test area, the “Großenhainer Pflege” to provide ecosystem services with and without consideration of the landscape structure. Especially concerning planning issues dealing with the mitigation of Climate Change effects, landscape structure might be an important driver (Wainger et al., 2010).

The test results have shown that assessment of an exemplary ecosystem service “ecological functioning” cannot be reduced regarding the impact of single ecosystems or—in our case—land cover classes. Additional effects such as fragmentation or biotope networks must be taken into account. Afforestation scenarios according to the original regional planning strategies in our test region could therefore not fulfill the aim to improve the ecological functioning of a landscape. In contrast, biotope networking aspects as they are expressed in the delineation of priority areas for nature and landscape resulted in considerable improvement of the landscape’s ecological functioning. Additionally, the conversion into more extensive land cover types increased the degree of hemeroby and therefore reduced the land use intensity at the landscape level. On the other hand, landscape fragmentation due to urban sprawl combined with the establishment of new roads strongly affects ecological functioning. Landscape fragmentation cannot be decreased simply by introducing more (semi-) nature areas, but by respecting their spatial context and connection.

The future development of the LM-based assessment of ecosystem services within PYL includes an enhancement of the spatial resolution through new land cover data with higher resolution (25 m × 25 m) and land cover and land-management classes, which represent much better the real land use in our application case. A challenge and planned further development will consist of introducing also LMs at the level of the patches (management aspects in single areas) and at the class level (variability of the management practices in forestry and agriculture) to further improve and combine the assessment of land cover, land-management and landscape structure changes and their impact on the provision of ecosystem services as a basis for a sustainable regional development.

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"Pimp your landscape" – an interactive land-use planning support tool

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Abstract

In the context of the INTERREG IIIA project IT-Reg-EU (http://boku.forst.tu-dresden.de/IT_Reg_EU/index.html) the tool "Pimp your landscape" (P.Y.L) was developed for solving land-use management conflicts in the Euro-Region Neisse. P.Y.L is a web-based tool with focus on visualizing and evaluating changes in the land-use pattern. Information on the land-use pattern is based on CORINE LAND COVER 2000. The maps are divided in sections of 10 x 10 km size. Each pixel in the maps represents the dominating land-use type of the 100*100 m² area. By clicking a pixel a new land-use type is assigned. The impact of each land-use type on different landscape functions is ranked on a relative scale from 0 (worst) to 100 (best). The ranking is based on indicator sets and expert knowledge. The user can choose between two modi: the Expert mode enables to include regional expert knowledge into the evaluation and to define a rule set, representing planning restrictions. The Game mode allows regional citizens to appraise the effects of planning measures. Application areas are participatory planning, management planning conflict solution and education. Tests with different user groups showed that i) further landscape functions, ii) refined evaluation of the land-use form impacts, and iii) neighbourhood relationships between different land-use forms should be integrated.

Keywords: land-use management planning, land-use management support systems, computer-based support, web-based tool, land-use impact assessment.

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1 Introduction

A growing need to consider many different and often conflicting societal targets in sustainable land-use management has posed considerable challenges for land-use planners (Blaschke [1]; Massam [11]; Tippett et al. [16]). Classic answers like e.g. intuitive or schematic approaches seemed to be not furthermore appropriate for such multifaceted problems. This raised the demand for solutions, which are able to integrate multiple stakeholder perspectives and various temporal and spatial scales (Kiker et al. [8]; Lenz and Peters [9]; Tyrvainen et al. [19]). Management support systems (MSS) and Spatial Decision Support Systems (SDSS) allowing for participatory approaches have proved to be most useful for complex, strategic problems that cannot be completely supported by algorithms and analytical solutions (Janse and Konijnendijk [7]; Turban et al. [17]; Volk et al. [21]). The systems should give support by (a) providing an overview of the problem area, (b) assessing the impact of each possible management strategy, (c) comparing the management alternatives and (d) estimating the preferences of different stakeholders or stakeholder groups (Booltink et al. [2]; Hurni [6]; Leung [10]; Rauscher [13]). Because MSS and SDSS are based on formalized knowledge, their application in management support has facilitated decisions that are reproducible and as rational as possible. The use of MSS and SDSS helps to better integrate knowledge on how different land-use management types and strategies affect the regional income, biological diversity and public services such as the provision of drinking water and recreation facilities. Furthermore, land-use management planning aspects dealing with border crossing questions as addressed by Natura 2000 or the EU Water Framework Directive (EU-WFD) can be supported by MSS and SDSS.

Beyond this background, "Pimp your landscape" (P.Y.L.) was developed for solving land-use planning conflicts between forestry, water management, nature protection and tourism in the Euro-Region Neisse. This 13,500 km^2 trans-national area is situated between Czech Republic (~ 25%), Germany (~25%) and Poland (~50%) Actually, about 1.7 million people live in the region. Main land-use types are agriculture and forestry (86%). Settlement and infrastructure amount to around 7%. Water bodies, the land-use form of highest trans-national interest due to flood protection and water provision, amount to around 2% of the surface area. About 162,100 companies are established in the region and the unemployment rate is highest in Poland and Germany (14-29%) (www.neisse-nisa-nysa.org).

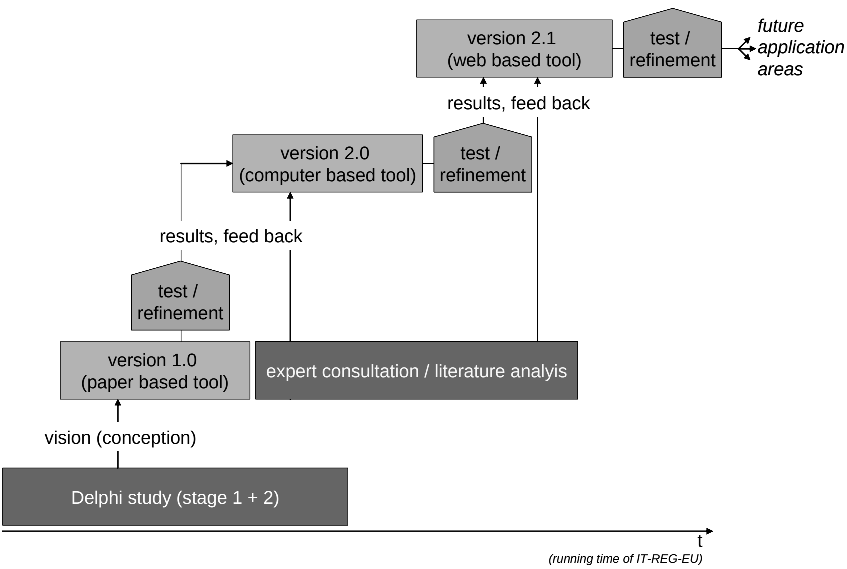
The region, part of the so called "Black Triangle", was since the mid of 20th century one of the most industrialized areas in Europe. It is still characterized by severe environmental problems concerning the border crossing water bodies, the forests and the soils. The current environmental status is affected to a large extent by political and economic as well as demographic changes taking place during the last 15-20 years. For most of the landscape-related environmental topics, this change has lead to a considerable improvement of air and water quality. Nowadays, the EU Water Framework Directive (EU-WFD), Natura 2000 targets and the up-coming EU Soil Protection Directive are posing border-crossing planning challenges along the Neisse River. Furthermore, EU infrastructural planning corridors request transboundary regional development coordination. In addition, the up-coming tourist industry demands for well working infrastructure systems. The question of the area-related prioritisation of the land-use targets is one of the major regional and transnational problems.

The presented paper intends (a) to introduce the background and development basis of “Pimp your landscape” (P.Y.L.), (b) to describe the conception of the tool and (c) to discuss possible application areas and development perspectives.

2 Material and methods – user needs analysis and expert consultation

P.Y.L. was designed in an iterative approach, starting with a Delphi study-based analysis of the user needs on how to design an optimal management support and conflict solving tool. First, the envisaged tool was tested as paper based version. The results of this test and an accompanying expert consultation delivered the basis for the further technical development. Expert consultation and literature analysis were also used for referencing the evaluation of land-use changes to existing studies and knowledge. A final user test served for refining the system and identifying development needs and technical weaknesses.

Fig. 1 resumes the development steps of P.Y.L.



see: www.letsmap.de

Figure 1: Development steps of P.Y.L. Some steps such as Delphi study and expert consultation were organized partially in parallel to other steps such as test phases and technical refinement.

2.1 User needs analysis – Delphi study approach

The development background of P.Y.L. is defined by border crossing land-use management and planning targets in the Euro-Region Neisse concerning forestry, water management, nature protection and tourism. The different stakeholder groups behind are partially collaborating on the realization of EU-directives like Natura 2000 and EU-Water Framework Directive. Partially they compete by addressing the same areas for different land-use targets. Thematically oriented expert groups (EUREX working groups) in traffic, economy, tourism, water, forestry, crisis management, health, history, statistics and education form the actually most important instrument for exchanging and discussing conflicts, conflict solutions and common strategies. These expert groups and here especially the working group forestry were inquired considering their visions for improving the exchange within and especially between the groups.

To analyze the users' needs, a Delphi approach was chosen (Cooke [3]; Dalkey and Helmer [4]; Scholles [15]; Turoff and Linstone [18]): Van Paassen et al. [20] used this approach e.g. to develop computer models facilitating the capability of learning about sustainable land-use in rice-cultivating regions. White et al [22] developed an empirically based area-type model with the assistance of the Delphi method. In contrast to opinion polls with random choice of the participants and missing opinion feedback, the Delphi method is thought to exclusively obtain a certain consensus among individuals holding special knowledge on the issue of interest (EVALSED [5], Schmidt-Thomé [14]). This approach seemed to fit well for the idea to address the experts involved in the EUREX working groups. Another advantage is the anonymity of Delphi participants, which allows them to interact, rethink, and compare their thoughts in a "non-threatening forum" without being influenced by each other's opinion (Miller [12]).

In the presented study, 32 experts, mainly from the EUREX working groups, their cooperating institutions and administrations participated in two Delphi stages. Representatives from forestry (46%), nature protection (33%), water management (11%) and regional planning (tourism, 10%) in Czech Republic, Germany and Poland were involved. Two groups of experts were differentiated: Group I (40% of the participants) participated at a stage of the Delphi study called "2b", which was preceded by a workshop on existing management supporting system solutions. This stage was carried out to see, how training aspects impact expert opinion. For this reason, these results of this stage 2b are later on presented separately. Group II (60%) did not participate at this workshop. In stage 1 of the Delphi study, the following questions were posed (in three languages):

A. What kind of information sources are you generally using to prepare interdisciplinary planning decisions?
B. Which tools are you using to visualize the planning process and to support your decision?
C. How do you think, an optimal support system should look like that helps to prepare the necessary information and support you as a decision maker?

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For each question, a set of alternatives was offered, which were asked to be evaluated on a scale from 1 (= always / most desirable) to 6 (= never / most undesirable). Additionally, free comments were possible. In stage 2 and 2b, only question C) was repeated. The Delphi study delivered the basis for the conception of P.Y.L., which was first realized and tested as paper based tool (version 1.0) to get a preliminary feed back and refinement option from the involved experts before designing a computer based version (2.0). This was again tested with the experts from the EUREX working groups, related institutions and organisations before being published as open-access web tool (version 2.1, see www.letsmap.de).

2.2 Expert consultation and literature analysis

One of the major user needs was to evaluate changes in the land-use pattern with regard to their effects on different landscape functions. Therefore, an expert consultation supported by literature analysis was carried out. A set of typical regional land-use forms was evaluated according to their impact on water quality, biodiversity / ecology, income / economy and tourism / aesthetics. To achieve comparability between the different indicator systems and formats, which are used for impact analysis, a scale from 0 (= most negative effect) to 100 (= most positive effect) was introduced, to which all results from expert knowledge and publications were referenced. Temporal aspects (i.e. changing impact with ongoing development of a land-use specific ecosystem) and neighbourhood relationships (e.g. changed impact in dependence from the neighbouring land-use forms) were not yet considered in this analysis. The following sources were used:

- *water quality* – expert consultation (Helmholtz Centre for Environmental Research - UFZ, Dept. of Landscape Ecology (Leipzig, Germany); TU Dresden, EUREX working group water)
- *income / economy* – literature analysis (forestry: “Wald-Verkauf nach dem EALG den fünf neuen Bundesländern. Dreifache Ersatzeinheitswerte für Waldflächen in EUR/ha.” BVVG Bodenverwertungs- und -verwaltungs GmbH, MoritzDruck, Berlin 2002., Statistisches Bundesamt Deutschland, SBD Internet: www.bundeswaldinventur.de, pasture: - “Deckungsbeitrag II für Stilllegung”, SMUL “Veränderte Landnutzungssysteme in hochwassergefährdeten Gebieten” Heft 12 10. Jahrgang 2005, agriculture: Bayerische Landesanstalt für Landwirtschaft Internet: www.lfl.bayern.de, Statistisches Bundesamt Deutschland, SBD Internet: www.bundeswaldinventur.de) and expert consultation (wetland, waterbodies and grassland, urban and industrial areas (Helmholtz Centre for Environmental Research - UFZ, Dept. of Landscape Ecology (Leipzig, Germany); TU Dresden, EUREX working group water))
- *biodiversity / ecology* – literature analysis (Kompensationsverordnung – KV “Verordnung über die Durchführung von Kompensationsmaßnahmen, Ökokonten, deren Handelbarkeit und die Festsetzung von Ausgleichsabgaben“ laut Hessische Naturschutzgesetz., Statistisches Bundesamt Deutschland, SBD Internet: www.bundeswaldinventur.de)

- *tourism / aesthetics* – expert consultation (Chair for Strategy and Landscape Development, TU Munich)

3 Results

3.1 User needs analysis

The results from the Delphi study proved that in general all kinds of information sources are used to make decisions and that no particular preference could be noticed for any specific information source (question A). However, for the planning and decision process, computer- and communication supported instruments are clearly preferred against paper based instruments (question B). Here, GIS and Office solutions were the most common instruments to design planning processes and to support decisions, followed by databanks and paper based map-material like forestry-, forest-function-, and biotope type-maps. Further options were special report programs from internal information systems. The definition of an “optimal system” seemed to be very subjective (question C). Especially in the first stage of the Delphi study, the experts proposed a wide range of “optimal” solution possibilities. In the second stage, online-portals and professional information and expert systems were most popular, followed by best practice manuals and decision trees. Stage 2b of the Delphi study revealed training effects: Compared to stage 2 including all experts, the participants of the workshop on existing management support systems gave in question C a higher score to so called “New Formats”. They gave also a more detailed description of what they understand by an optimal solution: a computer-based tool for visualizing and evaluating effects of regional planning measures focussing on changes in the land-use form and including recommendations for best practices and land-use management. The tool was demanded to be simple to use, to be designed in the form of a computer game and it should be accessible for anyone at anytime.

3.2 Expert consultation and literature analysis

Expert consultation and literature analysis resulted in a table estimating the region specific land-use pattern impact on regional land-use functions. In the Euro-Region Neisse, water quality, biodiversity / ecology, income / economy and tourism / aesthetics were defined as major land-use functions (Tab. 1). The land-use types were defined on the basis of the CORINE LAND COVER (CLC) 2000 classification. Fig. 2 describes the process of regional adaptation and abstraction of the CLC 2000 classification to a reduced number of land-use types, which were evaluated in P.Y.L. The reduction of the numerous CLC 2000 classes was necessary, because expert knowledge and published indicator systems did not support the impact assessment of all land-use types.

Bundling expert knowledge and knowledge from publications on the impact of different land-use types on landscape functions brought up another problem: The indicator sets used for different land-use types showed a brought variety. This complicates a comprehensive referencing of the land-use impacts on the

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described scale from 0 to 100 and demands for further research. Tab. 1 should therefore be considered as suggestion with regional reference to Euro-Region Neisse and not as generalizeable proposition.

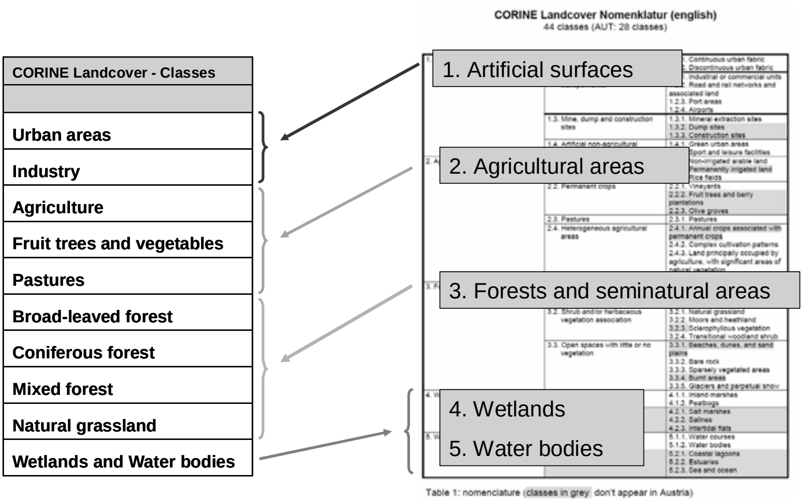

Figure 2: Regional adaptation of the Corine2000 classification as basis for evaluating the impact of land-use types.

Table 1: Regional evaluation table for land-use form impact.

CLC 2000 land-use forms	**value for land-use function**			
	water quality	*economy*	*ecology*	*tourism / aesthetics*
urban areas	0	100	0	0
industry	0	100	0	0
agriculture	20	80	30	20
fruit trees and vegetables	30	75	35	40
pastures	60	60	35	50
deciduous forest	80	30	100	80
coniferous forest	50	40	60	60
mixed forest	80	35	100	90
natural grassland	70	5	100	90
wetlands & water bodies	100	5	100	100

3.3 Conception of P.Y.L. – user interface and technical development

Based on the Delphi-study results and the paper based version feed-back, P.Y.L. was developed as a web-tool for simulating and training the effects of land-use pattern changes. Information on the land-use pattern is based on CORINE

LAND COVER (CLC) 2000 maps (spatial resolution 100*100 m² = 1 Pixel). Additionally maps of highways and water bodies are extracted from the topographic map of the region in the scale of 1:100.000. The maps are divided in sections of 10 x 10 km size and transferred into GIF-format to reduce the transfer time to the browser of the user. Each pixel in the maps represents the dominating land-use type of the 100*100 m area. By clicking a pixel it is possible to assign a new land-use type: a selection box pops up with the land-use forms to be chosen. A click on the desired land-use type (e.g. coniferous forest) assigns this new land-use form.

The impact of each land-use type on water quality, income / economy, biodiversity / ecology and tourism / aesthetics based on indicator sets and expert knowledge is ranked on a relative scale from 0 – 100 (cp. section 3.2). A legend, which can optionally be activated by mouse click, informs the user about the colours of the land-use types and their impact value for the different land-use functions on the scale from 0 - 100. For the displayed map segment, the average values for water quality, economy / income, ecology / biodiversity and tourism / aesthetics are displayed as trend table and in the form of a star diagram. The average values result from the number of pixels in the segment, the assigned land-use forms and their impact values according to Tab. 1. Changes of the land-use pattern are permanently visualised in a trend table in form of trend arrows (tendency: upwards / downwards / remaining equal) and in a star diagram, where the comparison to the start situation is highlightened by coloured graphs. Regional minimum values for each of the land-use functions can be introduced in order to demonstrate undesirable development trends (e.g. unilateral maximization of economy without consideration of ecology). At the beginning, a dummy value of 20% of the actual average value is set for each of the land-use functions, which however can be changed by the user. The thresholds are displayed in the star diagram as red dots, and respectively in the table as “critical value”. Any exceedance of this threshold results in a warning message and the “critical” move can be revised. The user however has the option to continue also without revising the move: this opens the option to compensate the momentary threshold exceedance by subsequent moves.

P.Y.L. is designed as combined game / expert system. The game modus is thought for users without professional background, who would like to acquire basic knowledge about effects of land-use pattern changes in their region. Here, experimental experience and fun in using the tool are the leading development vision to motivate the users. In the game modus, users are allowed to make any change of the land-use form and pattern, they want to test. At the start of the game modus, the users are asked to assign an optimization target, i.e. they must decide which of the land-use functions is defined as target function. To create a “game feeling”, the playing time is limited: the user can choose between a playing time from 1 up to maximally 10 minutes and after the first click on a pixel, the playing time runs. It is possible to play against other users, when choosing the same map, target function and playing time. In this case, a score list is displayed at the end of the game, ranking the users according to their results in maximizing the target function and the number of moves they needed for. To quicken the game, the user can choose between different raster sizes (1*1 = basic resolution of 100*100m², further options vary from 2*2 until 16*16): this offers the possibility to change all pixels in one raster with one click, assumed they belong to the same land-use form. Independently from the raster sizes, the basic resolution of 100*100 m is used to calculate the number of moves in the game. At the end of the game, it is possible to look once again at the game process in slow motion by mouse click on "Replay". This option is thought to enable the user to visualize the planning process and to see with which moves he achieved the end result. Fig. 3 shows a screen shot of the game modus.

The expert modus was conceived for regional planners and professionals from forestry, water and environmental management. The development vision was to provide a tool for training and exchange on planning targets. The expert modus offers the user a wide range of modification possibilities in the game environment by the administration level. Here, the users are allowed to modify and to introduce their special estimation on land-use form impact on land-use functions.

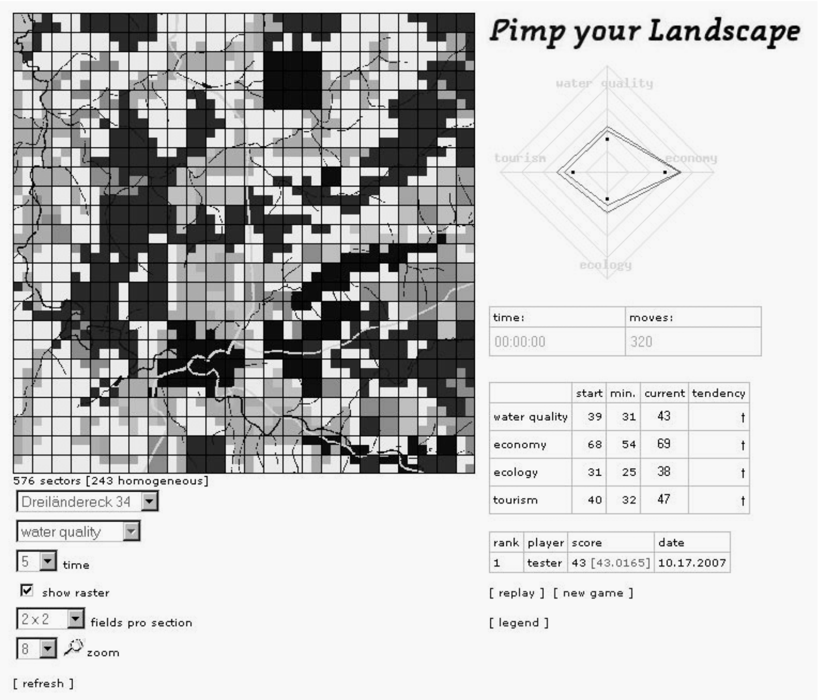

Figure 3: Screen shot of the P.Y.L. game modus.

They can also set minimum / maximum thresholds for the average values of each land-use function in the region, which cannot be exceeded for the regional land-use functions to avoid unilateral optimization. The administration level provides therefore a matrix for flexible rule handling and a module for modifying the evaluation table and the minimum / maximum thresholds. This modification options in the expert modus affect also the functionality in the game modus: it is possible to adapt e.g the evaluation basis of P.Y.L. to a specific regional situation through expert knowledge and to use the game modus as kind of participatory e-Government tool to enable the exchange between expert driven and citizen desired regional development. This is actually tested in the context of open cast mining restoration in the vicinity of Markkleeberg.

In the expert modus, rules are introduced, which represent restrictions in the free development of the land-use pattern given by regional planning targets or EU-directives such as EU-WFD, Natura 2000, EU Soil Protection Directive or the Biodiversity Convention. The restrictions for changing the land-use pattern in dependence from the land-use form and its localization to neighboured land-use forms were transferred into allowed or forbidden moves. Taking Natura 2000 as an example, e.g. forests, natural grassland, wetlands are not allowed to be changed. A minimum quota of x% of natural grassland, forest and wetland must be kept (threshold). Coniferous forest is allowed to be transformed into deciduous forest but not vice versa. These rules can be adapted by the user on the administration level of P.Y.L. In the expert modus, no time limitation is given. The pixels can be changed as long as the rules admit it. Only the user decides when he has reached the optimal situation. After 50 moves the user has the possibility to click on “Replay” to look at the previous game-process. Furthermore, the user can intervene in the “Replay” process and thus change moves he did before. This is advantageous in cases where he doubts about the usefulness of decisions for planning targets referring to the displayed results in the trend table and the star diagram. This avoids the necessity to start P.Y.L. again at any time when the user is not satisfied with his results.

One of the major development challenges of P.Y.L. was the combination of permanent and modifiable map details without using GIS functionalities with their extremely high complexity. Furthermore, it was demanded that each pixel should contain the full information not only about the major land-use type but also about the presence of permanent details like water bodies, streets, etc. Therefore, a colour code management enabling the identification, administration and allocation of colour codes was introduced. Furthermore, a map management module was integrated. The module supports displaying the proportion of the landscape-maps. A main functionality is linking information on permanent details like streets, water bodies and railways with the pixel properties. This data aggregation technology allows for an optimised loading time of the maps and a fast actualization of the land-use pattern per mouse click. Additionally, zoom functionality is supported, which helps the user to adapt the game surface optimally to his technical facilities (e.g. size of the screen). Also the handling of different raster sizes for enabling large scale changes is a result of this special aggregation technology.

4 Application areas and development perspectives

4.1 Application areas

P.Y.L. is a powerful instrument to demonstrate effects of changes in land-use pattern. P.Y.L. can easily be adapted to any region considering the map material, the evaluation basis, planning restrictions and the land-use functions to look at. The main aim of the here presented tool was to create a discussion and conflict solution basis for regional planning stakeholders in the Euro-Region Neisse. Their major interest was how to deal with border crossing planning restrictions resulting from Natura 2000 and EU-WFD.

In a respective workshop, experts from water management, nature protection and forestry from Czech Republic, Germany and Poland were asked, to optimize the land-use pattern according to their needs (a) without any restrictions and (b) with planning restriction. Fig. 4 shows the results from this test.

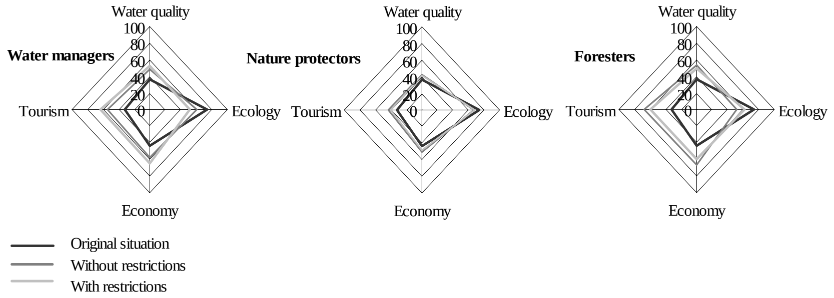

Figure 4: Evaluation results of a stakeholder test run with experts from water management, nature protection and forestry.

All three groups followed different planning visions and experienced the effects of planning restrictions. The water managers achieved almost a balance of the four landscape functions with and without planning restrictions. The group nature protection avoided major changes in the land-use pattern and learned from the evaluation results that their strategy endangered their target to increase the function “ecology”. The foresters experienced that especially the planning restrictions of Natura 2000 restricted slightly their intention to increase the function “economy”. At the end of the test, the groups achieved a compromise for an optimal land-use pattern, which satisfied the needs of the different stakeholders and considered the different national planning targets in the three country corner of the Euro-Region Neisse. Apart from the use as transboundary land-use management system, P.Y.L. can also be used for participatory approaches in regional planning. One example is open cast mining restoration in the vicinity of Markkleeberg near Leipzig. Here, the expert modus is planned be adapted to the regional experience and knowledge in land-use form impact on ecology, regional income, regional recreation facilities and water quality. The game modus is used as e-Government tool and allows the citizens to test their visions of how to design the former open cast mining area and to make propositions to the regional planners. The evaluation functionality of P.Y.L. supports in this case the citizens to argue better, why they propose a certain planning alternative, i.e. which target function they wish to be optimized. In the vicinity of Dresden, P.Y.L. is planned to be used to test different land-use pattern with regard to their effects on the regional climate change mitigation strategy.

Here, expert knowledge, measurement costs and government aid possibilities will be brought together to identify regional activity corridors and to propose a land-use form overlapping development strategy for policy support.

In the context of the EU-programme "Education for sustainable development", P.Y.L. is proposed to be adapted for the application in environmental pedagogic in the border area between Czech Republic and Germany of the Euro-Region Neisse. The intention is, to train the ability of pupils to understand complex ecosystem processes in landscape context and to further the trans-national exchange between regional education facilities.

4.2 Development perspectives

Test runs of the version 2.1 (web-tool) revealed a number of user demands and development perspectives of P.Y.L. One of the major challenges to be realized is the consideration of neighbourhood relationships between the different land-use forms and localization effects of a distinct land-use form in the landscape. This would help to evaluate more realistic the impact of land-use pattern changes on the landscape functions. Furthermore, temporal effects, e.g. changing impact of a land-use form such as forestry on a land-use function such as water quality over time should be considered in the future. Here, research on suitable indicators, indicator systems and approaches of comprehensive bundling of different indicators is an ongoing task in the P.Y.L. development. Much easier to be realized in the future are some technical demands such as zoom functionality in the maps, help desk and multilingual support. A precondition for broader use of the web-tool is the optimization of the map material. Actually, a predefined set of maps based on CLC 2000 is integrated in P.Y.L., which does not yet allow for a free choice of the region to be considered. Here, further technical development and linking to open access material is necessary. The future vision is to combine P.Y.L. with web-GIS applications in the context of e-Government solutions.

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Pimp your landscape - un logiciel pour la gestion interactive des paysages : potentiels et limites

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LE PHÉNOMÈNE "D'HYPER-INDICATION" OU POURQUOI LES CONSIDÉRATIONS MULTICRITÈRES NE SE RETROUVENT PAS DANS LA PRATIQUE

La vision multifonctionnelle des forêts et, plus largement, des paysages pose un grand défi aux propriétaires et aux gestionnaires : comment intégrer des considérations multiples en une seule décision ? En prenant comme exemple le cas de la gestion et du développement durable des forêts, on voit qu'il existe un nombre très important de critères et d'indicateurs pour mesurer la durabilité de la gestion. Ainsi, dans la démarche de la Conférence ministérielle pour la protection des forêts en Europe (CMPFE), un ensemble de six critères et de trente-six indicateurs est développé et ceci uniquement pour un seul type d'occupation du sol. De plus, cet ensemble de critères et d'indicateurs est critiqué quant à sa pertinence et à la possibilité de le prendre en compte dans la pratique (Wjewardana, 2008). On peut bien imaginer qu'avec le grand nombre de types d'occupation du sol pouvant être rencontrés dans un paysage, le problème de la mesure de la durabilité de la gestion devient d'une grande complexité. Mais restons-en à la gestion forestière : le problème dans ce cas est que les propriétés forestières, à tout le moins en Allemagne, ne sont pas exclusivement jugées par les citoyens sur la base de la durabilité de leur gestion. Le public considère plutôt l'accomplissement de fonctions sociétales multiples, ce qui requiert d'intégrer beaucoup plus de considérations dans les décisions. C'est la raison pour laquelle quelques grandes propriétés forestières commencent à développer leurs propres (et beaucoup moins gros) systèmes de critères et d'indicateurs (BaySF, 2007).

De telles approches n'envisagent pourtant de mesurer le niveau de réalisation des différentes fonctions que de manière rétrospective (par exemple, Wolfslehner *et al.*, 2005), c'est-à-dire que la qualité des mesures d'aménagement prises n'est évaluée qu'après leur réalisation. De ce fait, le pauvre gestionnaire demeure seul avec son problème de décision multicritère.

Pour entraîner et aider les praticiens dans de telles situations et pas seulement dans la gestion forestière, de nombreux systèmes et solutions techniques ont été développés par les chercheurs (Kangas et Kangas, 2005 ; Karmakar *et al.*, 2007 ; Matthies *et al.*, 2007). Leur applicabilité dans la pratique est parfois contestée à juste titre à cause de leur grande complexité (Uran et Janssen, 2003). Souvent, de tels systèmes sont exclusivement conçus comme des systèmes experts qui requièrent une longue phase d'entraînement. De plus, ils sont souvent très liés à l'étude de cas pour laquelle ils ont été développés et ne peuvent être utilisés dans des conditions pratiques s'écartant de leur environnement de développement (Kaster *et al.*, 2005). Enfin, ils contribuent rarement à des processus interactifs et participatifs pour préparer des décisions en matière de planification (par exemple, Janssen *et al.*, 2006 ; Tyrväinen *et al.*, 2006).

Pourtant, la demande se fait de plus en plus pressante de disposer d'outils intégrant un grand nombre de considérations et de connaissances afin d'être capable de prendre des décisions raisonnables. Ceci correspond à une sensibilité croissante du public aux aspects environnementaux. La discussion actuelle sur le changement climatique et ses effets en est un bon exemple. Elle atteste qu'un nombre croissant de critères doit être pris en compte dans la gestion de la forêt et de l'environnement (Pahl-Wostl, 2007 ; Deboudt *et al.*, 2008).

PIMP YOUR LANDSCAPE - CONCEPTION ET MISE EN ŒUVRE DU SYSTÈME

Idée et environnement de développement de *Pimp your Landscape*

Pimp your Landscape est un logiciel interactif d'aide à la prise de décision multicritère dans l'aménagement d'un territoire. Un exemple de champ d'application est l'optimisation régionale des proportions de différents types d'occupation du sol en vue de la production d'eau potable tout en tenant compte de l'économie et de la biodiversité régionales. *Pimp your Landscape* peut être traduit en français par « Habille ton paysage ».

À l'origine, *Pimp your Landscape* avait été développé afin d'aider à la résolution des conflits entre les multiples groupes qui intervenaient dans l'aménagement et la gestion du territoire d'une région s'étendant sur trois États, l'« euro-région » Neisse. Cette région se trouve le long de la rivière Neisse et se situe en République tchèque, en Allemagne et en Pologne. Dans cette région, les directives européennes, directive-cadre sur l'eau et directive Habitats, posent des problèmes transfrontaliers de planifications régionale et supra-régionale. Cette région est dominée par l'agriculture et d'anciennes mines de lignite à ciel ouvert. La mise en valeur économique des forêts qui, pour leur majorité, relèvent du secteur privé, le reboisement (des mines à ciel ouvert)

Figure 1 **LOCALISATION DE L'« EURO-RÉGION » NEISSE**

et l'introduction de systèmes agroforestiers se trouvent en concurrence avec une volonté de développer le tourisme régional, une demande de garantie de la qualité des eaux de la Neisse et la mise en place d'une proportion identifiée de sites d'intérêt communautaire (Natura 2000). La figure 1 (p. 22) permet de localiser la région considérée.

La conception et le développement de *Pimp your Landscape* présentés dans cet article se réfèrent pour l'essentiel à l'euro-région Neisse. Cependant, le logiciel a très tôt été adapté au cas de deux autres régions : la région industrielle et urbanisée de Leipzig-Halle-Bitterfeld et la région forestière des landes de Düben, régions d'Allemagne dans lesquelles des problèmes de complexité comparables avaient été identifiés.

Analyse des demandes des utilisateurs : l'enquête Delphi

Le principe de développement de *Pimp your Landscape* repose dès le début sur une implication des utilisateurs. Dans le cas qui nous intéresse, une étude préalable avait révélé que les administrations chargées de la gestion des forêts et de celle de l'eau, les bureaux de planification régionale ainsi que les organisations gouvernementales et non-gouvernementales de protection de la nature et de l'environnement, jouaient un rôle majeur dans les processus d'aménagement du territoire. Dans l'euro-région Neisse, un élément particulier favorisait cette approche : l'existence de groupes de travail interdisciplinaires et transfrontaliers EUREX, groupes mis en place pour favoriser la communication entre les trois pays voisins. Sur la base de la structure de ces groupes, une approche de type *enquête Delphi* a été choisie afin d'identifier les intérêts et les besoins des utilisateurs. Une enquête Delphi est une méthode sociologique d'enquête systématique et successive qui inclut une rétroaction des participants. Contrairement aux autres types d'enquête, les participants ne sont pas choisis aléatoirement : l'enquête Delphi travaille avec des experts sélectionnés de manière à assurer une bonne représentation des différentes branches de l'économie. La méthode a pour objet d'obtenir des connaissances approfondies sur des tendances et des avancées technologiques. Le nom de la méthode vient de l'oracle de Delphes qui prodiguait à ses auditeurs des conseils pour l'avenir.

Trente-deux individus représentant trois groupes-cibles avaient été identifiés afin de participer à l'enquête Delphi. Ces trente-deux individus venaient, pour 46 %, des administrations chargées de la gestion des forêts, de l'agriculture et de l'eau, pour 21 %, des bureaux d'aménagement régional et, pour 33 %, des organisations de protection de la nature et de l'environnement. Ils représentent les groupes les plus importants qui participent au développement des plans régionaux et constituent un instrument majeur de communication entre les trois États représentés dans l'euro-région Neisse. D'autres groupes, par exemple des organisations non-gouvernementales (chasseurs...) ou des clubs de touristes, avaient été contactés. Ils n'ont pas été intégrés dans l'enquête Delphi parce qu'ils ne participaient pas activement aux processus et aux décisions relatifs à l'aménagement.

L'enquête Delphi s'est déroulée en deux étapes. Dans la première étape, trois questions étaient posées. La dernière question (c) était répétée dans la seconde étape. Pour une partie des participants, cette seconde étape était précédée par un atelier destiné à présenter des solutions déjà disponibles. Il était demandé aux participants de spécifier :

Question a : quel type de source d'information ils utilisent afin de se préparer à la prise de décision multicritère et interdisciplinaire ;

Question b : quels outils (soit informatiques, soit à base papier) ils utilisent afin de visualiser les critères de décision multiples et le processus d'aménagement ;

Question c : comment, de leur point de vue, un outil optimal d'information et d'aide à la décision doit être conçu.

Pour chaque question, un certain nombre d'alternatives étaient proposées aux participants à qui il était demandé de les évaluer suivant une gamme allant de 1 (toujours ou la plus souhaitable) à 6 (jamais ou la moins souhaitable). De plus, ils avaient la possibilité d'ajouter des commentaires et des propositions individuels.

En conclusion de cette première étape de l'enquête Delphi, il est apparu que :

Question a : de façon générale, de nombreuses sources d'informations sont utilisées pour préparer les décisions à prendre quant à la gestion d'un territoire et il n'apparaît pas de préférences particulières entre ces sources ;

Question b : au cours du processus de prise de décision, les outils informatiques et les outils de communications sont préférés aux outils à base papier, parce que leur utilisation et leur mise à jour sont plus flexibles ;

Question c : la définition d'un outil optimal d'aide à la décision est très subjective (étape 1).

Au cours de la seconde étape de l'enquête Delphi, les outils qualifiés de novateurs par les participants dans sa première étape ont obtenu des scores élevés. Des outils de visualisation des effets des mesures d'aménagement et des outils basés sur des résultats d'expérience ont été proposés. Dans le groupe de participants pour lesquels l'étape 2 avait été précédée d'un atelier, un nombre encore plus élevé de réponses en faveur des outils novateurs a été observé.

En résumé, les usagers ont indiqué qu'un outil optimal :

— devait être facile à comprendre et à manipuler ;
— devait être accessible de manière libre et permanente ;
— devait permettre une visualisation des processus et des effets de la planification ;
— devait pouvoir s'appuyer sur des exemples réels (des cas d'étude).

En outre, les effets de l'aménagement doivent pouvoir être évalués en permanence et d'une façon aisée à comprendre (pas de liste d'indicateurs) par l'usager.

Profil de développement de *Pimp your Landscape*

Pour préciser la conception du logiciel, une version papier en a été développée et a été testée au cours d'un atelier comprenant vingt personnes ayant participé à l'enquête Delphi. L'atelier était organisé sous forme d'un jeu de rôles dans lequel il était demandé aux participants de se ranger en trois groupes (les forestiers, les gestionnaires de l'eau et les écologistes) afin d'observer leur attitude dans des situations de décision multicritère quant à l'aménagement d'un territoire. De plus, étaient testés un exemple de planification avec restrictions dérivées de la directive-cadre sur l'eau et de la directive Habitats (Natura 2000) ainsi qu'un exemple libéré de ces restrictions. À la suite de cet atelier et des interviews qui y ont été réalisées, le profil souhaité pour *Pimp your Landscape* a été esquissé comme suit :

• La visualisation de la région, de la mosaïque des parcelles et de la distribution spatiale des différents types d'occupation du sol doit reposer sur l'utilisation de CORINE LANDCOVER 2000. La référence à l'occupation du sol constituait une forte demande des participants à l'étude parce que c'est la seule base commune de référence qui existe dans les trois États de l'euro-région Neisse. En effet, CORINE LANDCOVER 2000 est un ensemble de cartes digitales qui est disponible pour toute l'Europe et constitue de plus un standard permettant une classification homogène des types d'occupation du sol. L'existence de cette référence permet ainsi de traiter des questions relevant de la gestion de territoires transfrontaliers. La résolution de 100 x 100 m² (1 ha = 1 cellule sur la carte) qui a été retenue cadre bien avec les besoins de la planification forestière. Les cartes sont importées dans le système avec leurs coordonnées géographiques, ce qui facilite l'échange des données et des résultats de la simulation avec des systèmes d'information géographiques. Enfin, pour répondre à une demande de simplification des décisions à prendre, le nombre de 44 types d'occupation du sol introduits dans CORINE LANDCOVER 2000 a été réduit à 10 par fusion de types voisins ou non-prise en compte de types très rares. Cette simplification a été établie après consultation des participants à l'enquête Delphi et de quelques experts supplémentaires.

Actuellement, les 10 types suivants sont introduits dans *Pimp your Landscape* :

— type 1 : villes et zones urbanisées (dont autres types de lotissements, infrastructures urbaines et espaces verts urbains) ;
— type 2 : zones industrielles (dont terrils et mines anciennes et en exploitation, souterraines ou à ciel ouvert) ;
— type 3 : agriculture ;
— type 4 : cultures spécialisées (fruits et légumes, vignes) ;
— type 5 : prairies artificielles ;
— type 6 : prairies naturelles ;
— type 7 : forêts de feuillus ;
— type 8 : forêts de conifères ;
— type 9 : forêts mixtes ;
— type 10 : plans d'eau et zones humides.

Il convient de préciser que, en cas de demande spéciale pour des régions particulières, il est possible de tenir compte d'autres types d'occupation du sol dans *Pimp your Landscape*. La seule restriction à cette possibilité est que l'on ne peut pas toujours évaluer l'impact d'un type particulier d'occupation du sol sur les quatre fonctions économie, écologie, tourisme et qualité de l'eau.

• Pour procéder à des changements dans la mosaïque et la distribution spatiale des types d'occupation du sol, il faut assigner de nouveaux types d'occupation par clic de souris sur les cellules d'un hectare.

• Tout changement dans la distribution spatiale des types d'occupation du sol est évalué du point de vue de l'équilibre, au niveau de la région ou d'une partie de la région, pour les quatre fonctions suivantes :

— fonction économie (revenu) ;
— fonction écologie (biodiversité) ;
— fonction tourisme (esthétique) ;
— fonction qualité de l'eau (potabilité).

La concentration sur ces fonctions globales était un désir explicite des participants à l'enquête Delphi. La raison en était que, avec la discussion sur des critères et indicateurs de la durabilité, la diversité des informations pour identifier une décision est devenue trop grande. Les quatre fonctions introduites dans *Pimp your Landscape* examinent d'un point de vue intégré l'ensemble des critères visant à l'aménagement durable d'une région. Au moins en Allemagne, l'équilibre des fonctions est le but recherché pour l'aménagement aux niveaux régional et sectoriel. En conséquence, les quatre fonctions ont le même poids dans l'évaluation des scénarios d'aménagement. Considérant la fonction tourisme, l'esthétique est le seul indicateur qui est applicable pour tous les types d'occupation du sol. Il existe de nombreuses études sur la valeur touristique de types d'occupation du sol isolés, mais seulement un tout petit nombre d'entre elles procurent une vue intégrée au niveau régional. Dans celles-ci, l'esthétique est utilisée comme l'indicateur le plus important.

• Pour estimer les effets des mesures d'aménagement du territoire, chacun des 10 types d'occupation avait été évalué du point de vue de son impact sur les 4 fonctions économie, écologie, tourisme et qualité de l'eau. Afin de rendre comparables les différents types d'occupation du sol ainsi que les nombreux indicateurs et systèmes d'indicateurs utilisables pour estimer l'effet d'un type d'occupation du sol sur une fonction, une gamme relative de valeurs allant de 0 (le plus mauvais effet) à 100 (le meilleur effet) a été choisie comme référence (cf. § "Évaluation multicritère", ci-dessous).

• Enfin, deux modes d'utilisation de *Pimp your Landscape* ont été demandés :

— un mode expert en vue d'aider les acteurs du processus d'aménagement à s'entraîner et à prendre les décisions ;

— un mode ludique destiné à permettre au public d'intervenir dans le processus participatif d'aménagement d'un territoire.

Évaluation multicritère - idées et réalisation

Par référence au point "estimation des effets" ci-dessus, le tableau I présente les valeurs attribuées à chacune des 4 fonctions de chacun des 10 types d'occupation du sol rencontrés dans l'euro-région Neisse.

Tableau I **Valeurs attribuées à chacune des 4 fonctions de chacun des 10 types d'occupation du sol rencontrés dans l'euro-région Neisse.**
Pour d'autres régions traitées par *Pimp your Landscape*,
ce tableau a été adapté en concertation avec des usagers et des experts régionaux.

Type d'occupation du sol (d'après CORINE LANDCOVER 2000)	Impact du type d'occupation sur la fonction			
	Économie	Écologie	Tourisme	Qualité de l'eau
Villes et zones urbanisées	100	0	0	0
Zones industrielles	100	0	0	0
Agriculture	80	30	20	20
Cultures spécialisées	75	35	40	30
Prairies artificielles	60	35	50	60
Prairies naturelles	5	100	90	70
Forêts de feuillus	30	100	80	80
Forêts de conifères	40	60	60	50
Forêts mixtes	35	90	90	80
Plans d'eau et zones humides	5	100	90	100

Le problème majeur rencontré pour réaliser un tableau de ce type était d'analyser et de sélectionner les divers indicateurs et systèmes d'indicateurs qui sont proposés pour chaque type d'occupation du sol et pour chaque fonction. Il existait même des cas où une absence complète d'indicateurs était constatée (exemple de l'évaluation de l'impact des différents types d'occupation du sol sur la fonction tourisme). De plus, il est très vite apparu que l'attribution des mêmes valeurs pour toutes les régions n'était pas raisonnable et qu'il fallait aussi tenir compte de l'expérience des divers groupes régionaux qui participent au processus d'aménagement d'un territoire.

Par exemple, les valeurs écologique et touristique d'un peuplement de feuillus vont dépendre fortement de la situation forestière initiale de la région considérée : elles seront plus faibles dans des régions forestières riches en feuillus, plus fortes dans des régions dominées par les conifères et particulièrement fortes dans des régions agricoles et industrielles. C'est la raison pour laquelle des versions du tableau I adaptées à chaque région ont été introduites dans *Pimp your Landscape*. Le tableau II indique de manière résumée comment ont été identifiées les valeurs données dans le tableau I pour l'euro-région Neisse.

Tableau II **Vue d'ensemble des différentes approches mises en œuvre pour identifier les valeurs attribuées à chacune des 4 fonctions de chacun des 10 types d'occupation du sol rencontrés dans l'euro-région Neisse**

Type de source d'information	Type d'occupation du sol	Fonction	Sources d'information utilisées
Données et indicateurs relevés dans des publications et règlements administratifs relatifs à l'impact d'un type d'occupation du sol sur ses fonctions	Tous types	• Écologie	(1) Loi de protection de la nature du land de Hesse (2) Données des offices nationaux allemands de la statistique (3) Résultats du second inventaire forestier national allemand
	Forêts de feuillus et de conifères	• Économie	(1) Prix de vente des forêts d'après (a) la loi de dédommagement public et de prestation compensatrice et (b) le standard d'évaluation de l'Association pour l'utilisation et de l'administration des propriétés foncières publiques (2) Données des offices nationaux allemands de la statistique sur les prix de vente
	Prairies artificielles, prairies naturelles, agriculture, cultures spécialisées		(1) Calculs nationaux de la contribution marginale des différents types d'occupation du sol (2) Calculs nationaux des prix de vente des produits (agricoles, forestiers, etc.) et des coûts indicatifs de mise hors production
Avis et connaissances d'expert	Tous types	• Tourisme • Qualité de l'eau potable	(1) Groupes de travail régionaux EUREX (2) Chercheurs reconnus
	Villes et zones urbanisées, zones industrielles	• Économie	
Estimations relatives par rapport à d'autres valeurs	Forêts mixtes, prairies naturelles, plans d'eau et zones humide		(1) Forêts mixtes : adoption d'un prix de vente moyen entre forêt de feuillus et forêt de conifères

Ludiciel ou système expert ? Comment utiliser *Pimp your Landscape*

La demande des utilisateurs était de disposer de deux modes d'emploi de *Pimp your Landscape* : un mode expert pour les professionnels engagés dans le processus d'aménagement du territoire et un mode ludique destiné à favoriser la communication avec les citoyens et pouvoir utiliser le logiciel dans un contexte de « e-Gouvernement » : dans le mode expert, les professionnels peuvent adapter la table d'évaluation à leurs connaissances et expériences. La version adaptée peut enfin être intégrée par exemple dans le portail web d'une région ou d'une commune (c'est ce qui est déjà appliqué dans la région de Leipzig). Là, les citoyens intéressés peuvent tester leurs idées sur des mesures de planification concrètes (boisement, construction d'une route) et ils reçoivent un retour par *Pimp your Landscape* sur les effets de leurs propositions pour les fonctions économie, écologie, qualité de l'eau et tourisme. Finalement, après avoir réalisé un résultat convenant à leurs buts, ils peuvent sauvegarder leur proposition dans le portail web. Avant la décision finale sur une mesure de planification, les décideurs peuvent analyser les différentes propositions et trouver une alternative de consentement plus grand. Naturellement, cela demande une répétition de ce processus de retour en plusieurs étapes.

La figure 2 (ci-dessous) présente la page d'accueil de *Pimp your Landscape* (www.letsmap.de) dans le mode ludique. Les trois régions-types qui ont été traitées (l'euro-région Neisse, les landes de Düben et Leipzig et environs) apparaissent à tour de rôle sur cette page.

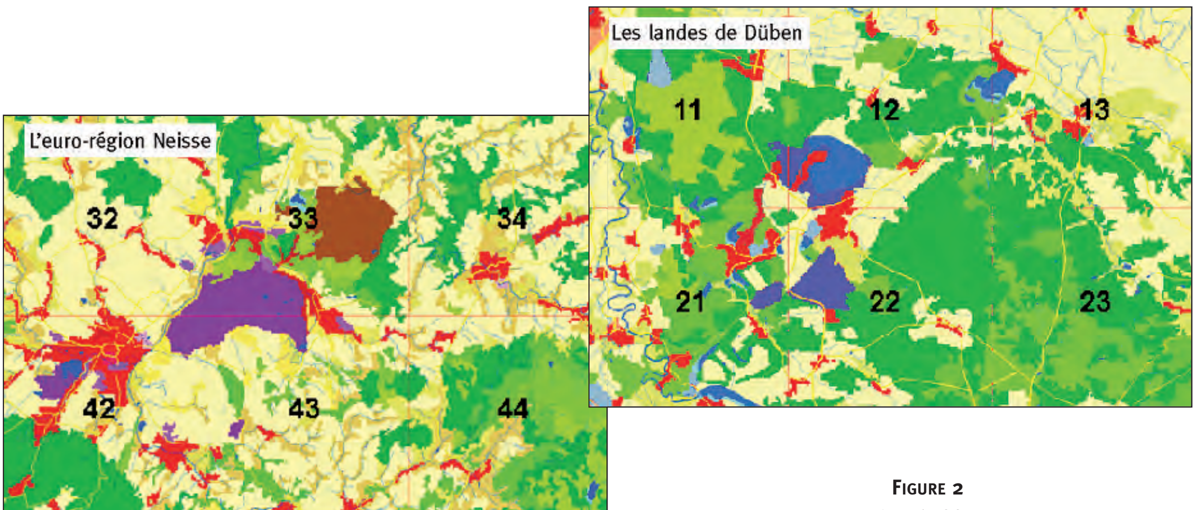
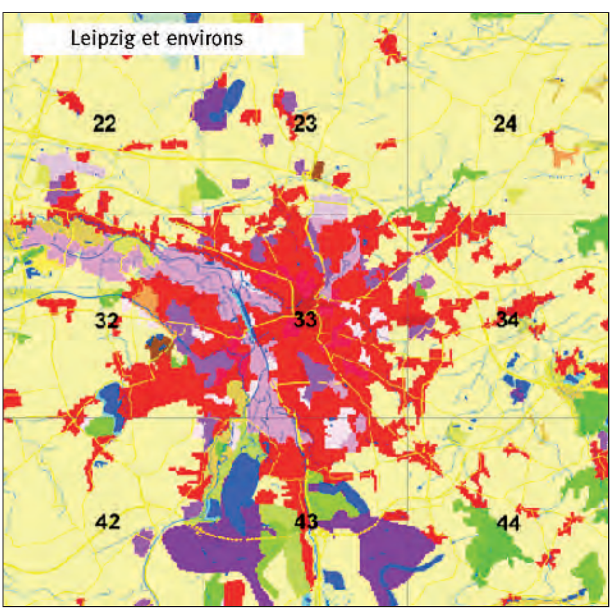
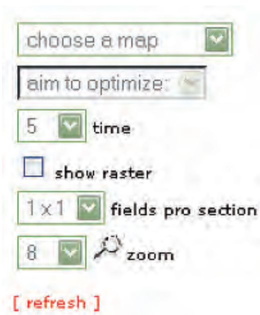


Figure 2

PAGE D'ACCUEIL DE *PIMP YOUR LANDSCAPE* AVEC PRÉSENTATION ANIMÉE DES RÉGIONS DISPONIBLES





Sachant que la résolution choisie pour les cartes est d'un hectare par cellule et qu'un certain nombre de tests pratiques ont montré qu'un utilisateur moyen n'était pas capable de travailler avec un nombre de cellules supérieur à 2 000-2 500, celui-ci est invité à choisir une zone de l'une des régions, soit par un menu déroulant, soit par un clic de souris sur la partie de la carte qu'il juge d'un plus grand intérêt afin d'y tester les effets des décisions d'aménagement. Les numéros indiqués sur les cartes des régions sont là pour l'aider à se diriger dans le menu déroulant.

Les différents types d'occupation du sol disponibles et leurs codes de couleur sont indiqués dans la légende de la page d'accueil (indication optionnelle par clic de souris). Les changements de type d'occupation du sol dans les cellules se réalisent par clic de souris : une fenêtre apparaît qui montre les divers types disponibles dans un menu déroulant. Pour correspondre aux habitudes personnelles des utilisateurs, l'ordre des types d'occupation du sol peut être changé. Par exemple, un utilisateur venant de la gestion forestière peut adapter ce menu de manière qu'il affiche d'abord tous les types de forêts, ce qui l'aide à travailler plus vite sur les changements qu'il veut réaliser. Après un clic sur un type, celui-ci est assigné à la cellule et le logiciel calcule le changement qui en résulte pour les quatre fonctions au niveau de la partie de la carte sur laquelle l'utilisateur a choisi de travailler. La valeur globale de chaque fonction sur la partie de la carte choisie est calculée comme moyenne des valeurs des cellules la composant. Les valeurs actualisées représentant les effets, sur les fonctions, des changements envisagés par l'utilisateur sont illustrées par un diagramme ainsi que par un tableau donnant la tendance de variation des quatre fonctions (figure 3b, p. 31).

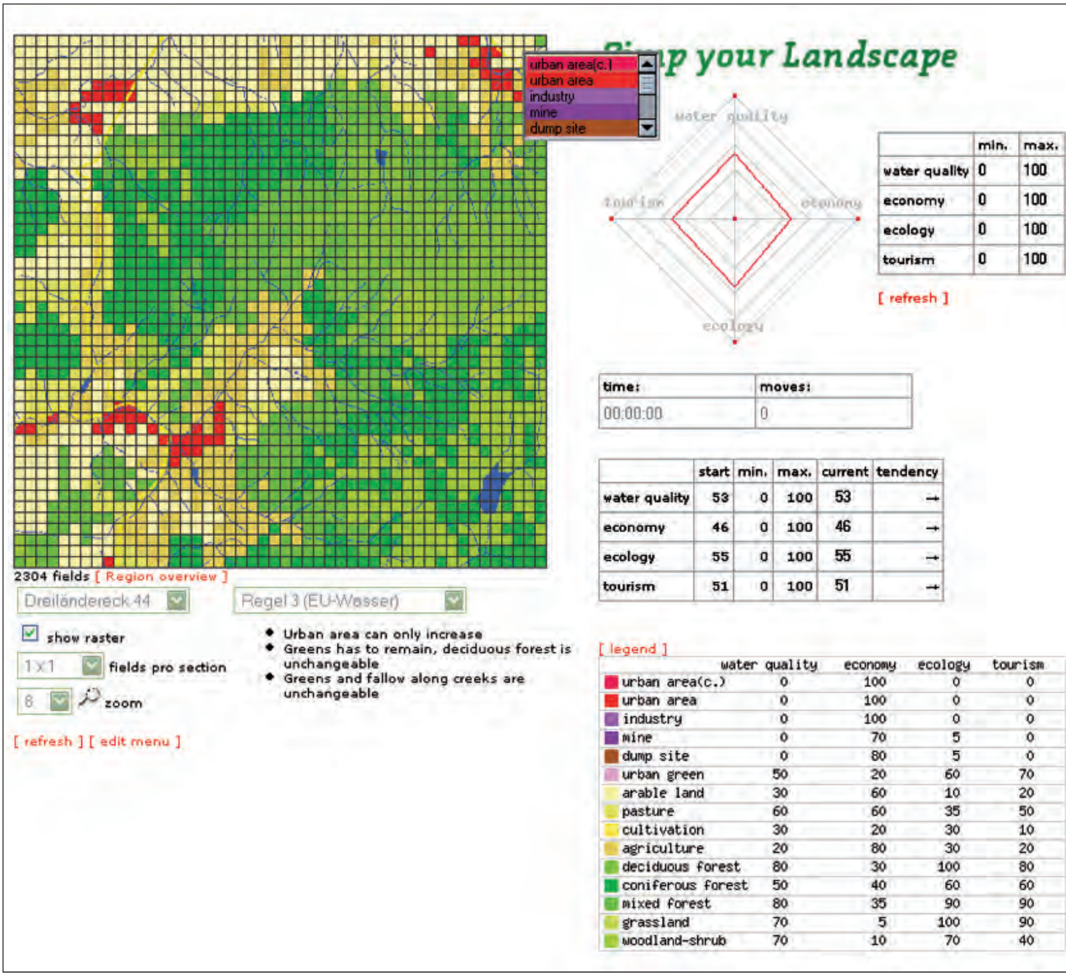
Afin d'accélérer le déroulement du jeu, il est possible de modifier la trame de résolution standard d'un hectare par cellule pour la porter jusqu'à 2 000 x 2 000 m^2 (soit 400 ha). Ceci est particulièrement utile pour les régions très homogènes.

Dans l'interface graphique de *Pimp your Landscape*, les attributs cellulaires susceptibles de varier (type d'occupation du sol et couleur) et les attributs permanents (cours d'eau, autoroutes, voies ferrées, etc.) sont visualisés conjointement. Par contre, dans le système du logiciel, ils sont manipulés de façon séparée : chaque cellule contient les informations complètes sur le type d'occupation du sol et les attributs permanents, mais on ne peut changer que le type d'occupation du sol. La mise à disposition d'attributs variables et d'attributs permanents est importante pour l'évaluation. La valeur d'une cellule pour les fonctions économie, écologie, qualité de l'eau et tourisme résulte de la valeur du type d'occupation du sol comme attribut variable et de l'emprise des attributs permanents. Par exemple, une cellule de forêt de feuillus se verra attribuer une valeur élevée pour la fonction qualité de l'eau si un cours d'eau s'y trouve. Au contraire, la valeur pour la fonction qualité de l'eau pourrait être diminuée par l'existence d'une autoroute.

Dans le mode expert d'utilisation de *Pimp your Landscape*, l'utilisateur est invité à choisir une carte (c'est-à-dire une partie de l'une des trois régions-types mentionnées au § "Ludiciel ou système expert ?", p. 27) et à indiquer s'il veut tenir compte de restrictions particulières dans la gestion du territoire choisi. Ces restrictions, qui peuvent résulter de directives européennes ou de la réglementation régionale, sont traduites en règles du jeu. Elles limitent les degrés de liberté en matière de modification de la mosaïque et de distribution spatiale des types d'occupation du sol. Ceci se visualise en cliquant sur une cellule : le menu déroulant dans la fenêtre pop-up est adapté aux restrictions prises en compte. Cela signifie que seuls les types d'occupation du sol qui permettent à une cellule de respecter les règles du jeu peuvent apparaître. Ainsi, des zones de conflit et des fenêtres d'opportunité sont identifiées.

Il est demandé à l'utilisateur de définir des valeurs-seuils, comprises entre 0 et 100, pour chacune des quatre fonctions considérées : économie, écologie, tourisme et qualité de l'eau. Ces valeurs-seuils ne doivent pas être atteintes, afin d'éviter une optimisation unilatérale. L'attribution des

FIGURE 3a **CARTE EN MODE EXPERT AVEC LES TYPES D'OCCUPATION DU SOL DISPONIBLES ET LA LÉGENDE QUI PRÉSENTE LES DIFFÉRENTS TYPES D'OCCUPATION DU SOL, LEURS CODES DE COULEUR ET LES VALEURS ASSIGNÉES**



valeurs pour chacune des fonctions sur la gamme 0 à 100 peut être adaptée aux conditions d'un échelon administratif local. Cette possibilité est offerte aux experts après leur enregistrement dans le système. À cet échelon local, les règles du jeu peuvent être également modifiées et importées dans le logiciel.

Dans le mode expert, il n'y a pas de limitation temporelle d'utilisation. Toutefois, des tests réalisés avec les utilisateurs ont montré qu'il leur était difficile de se souvenir, en fin de jeu, des essais réalisés et de leurs effets sur l'équilibre des quatre fonctions. De ce fait, une fonction a été mise en place qui récapitule les différentes étapes parcourues et rend possible l'arrêt et la reprise du processus d'aménagement. Ceci permet aussi de satisfaire une demande forte de travailler sur un grand nombre d'alternatives d'aménagement, en un temps très court.

Enfin, le logiciel permet d'échanger avec d'autres utilisateurs les résultats d'aménagement, c'est-à-dire les valeurs finales des quatre fonctions, dans la mesure où ces utilisateurs se réfèrent à la même carte et à la même règle du jeu.

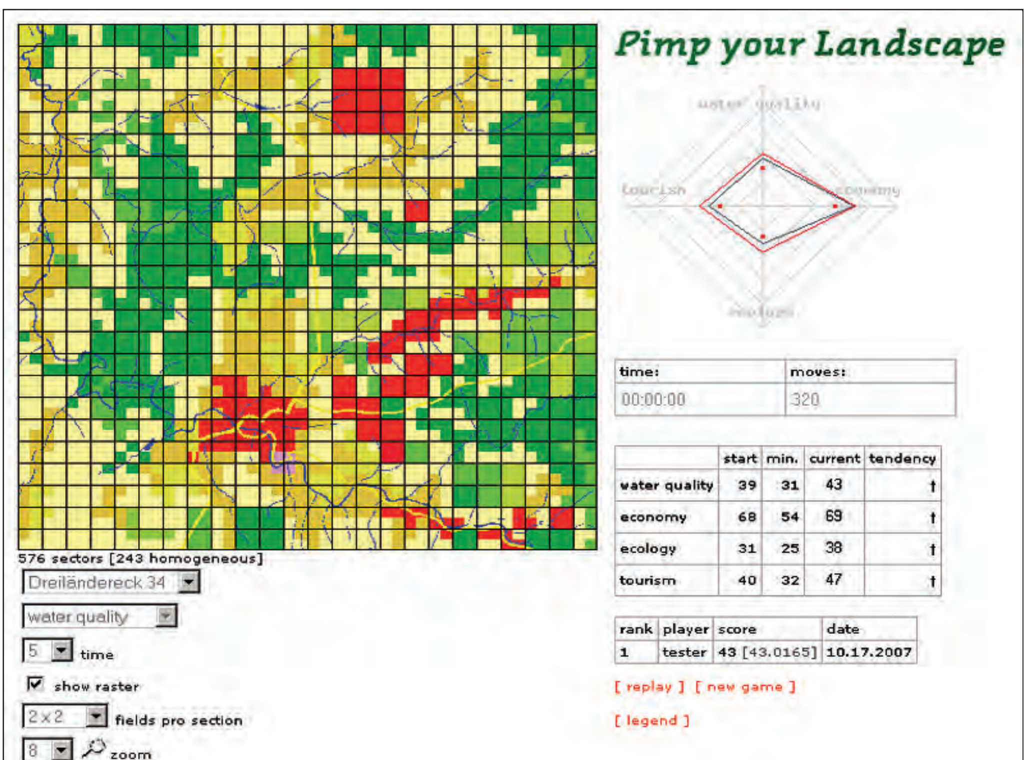
En mode ludique, également, il est demandé à l'utilisateur de choisir une carte. Dans ce cas, aucune restriction n'est imposée dans l'aménagement et toute idée, aussi folle soit-elle, peut être simulée. En revanche, l'utilisateur doit définir un but de développement, c'est-à-dire décider quelles fonctions il veut optimiser ou s'il souhaite parvenir à un équilibre entre elles.

Dans ce cas, un tableau des valeurs et un tableau des valeurs-seuils sont établis (cf. mode expert) et des mises en garde apparaissent si les valeurs-seuils sont dépassées afin de sensibiliser l'utilisateur quant aux décisions qui menacent un développement durable dans la région.

L'utilisateur a la possibilité de choisir une durée de jeu située dans une fourchette de 1 à 10 minutes. Cette option est particulièrement adaptée en cas de compétition entre plusieurs utilisateurs. Comme dans le cas précédent, ces utilisateurs doivent bien sûr se référer à la même carte et, cette fois-ci, se mettre d'accord sur un même objectif de développement.

Figure 3b **CARTE EN MODE LUDIQUE EN COURS DE JEU**

Le diagramme en haut et à droite montre la différence entre la situation initiale (polygone intérieur) et la situation courante (polygone extérieur). Sous ce diagramme, le tableau de tendance présente les valeurs initiales, les valeurs-seuils et les valeurs et tendances courantes des quatre fonctions pour la partie de la région sur laquelle l'utilisateur est en train de travailler. Au-dessous du tableau, la liste des champions est présentée : dans le cas considéré, un seul utilisateur était activé mais, dans le cas général, le nombre d'utilisateurs en compétition n'est pas limité.



En fin de jeu, une liste des champions est présentée et l'utilisateur peut jouer de nouveau.

Les figures 3a et 3b donnent une illustration de l'utilisation de *Pimp your Landscape* en mode expert (figure 3a, p. 30) et en mode ludique (figure 3b, p. 31).

EXEMPLES D'APPLICATION PRATIQUE

Actuellement, *Pimp your Landscape* connaît quatre domaines d'application :

• Prenant pour base les résultats des projets ENFORCHANGE et IT-REG-EU (voir remerciements, p. 34), le logiciel est utilisé pour faire dialoguer les divers groupes d'intérêt quant à l'organisation et aux objectifs de l'aménagement forestier à l'interface des autres types d'occupation du sol. Par exemple, dans l'euro-région Neisse et dans les landes de Düben, la question en débat est soit d'établir de nouvelles forêts, soit de modifier les forêts actuelles afin de répondre, sans trop de pertes économiques, aux demandes portant sur la protection de la nature et sur les approvisionnements en eau potable.

• Dans la région de Leipzig, le logiciel est utilisé pour aider au développement d'approches participatives dans l'aménagement de l'espace en général et dans l'aménagement des forêts en particulier. Dans un contexte très prégnant de réhabilitation d'anciennes mines à ciel ouvert, le tableau des valeurs de *Pimp your Landscape* a d'abord été adapté, à dire d'experts, aux types d'occupation du sol possibles dans un tel contexte. En une seconde étape, le logiciel va être intégré au portail web de la ville de Leipzig, permettant ainsi aux habitants de tester et de proposer des alternatives de réhabilitation et, au final, de se prononcer sur l'alternative la plus favorable.

• Dans le cadre d'une semaine de la science, les citoyens ont reçu la possibilité d'exprimer leur conception de la future forêt de leur région. Pour cela, *Pimp your Landscape* a été retravaillé de manière à être utilisable à l'échelle du peuplement au lieu de l'être à l'échelle de la région. Ainsi, la résolution est-elle dans ce cas d'un mètre carré et les surfaces des peuplements traités peuvent être de l'ordre de l'hectare. Le tableau des valeurs a été adapté pour rendre compte des effets des différentes espèces d'arbre sur l'économie, l'écologie, le tourisme et la qualité de l'eau et ce, sous le scénario le plus probable d'évolution du climat régional. Grâce à l'injection dans *Pimp your Landscape* d'informations supplémentaires quant aux potentialités des différentes essences de la région sous un climat modifié, les citoyens ont les moyens d'apprendre davantage sur les effets du changement climatique et ils disposent d'une opportunité réelle de faire valoir leur conception vis-à-vis du développement des forêts de leur région. À l'issue de cette initiative interactive, l'alternative qui aura été préférée par les citoyens sera plantée dans Leipzig sur une parcelle d'un hectare et la population pourra ainsi en suivre le développement.

• Une quatrième application importante de *Pimp your Landscape* concerne l'éducation dans le cadre du programme européen *Éducation pour le développement durable*. Le domaine d'application et le fonctionnement de *Pimp your Landscape* ont été adaptés aux besoins des élèves de différents niveaux dans un projet-pilote transfrontalier d'éducation à l'environnement de l'euro-région Neisse. L'idée directrice consistait à utiliser internet afin de proposer un outil multilingue de communication à des élèves voisins de République tchèque, d'Allemagne et de Pologne. Il s'agissait de donner à traiter à de petits groupes internationaux d'élèves de petits projets d'aménagement forestier. En utilisant *Pimp your Landscape* dans son mode ludique, ils ont appris à comprendre le fonctionnement de systèmes complexes que sont les forêts et ceci, en interaction avec les autres types d'occupation du sol de la région.

PIMP YOUR FOREST ?
RESTRICTIONS ACTUELLES ET PERSPECTIVES DE DÉVELOPPEMENT

Pimp your Landscape est un outil d'apprentissage du fonctionnement des systèmes complexes que sont les paysages. Le logiciel vise à intégrer, à cette échelle du paysage, les multiples interactions existant entre les divers types d'occupation du sol. Il peut être utilisé pour aider l'aménagiste forestier dans le contexte d'une région. L'idée de mieux comprendre le rôle des forêts dans la "performance" d'une région en ce qui concerne les fonctions écologiques, économiques et sociales a constitué une motivation majeure pour développer cet outil. S'agissant des gestionnaires forestiers, le logiciel vise à leur fournir par exemple des arguments renouvelés pour installer de nouveaux boisements dans une perspective multicritère. Eu égard aux changements profonds qui interviennent dans la structure de propriété des forêts allemandes, changements qui s'accompagnent d'une perte énorme dans l'estime du public, *Pimp your Landscape* unifie des approches d'aménagement participatif et d'intégration de connaissances d'experts. Ainsi, une communication souvent difficile entre ces derniers et les citoyens est facilitée. Néanmoins, *Pimp your Landscape* ne peut pas être utilisé pour tester les différentes stratégies d'aménagement au niveau d'un peuplement ni pour en débattre. Pour les propriétaires forestiers, la restriction d'application consiste dans la classification grossière des forêts donnée par CORINE LANDCOVER 2000 et la résolution maximale d'un hectare par cellule.

De grands défis se posent encore pour le développement ultérieur de l'outil (Fürst *et al.*, 2008). Le travail le plus important qui reste à réaliser consiste à analyser les multiples systèmes d'indicateurs qui sont utilisés pour évaluer l'impact des divers types d'occupation du sol sur les fonctions évaluées à l'échelle du paysage. La combinaison entre dire d'experts et indicateurs disponibles semble être une voie prometteuse afin de garantir une évaluation à références régionale et supra-régionale. Cependant, il faut reconnaître que, jusqu'à présent, ni un ensemble d'indicateurs de portée générale, ni une combinaison optimale de ceux-ci, n'ont pu être identifiés. Cette identification constitue un enjeu très important pour les années qui viennent.

Au sortir des dernières étapes de test de *Pimp your Landscape*, une demande des utilisateurs était que le logiciel puisse tenir compte de la dynamique temporelle et des influences mutuelles des types de gestion d'un territoire à l'échelle du paysage. Un bon exemple est celui de l'impact de la forêt sur la qualité de l'eau : si l'on considère une forêt établie récemment dans une région agricole, ses effets sur la qualité de l'eau vont se développer sur une période de plus de cent années. Or, aujourd'hui, l'évaluation réalisée par *Pimp your Landscape* suppose que la forêt, sitôt qu'elle aura été installée, produit les mêmes impacts que ceux d'un écosystème qui a toujours existé.

Relativement à la dynamique temporelle, il est nécessaire de consolider le système avec des modèles *ad hoc* mis au point ou à mettre au point pour les divers types d'occupation du sol, modèles qui, malheureusement et quand ils existent, ne satisfont pas la seconde demande des utilisateurs, à savoir gérer les interactions à l'intérieur des paysages. Pour résoudre ce problème, *Pimp your Landscape* est développé depuis 2008 sous forme d'automates cellulaires (voir par exemple Mathey *et al.*, 2008). Cela comprend la modélisation des interactions multiples entre les cellules (effets de voisinage des différents types d'occupation du sol), l'intégration d'attributs additionnels (informations sur la géographie, la topographie, le climat et le type de propriété) dans l'évaluation et l'utilisation d'un système de règles pour décrire le développement dynamique d'un paysage et l'introduction de restrictions quant aux mesures d'aménagement. Celles-ci peuvent être par exemple des limites pour l'existence d'un type particulier d'occupation du sol (comme la disponibilité de l'eau) ou aussi des limites basées sur la situation de la propriété (comme la disponibilité des parcelles pour réaliser le tracé d'une route).

Redisons que le problème principal est que les connaissances sur les processus dynamiques et celles concernant les interactions spatiales ne sont que très partiellement disponibles. Pour cette raison mais aussi pour rester fidèles aux racines participatives de *Pimp your Landscape*, les expériences et les connaissances des praticiens et des experts relatives aux processus temporels et aux interactions spatiales doivent et vont être consultées de nouveau.

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PIMP YOUR LANDSCAPE – UN LOGICIEL POUR LA GESTION INTERACTIVE DES PAYSAGES : POTENTIELS ET LIMITES (Résumé)

L'article présente *Pimp your Landscape*, un logiciel interactif d'aide à la prise de décision multicritère et multiagent dans l'aménagement d'un territoire à l'échelle du paysage. *Pimp your Landscape* permet d'évaluer et de visualiser les effets résultant d'un changement de distribution spatiale des divers types d'occupation du sol. L'utilisateur de ce logiciel peut modifier cette distribution spatiale par simple clic de souris. Compte tenu de la disponibilité de cartes et de l'homogénéité de la classification des types d'occupation du sol au niveau européen, CORINE LANDCOVER 2000 a été retenue comme base cartographique. *Pimp your Landscape* offre deux modes d'utilisation : un mode expert destiné aux professionnels pour aménager un territoire et un mode ludique destiné aux citoyens. Le mode expert offre des possibilités importantes d'adaptation du système aux particularités et demandes régionales. Il est possible, par exemple, d'introduire dans l'aménagement des restrictions susceptibles de résulter de directives européennes ou de régulations régionales. Le mode ludique quant à lui établit un lien entre les connaissances d'experts et les demandes des citoyens dans un processus d'aménagement participatif. L'article se termine par la présentation de quelques exemples d'application incluant des aspects forestiers et par une discussion quant au développement ultérieur du logiciel.

PIMP YOUR LANDSCAPE : A SOFTWARE APPLICATION FOR INTERACTIVE LANDSCAPE MANAGEMENT — POTENTIAL AND LIMITATIONS (Abstract)

The paper introduces *Pimp your Landscape*, a software tool for supporting multicriteria decision-making and participatory processes in land-use management at landscape level. *Pimp your Landscape* visualizes and evaluates the effects of changes in the land-use pattern considering key functions at the landscape level. The user of *Pimp your Landscape* is able to design his landscape by mouse click. In view of the availability of maps and comparability of land-use classifications on a European scale, CORINE LANDCOVER 2000 was chosen as the cartographic base. *Pimp your Landscape* works in two modes — an expert mode, which is designed to support and train professionals in land-use management planning decisions, and a game mode enabling anyone to test their visions on how to optimize their region. The expert mode provides advanced possibilities to adapt the evaluation system to regional characteristics and demands and to test and introduce planning restrictions that arise from EU directives or regional regulations. The game mode helps to introduce both expert knowledge and citizens concerns in participatory planning processes. The paper ends with a description of some application examples that include forestry aspects and a discussion on future developments of the software.

#4 Fürst, C., Vacik, H., Lorz, C., Potocic, N., Krajter, S., Vuletic, D., Makeschin, F. (2010a): **How to support forest management in a world of change? Results of some regional studies.** Environmental Management 46(6): 941-952.

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How to Support Forest Management in a World of Change: Results of Some Regional Studies

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Abstract This article presents results of several studies in Middle, Eastern and Southeastern Europe on needs and application areas, desirable attributes and marketing potentials of forest management support tools. By comparing present and future application areas, a trend from sectoral planning towards landscape planning and integration of multiple stakeholder needs is emerging. In terms of conflicts, where management support tools might provide benefit, no clear tendencies were found, neither on local nor on regional level. In contrast, on national and European levels, support of the implementation of laws, directives, and regulations was found to be of highest importance. Following the user-requirements analysis, electronic tools supporting communication are preferred against paper-based instruments. The users identified most important attributes of optimized management support tools: (i) a broad accessibility for all users at any time should be guaranteed, (ii) the possibility to integrate iteratively experiences from case studies and from regional experts into the knowledge base (learning system) should be given, and (iii) a self-explanatory user interface is demanded, which is also suitable for users rather inexperienced with electronic tools. However, a market potential analysis revealed that the willingness to pay for management tools is very limited, although the participants specified realistic ranges of maximal amounts of money, which would be invested if the products were suitable and payment inevitable. To bridge the discrepancy between unwillingness to pay and the need to use management support tools, optimized financing or cooperation models between practice and science must be found.

Keywords Forest management · Management support tools · User requirements · Delphi study · Information and decision process · Market potentials

Introduction

Forestry has undergone a considerable change of its socio-cultural acceptance and public perception since the 1950s. Before, timber production, contribution to national economy, and the provision of employment in rural areas were major requests of society. After World War II the complexity of societal demands increased. Foresters faced more and more the need to integrate multiple and often contradicting demands on forest management planning (Fürst and others 2007; Johann 2007; Vos and Meekes 1999). An agreed aim for future development of Europe's forests was to ensure their sustainable use and management. However, a broad variety of regional concepts and interpretations of sustainable forestry can be found for Europe (Kissling-Näf and Bisang 2001; Andersson and others 2000; Farell and others 2000). Recently, the target to obtain 20% of Europe's energy needs from renewable sources by 2020 (EU renewable energy policy) sharpened the discussion on the compatibility of an increased timber use from forests and the sustainable fulfillment of other functions of forests on

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landscape level, such as provision of drinking water, conservation of biological diversity, or provision of recreation areas (Stupak and others 2007).

The majority of forests in Europe have multidimensional use, i.e., forests fulfill at the same time a number of ecological, economic, and social functions (Farell and others 2000). A functional prioritization of forest is rather the exception then the rule, e.g. protective forests (water, erosion, and recreation), nature conservation areas or agroforestry systems, where substantially different management strategies must be applied (Führer 2000). The broad variety of overlapping demands affects management strategies as well as operational plans and leads frequently to considerable target conflicts. Therefore, it should be discussed (i) how to deal with the resulting target setting and decision problems and (ii) how to improve the decision-making processes and decision support capabilities in the context of increasing complexity (Rauscher and others 2005).

The concept of multifunctionality forces forest managers to consider a broad range of ecosystem attributes at various spatial and temporal scales (Baskent and others 2008). In consequence, multifunctional use of forests became subject to critical discussions (e.g., Parviainen and Frank 2003; Buttoud 2002; Führer 2000). In many European countries even the importance of forestry as a key supplier of renewable resources is questioned. Instead, the provision of non-marketable goods and services, such as recreation, biodiversity, C-sequestration, climate protection, and nature conservation became more and more important (Spieker 2002). However, the provision of industrial wood is worldwide still of highest importance and has led to overexploitation and destruction of natural forests (e.g., Castella and others 2006; Shimamoto and others 2004; O'Didia 1997). In addition, political decisions influenced by regional and local pressure groups prevail often over general societal needs, which have no or only a minor lobby (e.g., Montiel and Galiana 2005; Weiss 2004). Impacts and consequences of political decisions for forest and environmental management have to be analyzed in a way that biased overemphasis of economic or ecological aspects is avoided and unwanted impacts on environment and society are minimized (Wohlgemuth and others 2002).

As a further complication, changing environmental conditions must be considered in forest management (Martinez de Anguita and others 2008). These might affect the degree of fulfillment of forest functions and might even lead to the unattainability of socially desirable management tasks. An example is the output of biomass for energy production, which depends strongly on regional climate. Changing annual precipitation and temperatures might impact the amount of produced timber, the production time (rotation period) and the production risk.

These facts emphasize the need for tools, which support forest management on landscape level and in context with other land-use forms to balance the effects of possible future scenarios. In this regard, modern forest management might benefit from a scientific view on forest ecosystems and from tools for modeling, decision support, and Information and Communication Technology (ICT). Due to the general complexity of management questions, a system analysis including feedback and dependencies between the different system elements seems to be the most reasonable approach (Wolfslehner and Vacik 2008). The rationale is to combine the strengths of available tools, methods, and models for supporting forest management at strategic and operational planning level. However, the use of support tools in practice requests the acceptance by the user. Systems, which deal with complex questions address often only scientists and run the risk to become too complicated for the end-user in practice (Uran and Janssen 2003). Therefore, consideration of user requirements must be a crucial part of the technical development from the beginning on.

This article presents results of a number of studies dealing with the following questions, (i) major needs in forestry considering management support tools and their most important application areas, (ii) most desirable properties for an optimized management support tool, and (iii) marketing potentials for such tools. The findings were summarized to obtain a broader view on application areas, optimal concepts, and market potentials of management support tools. Every study was carried out with different regional focus. The study "REFORMAN" was funded in the frame of the Era-Net activity SEE with focus on Middle and Southeastern Europe. A parallel analysis with focus on Eastern Europe was carried out in the study "REG-TRANSEKT" within the program "Marketing of research results in Middle, Eastern and Southeastern Europe" of the German Federal Ministry of Education and Research. The regional studies "IT-REG-EU" (INTERREG III a) and ENFORCHANGE (Sustainable Forestry, German Federal Ministry of Education and Research) complemented the analysis with focus on the Euro Region Neisse (Czech Republic, Germany, Poland).

Owing to the different regional focus and extend of the studies, the number and the origin of persons involved are not fully identical. Those who replied on question (i) formed a subset of those who contributed to the market potential analysis (iii). For question (ii) an in-depth analysis was carried out in Germany, Czech Republic, and Poland and the participants formed a subset of those who contributed to question (i) and (iii). The selection of the participants intended to involve users from different hierarchical levels in forest administration or forest enterprises and from forest-related economic and administrative institutions. In addition, it was essential to involve persons, who were willing to contribute to the studies over a longer time period and who could be contacted electronically or by phone/fax by the regional partners. This procedure might have excluded the point of view of those, who were not part of this group. In consequence, the choice of participants was not random and therefore results might be biased.

Case Study Regions and Frame Conditions

Within the above described concerted studies major fields of interest, areas of application, and user needs regarding management support tools in forestry were analyzed. The studies included experts from Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Germany, Serbia, Slovakia, and Slovenia; a few participants were from Poland and The Netherlands (Fig. 1).

A general aim of these studies was to see if differences exist depending on the political and socio-economic background in the countries and the current management system in forestry. An analysis of the impact of differing political and socio-economic frame conditions in the involved countries on forest policies was done on the basis of national reports and additional surveys (Vuletic and others submitted). The legislative frame in each of the participating countries consists of various legal acts. However, these acts define (even in the new member and candidate countries of the EC) very similar ideas of forest management as well as nature protection issues related to national forest policies. The analysis of instruments and tools used in forest legislation shows a broad agreement of forest and environmental policies in the different countries. Regarding the impact of different socio-economic frame conditions in the participating countries, no trend could be found that economic, ecological, or social services are of different importance in the emerging economies in Eastern and Southeastern Europe compared to “old” economies such as Austria or Germany.

As a Europe wide trend a separation of tasks of physically managing forests from the governmental tasks of policy, legislation, and supervision can be observed since more than 25 years (e.g., Ljungman 1994; Pettenella 1994). A detailed description of the resulting different institutional structures and approaches, variation in legal rights and duties between private and public institutions, and also differences in the share of duties between national and local levels exceeds by far the scope of the presented analysis. However, based on the above mentioned national reports, different development states of such a separation

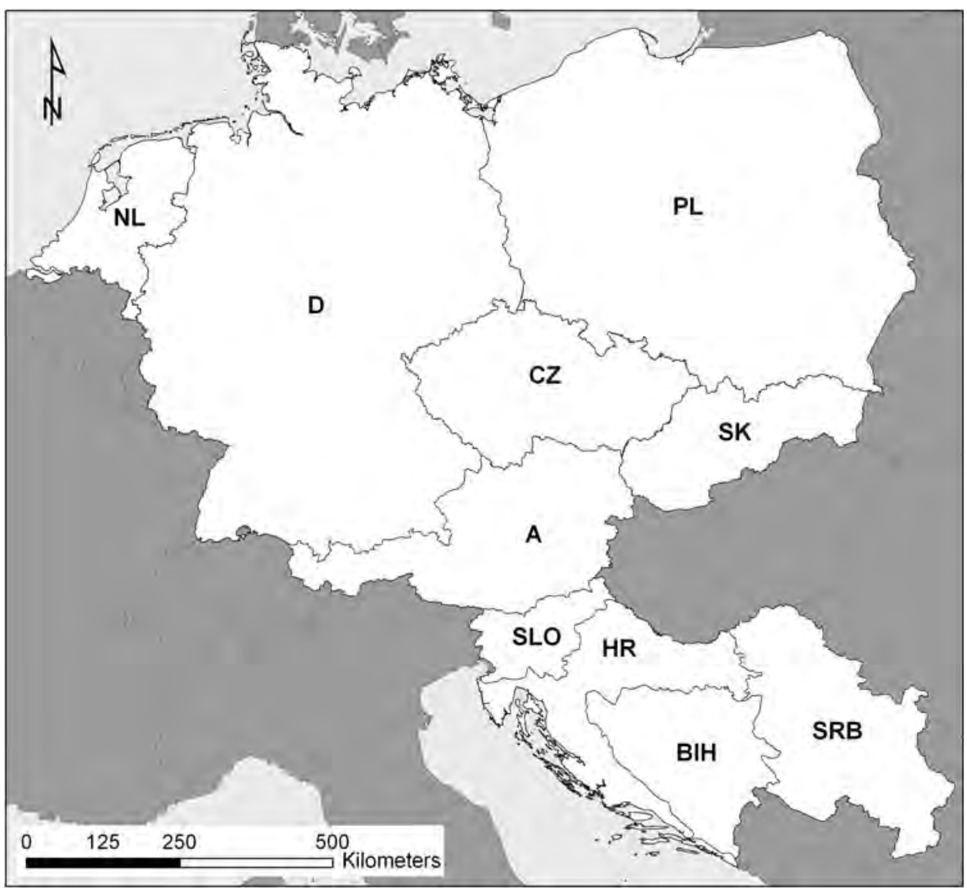


Fig. 1 Countries that were involved in the study series in Europe

could be identified in the participating countries. They result in different the legal forms of state forestry and how and where the supervision and consultancy on non-governmental forests is managed.

Principally, two clusters can be identified, (i) countries with a more or less "traditional" form of the forest administration where management of state forests and support of non-governmental forest owners are not institutionally separated. This applies, e.g., for Czech Republic, Poland, Slovenia, and some federal states of Germany. (ii) In most other countries state forest enterprises have different legal forms, from joint stock companies to public corporations. These institutions are almost exclusively responsible for the management of governmental forests, while supervision and consulting of non-governmental forests is carried out by separate (governmental and non-governmental) institutions. Within the scope of the presented studies, the question was raised if differences between these two clusters can be observed regarding the use of management support tools and the used types of management support tools.

Analysis of User Demands

Analysis of Major Application Areas Where Management Support Is Needed

Possible areas of interest for supporting forest management were analyzed in a discursive process, using mind-mapping techniques (Buzan 1995) in two regional workshops. These were held in Croatia with a focus on participants from Central and South-Eastern Europe and in Slovakia with focus on participants from Eastern Europe. A total number of 27 participants contributed to this analysis. The majority came from national forest administrations or state forest enterprises and some from agencies and NGO's dealing with forestry and environmental management. The participants were asked to express their ideas on present and future application areas for management support. In a second step, the participants had to decide on which scale levels (local/regional or national/EU level) they would assign the identified future application areas. In a subsequent discussion the findings were clustered to more generic terms for the application areas to identify trends for present and future and for local/regional and national/EU wide level.

User Requirements Analysis

The user requirements analysis asked for an optimal solution of a decision support system. This analysis was designed as Delphi study (Cooke 1991; Dalkey and Helmer 1963; Scholles 2001; Turoff and Linstone 1975). In contrast to opinion polls with random choice of the participants and missing opinion feedback, the Delphi approach is thought to obtain a consensus among individuals, which have special knowledge on the issue of interest (EVALSED 2003; Schmidt-Thomé 2005). A further advantage of the Delphi method is the anonymity of its participants, which allows them to interact, rethink, and compare their thoughts in a "non-threatening forum" and thus without being influenced by each other's opinion (Miller 1993). Van Paassen and others (2007) used the approach to develop numeric models facilitating the capability of learning about sustainable land-use in rice-cultivating regions. White and others (2004) developed an empirically based area-type model using the Delphi method. Within the presented study, the Delphi method was applied for an in-depth analysis with a number of selected experts in Czech Republic, Germany and Poland. The three countries share the management planning responsibilities within the Euro region Neisse. This region was chosen as a representative example, since the political situation poses specific demands on regional forest managers and management planners. They are not only forced to consider the legal background and various needs of actors in the national planning process, but they also have to achieve agreement with their counterparts in the respective neighboring countries. Examples for this challenging process are delineation of habitat protection area (Natura 2000, habitat directive 92/43/EWG) or management of forests to mitigate flooding from the Neisse River. In consequence, the interest to be supported by sophisticated management tools is particularly high (Fürst and others 2008).

32 experts from forestry (47%), nature protection (33%), water management (10%) and regional planning including tourism (10%) in Czech Republic, Germany and Poland were involved in this regional study In the first round of the Delphi study three questions were asked.

I. What kind of information sources are you usually using to prepare interdisciplinary planning decisions?
II. Which tools are you using to visualize the planning process and to support your decision?
III. How do you think an optimal support system should look like that helps to prepare the necessary information and support you as a decision maker?

For each question a set of pre-selected alternatives was offered including the possibility to give additional comments. The participants were asked to evaluate the alternatives and their own comments on a scale from 1 (=always most desirable) to 6 (=never/most undesirable). In the second round of the Delphi study only question (iii) was repeated including pre-selected answering alternatives and the possibility to give additional comments. For the second round an evaluation of the results from the first round was prepared and communicated to the participants of the study in the context of a workshop. For those who could not participate in the workshop a document was prepared to enable this group to participate in the second stage of the Delphi study.

Market Potential Analysis

With regard to the market potential analysis the Delphi study outcomes helped to identify some exemplary management and decision support tools. Some selected tools were integrated as test versions or linked with the webpage of the online-questionnaire of the market potential analysis. This comprised GIS-based solutions as well as decision and management support tools on different scale levels for environment, forestry, and agriculture. All examples were offered for testing at the project webpage. The intention was to give the participants examples of different level of complexity to support them in better appraising their willingness to pay for such exemplary solutions.

The market potential analysis was carried out (i) to complete information on major application areas and user requirements and (ii) to get information on the willingness to pay for management support tools. The analysis was designed as one-time survey (Borg and Gall 1989) as online questionnaire. Again, a set of standardized alternatives for answers was offered, including the option of additional free comments. A number of 37 end-users from Central, Eastern and Southeastern Europe participated in this study. The participants were asked 10 questions split into four blocks. The questions in block I coped with the professional background of the participants. Block II was dedicated to conflict fields on local/regional and national/EU level, where management support systems could be helpful. In Block III, the phase in the decision process, where support would be preferred and the preferred technology were asked. The last question block IV analyzed the willingness to pay for different possible types of management support tools.

Results

Analysis of Major Application Areas Where Management Support Is Needed

Results of the mind mapping based identification of application areas were transformed for better understanding into two diagrams (Fig. 2a, b). Application areas were ranked at the abscissa in ascending order according to the number of answers with reference to future application areas. This was done to make better comparable Fig. 2a and b. The latter figure specifies at which spatial scale the future application areas are considered to play a role.

At present the application area "forest management planning" is considered as most important application area and is defined in a very narrow sense according to terms assigned by the participants (Fig. 2a). Still, traditional instruments such as paper-based forest management plans or written documents (operational instructions on Management Planning Unit level) are used and considered as sufficient in the current situation. The application area "landscape planning", i.e., integration of forest management planning into land-use management planning, was the second most important area. All other application areas were ranked much lower. In contrast, the participants see the support of new laws and directives ("law support") as most important application area for a possible management support tool. Terms assigned to this generic term refer mainly to the support of the realization of EU regulations and reflect thus the expected increasing complexity in legal aspects, which must be considered in management decisions.

By comparing present and future application areas a trend is emerging from preferred support in sectoral planning (expressed by the high importance of forest management planning) towards "landscape planning" and integration of multiple stakeholder needs in planning ("participatory planning"). The application area "forest management planning" is believed to loose substantially in importance in the future. Parallel to this finding, "operational decision support" seems to be more relevant at present. The participants saw also a need to address in the future ongoing changes to higher extent, a topic which is not seen to be as important at present. This was expressed by the identification of a future application area "adaptive planning" with specific reference to Climate Change. In addition "policy support" was exclusively identified as a future application area.

By looking at future application areas (Fig. 2b), the participants assigned the application areas "adaptive planning" and "policy support" and also "communication and conflict negotiation" especially on national level/EU level. By comparing results (Fig. 2a, b) it becomes obvious that application areas on national/EU wide level are believed to gain in importance. Those application areas, which are thought to play only a minor role in the future (Fig. 2a) such as "forest management planning", "integrated planning", or "landscape planning" are mostly found on local/regional level (Fig. 2b). An exception is the application area "participatory planning", where higher importance is seen on local/regional level due to an expected increase of the involvement of local and regional stakeholders in the definition of forest management targets on operational level. The participants agreed that the extreme importance of the

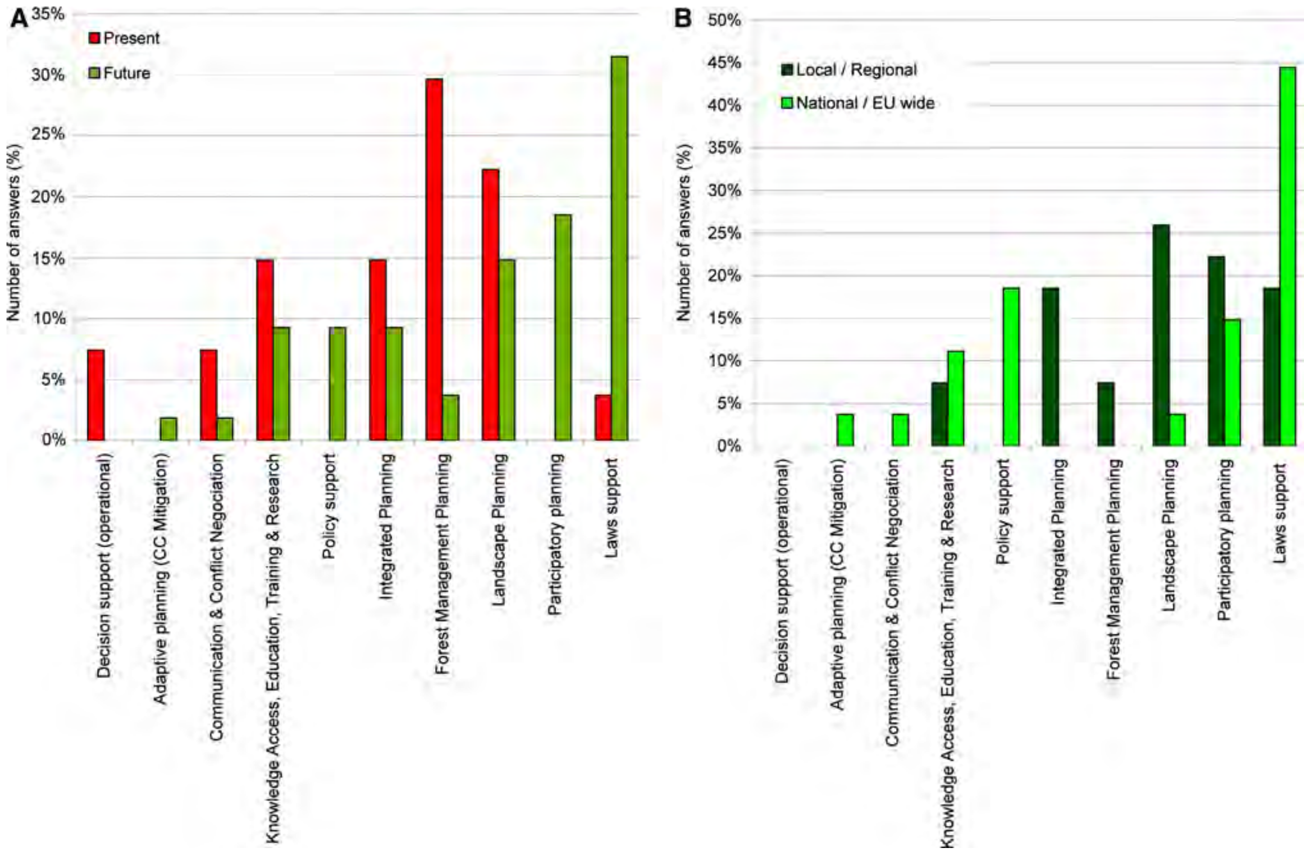


Fig. 2 **a** Application areas for management support at present and future; **b** future application areas for management support on local/regional and national/EU-wide level

support of the implementation of laws and new regulations/directives on national and EU level refers mainly to nature protection (e.g. Natura 2000, Biodiversity Convention, etc.) with a high uncertainty of their impact on forest management planning.

User Requirements Analysis

The Delphi study revealed that multiple information sources are usually used to make decisions without any particular preference (question I). This comprises information from publications, consultation of expert knowledge, web-based information, and personal and institutional experiences. However, in planning and decision processes (question II) computer-based tools and tools supporting the communication with other actors are clearly preferred against paper-based tools, e.g. handbooks or written guidelines. Geographical Information Systems (GIS) and standard Office applications are the most common instruments followed by interactive databases and institution-specific planning software. The analysis showed that professional system solutions for decision support are used very rarely in the participating countries. More frequently, a subjectively composed, "home-made" combination of fragmented solutions (spreadsheets for calculation, mailing for communication, GIS for visualization and spatial analysis) is used, where single components are not or only badly linked. Consequently, the definition of an optimal system (question III) seemed to be very subjective or institution specific in the first Delphi study run. The participants proposed a wide range of desirable solutions and attributes with no preference. In the second run, after learning from the high variability of preferences in the first run, the participants favored online-portals and professional information/expert systems, followed by best practice manuals and electronic decision trees. A consensus on the most important attributes of an optimal management support tool was achieved. An optimal tool according to the participants is characterized by

(i) broad accessibility for users at any time and any place, e.g., provision of an online service or online support.
(ii) the possibility to integrate iteratively experience from case studies and from regional experts as well as future scientific results into the knowledge base of the tool (i.e., learning system). The need to refer the

support as best as possible to real-world conditions and most recent knowledge was emphasized by the participants.

(iii) self-explanatory user interface, as precondition for broad acceptance and use. The system must be suitable for users inexperienced with the use of computer-based tools. This is especially the case on the operational level in management planning, which so far was more or less excluded from the use of electronic or even web-based management support tools.

In summary, an optimal solution was defined to be "a common management support basis for different actors involved in planning decisions, which provides generalized conclusions on the effects of forest management measures in the landscape context".

Market Potential Analysis

The 37 participants of the market potential analysis came from Germany (34%), Slovakia (26%), Czech Republic (26%), Poland (5.5%), Slovenia (5.5%), and Croatia (3%). Most of the participants worked in education (23%) and administration on regional (23%) and national (18%) level. Some work in nature protection organizations (15%) or other NGO's (3%) and as consultants (9%), at public enterprises (6%) and at research organizations (3%). The working position of the participants was mostly connected to research and development (34%), followed by administrative (26%) and management (25%) positions. A lesser number was working in production (6%) as well as landscape protection (3%), landscape planning (3%) and development planning (3%).

The participants identified a clear dominance of conflicts on a local to regional level between infrastructural planning (road construction, housing) and land-use management, including forest management. All other fields of conflict seemed to be of lower importance (Fig. 3a). On a national and European level a broader variety of fields of conflict were considered as important. The conflict of interests between nature protection, land-use management, and forest management seemed to be of highest importance (Fig. 3b). However, these tendencies were less distinct compared to local to regional level. Thus, they provide less information on conflict fields best supported by using management support tools. Figures 3a and b show the quota of answers, which were given to the ranks at each term. The ranking of alternatives was conducted on a scale from 1 (most important) to 5 (least important/unimportant).

Considering the application of management support tools the participants showed a preference to use them during planning and preparatory phase (Fig. 4a). However, the preference trends shown in Fig. 4a are fairly inexplicit. Depending on the stakeholder's main activity areas, also the use in the implementation and planning phases gained importance. The preferred technological solutions were freeware download from internet or free online services. Products and services liable to pay costs were hardly ever preferred and written documents even less (Fig. 4a, b). The ranking of the alternatives was again on a scale from 1 (most important) to 5 (least important/unimportant).

A difference in the needs and aims of two country clusters "countries with traditional forest administration" and "countries with separation of forest administration and forest management" could not be found in the presented study. This was also confirmed by direct discussions with the participants.

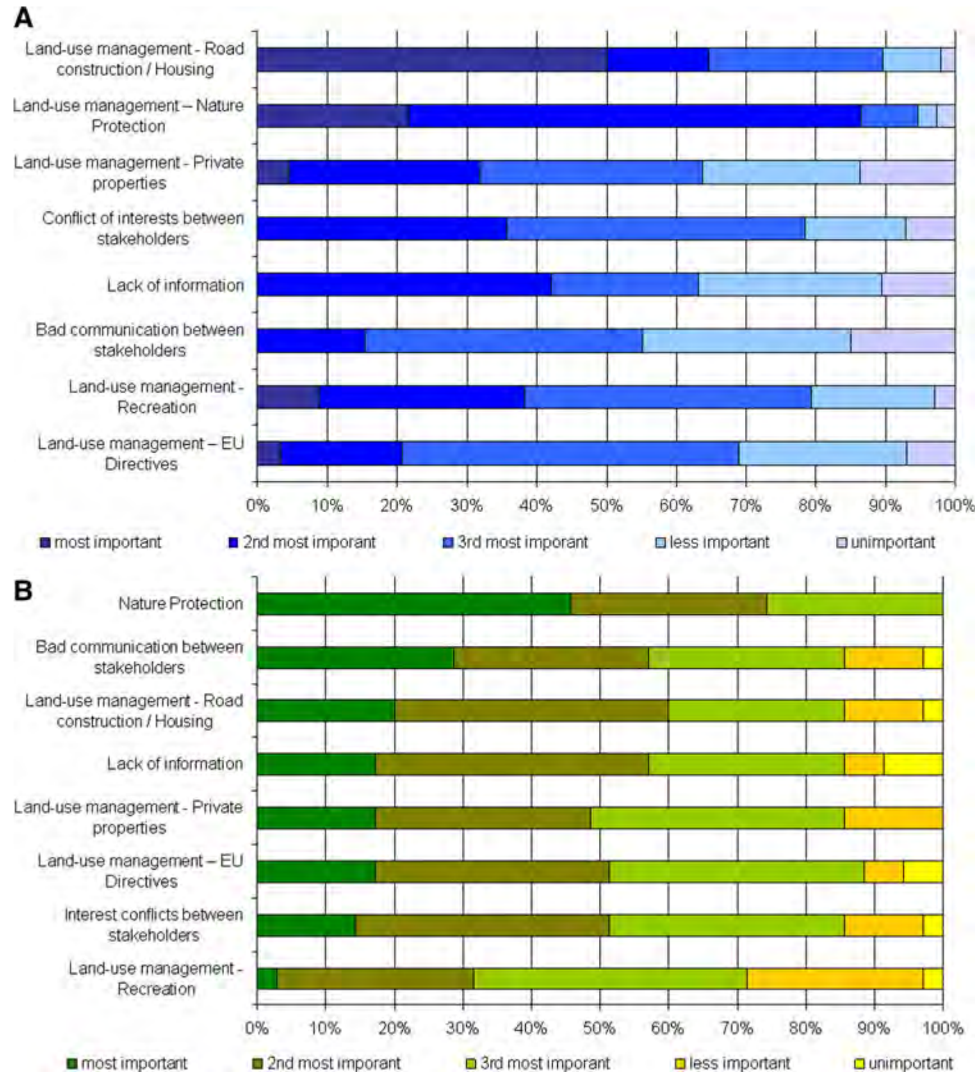
The analysis of the willingness to pay for management support tools revealed that such willingness nearly does not exist. The users had the option to test different tools, which were implemented on the questionnaire webpage and they mostly had a look on them proofed by the clicking rates and session lengths, which were automatically recorded by the system. Consequently, at least basic knowledge on the presented exemplary solutions with different levels of complexity can be assumed. Around 90% of the participants pointed out that they would prefer not to pay for purchasing a management tool or service. If participants are forced to pay for software licenses or services, they would prefer to pay maximally one time to avoid annual or monthly fees. The willingness to pay a lump sum for software was higher than for online services. Participants were even willing to pay up to 1,000 € for a software, but only up to 100 € for an online service. An acceptable sum for a written document, e.g. a handbook amounted to 50 €.

Discussion

The presented studies were carried out to identify trends of user preferences considering the use and the profile of management support tools. An additional aim was to get an idea on possible future research fields in the different participating countries with a focus on Central, Eastern and South-Eastern Europe. However, the concerted analysis of these studies might have led to biased results, since participants were not the same in all studies, but were selected for reasons explained in the introduction.

Consequently, some of the identified trends might be singular and also influenced by subjective needs and experiences of the participants. The rather contradicting picture of use of information sources and in application of management support tools in different phases of the planning process might result from individual preferences of

Fig. 3 **a** Conflict fields on local to regional level; **b** conflict fields on national to EU level



the participants. Other reasons might be heterogeneous working areas and working positions, which result in differentiated responsibilities at the hierarchy levels in planning, decision preparation, and decision making processes (Speier and Brown 1997).

However, other trends seemed to be recurrent in the studies and thus might be considered as generalized. High importance of management support tools for the implementation of laws and new regulations/directives on national and EU level was identified at the application area analysis and goes along with the results of the market potential analysis. On a national and an EU wide level, conflicts between nature protection and forest management planning are identified as the most important area, where management support tools could be supportive. Comparable trends are also reported from other economic branches (e.g., Henle and others 2008). On local and regional scale, a high importance of planning support with regard to conflicts between infrastructural development and forest management was found in the application area analysis and the market potential analysis. This is supported also by results of other studies (e.g., Manners 1981). The trends on conflicts on a local/regional level are more distinct compared to the national and EU level. However, this is not true for the application area preferences at different scale levels. Here, more or less different profiles for management support tools can be derived from the study results. On local to regional level support of interdisciplinary and participatory communication processes in planning and support of linking forest management planning into planning processes on landscape level are seen as important features. On national/EU level the most important trend was the request of an active support (i) of early recognition of possible legal restrictions and consequences of management decisions and (ii) of the development of policies and strategies. ICT tools seem to correspond rather with the management support needs on local/regional level, while scenario simulation and visualization tools seemed to be

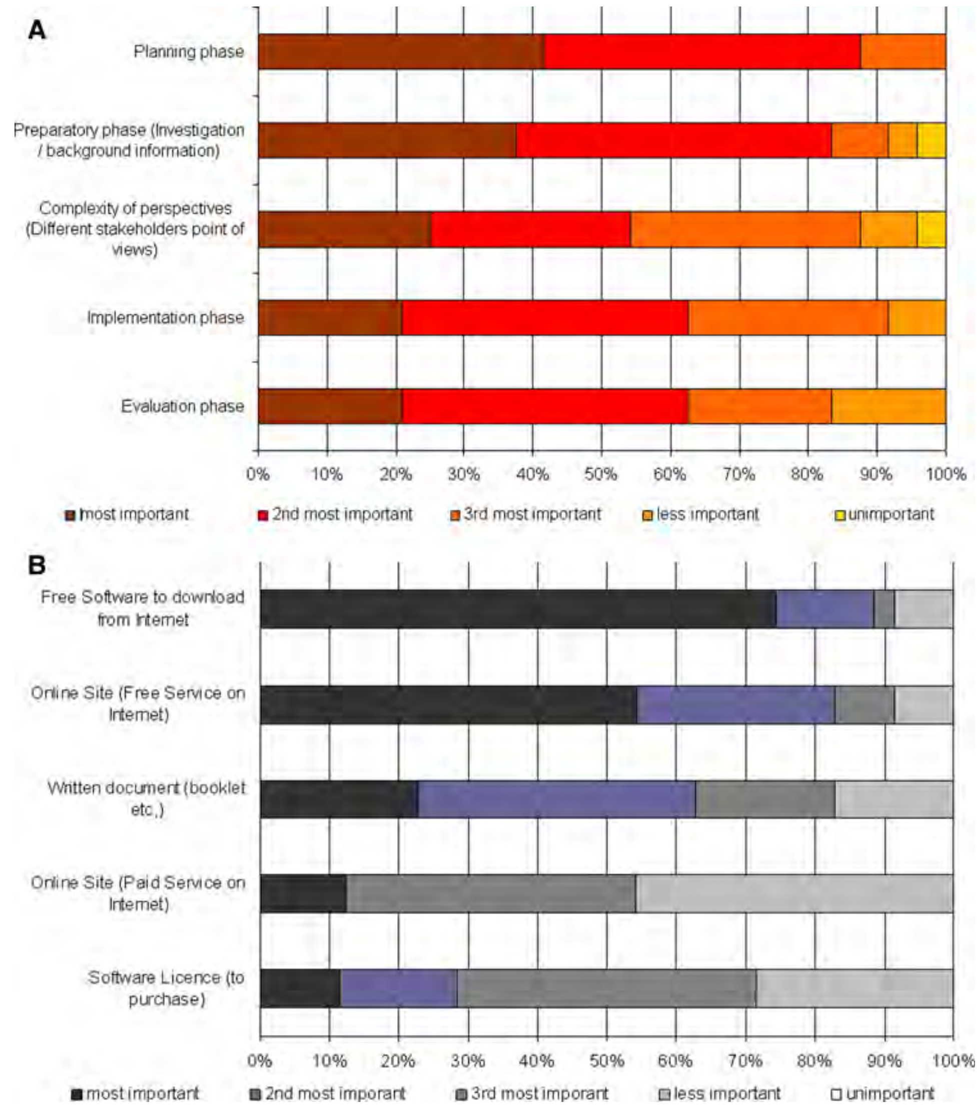


Fig. 4 **a** Preferences of the application of management support tools in different phases of the decision process; **b** preferred technological solutions

more appropriate for management support on national/EU level. A subsequent step to support this assumption would be to test respective tools on different scale levels. However, this would have exceeded by far the scope of the presented studies.

The Delphi study helped to identify some examples for preferable tools and solutions having different levels of complexity, but can be applied on the different scale levels. These tools were offered to the study participants for test to support them among others in specifying their willingness to pay in the market potential analysis. The results on desirable attributes of an optimal tool at the user requirements analysis and the market potential analysis add very well. However, the described preselection of examples might have had an influence on the participants and their opinion. The participants in both studies preferred computer-based tools, which support interaction and communication in planning processes over paper-based tools. This goes along with the statement of the application area analysis that at present, mostly paper-based tools such as the "simple" forest management plan and not the "desired" interactive instruments are in use (see also Matthies and others 2007)—at least in the participating countries. In consequence, the free access to computer-based support instruments is a consistently repeated demand in both studies. The preference of cost-free solutions and low willingness to pay for support unify the participants of the user requirements and the market potential analysis. This is not so much a result of a lacking awareness of possible benefits of such tools. As shown in our studies, the participants specified very clearly their needs and ideas on desirable solutions. But very often, the offered solutions do not correspond to the need of simple handling and navigation (Uran and Janssen 2003). The low willingness to pay for support should thus be seen rather as unwillingness to pay for products with a lack of user friendliness and relevance. Different "home-made" forest GIS (Geographical Information System) or MIS (Management Information System) solutions are developed or under development by the forest administrations and state forest enterprises. For example, the participants of the study reported that a combination of digital site maps, results from forest inventory and data from growth and yield tables or forest growth models is often used to predict timber resource development under different management scenarios. However, these very specific solutions do by far not meet the criteria for a decision or management support tool. They are often preferred because their actual cost of development and adaptation are not accounted as additional financial effort. The maximal amounts of money the participants are willing to invest of up to 1,000 € for software, 100 € for online services and 50 € for handbooks are realistic compared to marked prizes for software or books and reveal a latent existing openness for suitable products. A contradiction seems to exist between the finding of the user requirements analysis that online tools are by far preferred and the lower amount and willingness to pay for them compared to software tools. This should be seen in the light of financial planning at state run or state associated institutions and the subjective whish of the participants to sustain an achieved comfort over a longer period. Once software is installed, it can be used independently from budgeting, while the financial means to sustain an online-service must be included actively in the yearly budget. This depends strongly on financial return by harvesting or provided services and on administrative rules and political decisions.

The missing differences in the user requirements between the two clusters "countries with traditional forest administration" and "countries with separation of forest administration and management" might be owed to the fact that reforms of the more traditional solution a forest administration are also discussed. Vuletic and others (submitted) neither found a strong impact of differing socio-economic frame conditions on the valuation of forest functions and services, nor big differences in the legislative frame, which specifies tasks for forest management and nature protection issues in forestry.

It seems that a more or less common understanding of forest management tasks, possible future challenges and resulting user needs in management support is developed in the countries participating in the presented case studies.

Maxim and van der Sluijs (2007) identified six criteria for quality test and confirmation of a case study for checking the quality of the knowledge produced, which could also be applied on the results of the presented studies.

i. Reliability of information: => in all cases, information was based on the existing and available scientific knowledge.
ii. Robustness of information: => criticism by the participants were taken into account.
iii. Use of information produced by other stakeholders: => here, a shortcoming of the study can be identified as only selected stakeholders were integrated.
iv. Relevancy of arguments for targeted subjects: => the relevance was ensured by prevailing and parallel analysis of ongoing research and by the implicit consideration of stakeholder's points of view in the different studies.
v. Logical coherence of the discourse: => the different studies and analysis were conceived in a complementary way and the results were not contradictory.
vi. Legitimacy of the information source: => in all three studies, participants shared a special interest in forestry and forest management planning. All of the participants are faced with the multiple aspects and challenges of forest management planning on sectoral and trans-sectoral level.

Conclusions

A future need for computer-aided management support tools in forest management planning was identified in the presented studies. This is a result of an increasing number of actors in planning processes and an increasing complexity of information and considerations, which must be integrated in forest management decisions. The participants emphasized their need to be better supported especially in the implementation of laws, regulations, and directives in management planning. In addition, they identified the interest conflicts between (i) forest land-use and nature protection on national and EU level and (ii) forestry and infrastructural planning on local and regional level as a major reason for the need of improved management support solutions. Although, the participants pointed out a low willingness to pay for respective tools and services. Until now, increasing complexity and uncertainty in planning is a future threat in forestry. Existing management planning instruments are still considered as sufficient to address the current and future challenges. So far, no public pressure exists to prove the specific advantages of a management decision in the light of other alternatives. "Home-made" support solutions might give a feeling to be well prepared despite they support only partly increasingly complex processes in decision making.

Comparable marketing potential analysis for environmental management support tools can be found only rarely (e.g. Asgary and others 2007) and are not existent for forestry. Therefore, it was not possible to compare or validate the identified trends. However, as a well-known economic rule the willingness to pay for future benefit is at all times very low. If a willingness to pay exists, it is mostly rather hypothetical (see e.g. Blumenschein and others 2001, Price 2007).

The discrepancy between the willingness to pay for management support tools and the identified future needs in using such tools suggest a need of alternative solutions for the mutual benefit of research and practice. A reasonable model could be the combination of freely available products and services with sponsoring or advertisement activities. A cost-differentiated access could be discussed, which guarantees a free access to basic solutions and a staggered fee for solutions with widened usage and application areas as yet realized in numerous web-based services. Finally, a future challenge for research is to develop generic solutions, which diminish the costs for their adaptation to different application areas and thus make development more efficient and accessible to a broader group of users. Here, the argument of a generic system standard with standardized interfaces to existing data pools and the hereby possible exchange with others users would also be a major factor to overcome the natural skepticism of users from practice against scientific solutions.

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SPECIAL FEATURE

Squaring the Circle? Combining Models, Indicators, Experts and End-Users in Integrated Land-Use Management Support Tools

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Abstract The most important challenges faced in the field of integrated land-use management are (i) harmonizing and integrating different datasets, (ii) selecting appropriate indicators, (iii) fitting suitable models to adequate scales, and finally (iv) integrating data, indicators and models into systems that allow both a high level of participation and flexibility with the adaptation to a variety of questions and applications. The articles of this special issue "Squaring the Circle? Combining Models, Indicators, Experts and End-Users in Integrated Land-Use Management Support Tools" demonstrate the challenges that are related to this topic. The case studies present examples of such integrated systems in order to recommend best practices to support land-use management and to reveal existing shortcomings. As a conclusion, seven features of a successful applicable integrated land-use management support system are derived: (1) ability to deal with discontinuity in information and datasets, (2) contribution to solve the problem of indicator diversity, (3) structuring the decision-making process, (4) support of participation processes in generating decisions, (5) development, comparison and evaluation of land-use alternatives, (6) assessment of the efficiency and trade-offs of management options, and (7) assistance of stakeholders in group communication processes.

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Keywords Land-use management · Decision support tools · Participatory planning approaches · Stakeholder needs · Impact assessment

Introduction

Land-use management is a multidisciplinary field that is confronted by an increasing level of complexity. Issues such as cross-sectoral policy making (e.g. agriculture, forestry), land-use planning and integrated ecosystem service management (e.g. water management, nature protection, tourism) make it necessary to involve multiple stakeholders (Sterk and others 2009). Increasing demands from a public that is scrutinizing decision-making regarding land-use management and its effects on environmental conditions and ecosystem services add additional complexity (Messner and others 2006; Newham and others 2006; Milligan and others 2009). In a society characterized by globalization effects, large scale interactions between agencies and institutions at an international level influence decision-making even at a local level.

As a consequence of such multiple and sometimes confusing interactions, land-use management decision-makers are being confronted with an increasing number and diversity of rules, regulations and directives. This circumstance often poses problems with the application at different spatial scale levels—from the global to the continental level and from the continental to the national, regional and local level, respectively. This means that the scale of integrated land-use management (including analysis, modeling and assessment) is not restricted to the global level, but includes local and regional models of ecosystems and environmental processes (Parker and others 2002). Sectoral models at the local and regional level (e.g. agriculture and forestry) generally neglect interactions with other land-use types, and oftentimes ignore landscape structure aspects and spatial interactions of different land-use types, which are critical for a proper understanding of environmental processes; such models are often not compatible in their temporal and spatial resolution (Parker and others 2008; Baskent and Keles 2005; Botequilha Leitao and Ahern 2002).

Another well-known reason for an increase in the complexity of land-use decisions is the dynamic nature of the environmental parameters (climate, site conditions, etc.), which leads to uncertainties regarding their interactions (e.g. interactions between climate change and changes in ecosystem processes), and the rate and extent of change (Matthies and others 2007). Moreover, environmental data are officially available, access is often difficult (Allan and others 2006; Volk and others 2008), and data bases focused on different scale levels and land use categories are often incompatible.

Furthermore, the selection and interpretation of suites of sustainability indicators, some of which are focused on aspects of land-use change, can send ambiguous signals to land-use managers. There is an excessive number and variety of indicators to assess the impact of human activities on the environment at different scales—which leads to problems with the interpretation and harmonization of these indicators and oftentimes limits their usefulness in support of land-use management decisions (see e.g. Wijewardana 2008).

Another problem relates to the impact of the growing diversity of regulations with increasing temporal dimensions in management planning. An example is forest management planning with its division into strategic (long term = at least one rotation period) planning, tactical (mid-term = up to 30 years) planning and operational (short term = up to 10 years) planning (Baskent and Keles 2005). Strategic planning in forestry must necessarily respect development, resource provision or protection targets from politics and society. Once a strategic decision such as conversion of coniferous into deciduous forest stands is made, tactical and operational planning are forced to translate this decision into concrete planning measures and operations. In case, a strategic decision must be revised due to new, complementary or competing regulations, managing the tree species composition and stand structure according to a new strategy is difficult or takes at least several decades.

Challenges

Integrated land-use management assimilates in a comprehensive manner methodological approaches in management and evaluation from different land-use sectors. Appropriate management requires (i) harmonizing and integrating different datasets, (ii) selecting the right indicators, (iii) fitting the right models to the right scale, and (iv) integrating data, indicators and models into systems that allow both a high level of participation and flexibility in application to different questions. This seems to be comparable to the challenge of "squaring a circle". Squaring a circle is used here as a metaphor for doing something logically or intuitively impossible as it was in the ancient world the construction of a square with the same area as a given circle by using only a finite number of steps with compass and straightedge (see e.g. Hobson 1913).

Numerous approaches have been developed and are still being developed to promote an integrated land-use management. Originally developed to support business managers, decision support systems (DSS) have attracted much interest in the field of environmental management. Environmental decision support systems and procedures that combine multicriteria analysis (MCA) or optimization tools with models usually involve the integration of a broad information base. They are becoming increasing user-friendly, through careful user-needs analysis in the development phase and through the use of sophisticated stakeholder participation approaches in their application. Agent-based modeling and participatory approaches in the generation of tools and systems reflect the rising complexity of land-use management and the objective of arriving at integrated instead of segregated management concepts (Becu and others 2008; D'Aquino and others 2003; Parker and others 2003). Various integrated assessment and landscape modeling techniques are increasingly being applied as tools in support of land-use management or environmental and river basin management (see e.g. Janssen and others and Volk and others in this issue; Giupponi 2007; Newham and others 2006; Volk and others 2008). The complexity inherent in socio-biophysical systems and the various sources of uncertainty add further complications to such management, which faces a trade-off between the attempt to simplify the intrinsic complexity of such management planning, the need for scientifically robust approaches and detailed high quality data. Provision of transparent communication interfaces whenever public participation is considered, is a common challenge in DSS development (Matthies and others 2007).

Integrated landscape management tools that address this complexity pose the risk of getting too complicated for the end-user or even for the expert, and thus of never being used in practice. Giupponi (2007) states that despite the many DSSs developed in the field of environmental management, the risk of such systems failing to meet the challenge of real-world problems is reported to be high, and even the criteria for judging whether a DSS has been successful or not are often a matter for discussion (e.g. Newman and others 1999; Zapatero 1996; Uran and Janssen 2003). Giupponi (2007) emphasized that there is a widely recognized need to develop new support tools for decision-making in this field, with greater attention to the needs of potential users and to identification of the application context. The typical rationale behind the development of these tools is to increase the overall benefit of land-use through improved planning and prioritization of objectives. However, a predominantly scientific focus on the development of these techniques has the potential to obscure the practical realities of land-use management and to result in a lack of acceptance and adoption of both the systems and their output (Diez and McIntosh 2009; McIntosh and others 2007; Malczewski 2003). This can result in management tools having minimal impact on decision-making and management support.

In the process of integrated assessment and modeling, participation of stakeholders involved in land-use management is a crucial element for success. Stakeholders need to be able to provide feedback throughout the entire integrated assessment and modeling process to ensure tools to support decision making and land-use management and the results thereof are suitable for their needs. Likewise, researchers, including model developers, need to be able to acquire knowledge from communities and organizations with statutory responsibilities through participatory approaches.

Aim and Scope of the Special Issue

The Special Issue addresses the challenges of integrated land-use management supported by multidisciplinary landscape modeling and the use of suitable indicators and upscaling techniques. Several examples with different foci are presented by the authors. Challenges are described and conclusions are drawn about best practices for use in land-use management support. The articles focus on forest landscapes in Europe and highlight participation processes that aim to link scientifically-oriented models, stakeholders and an interested public at different planning and management scales. This is illustrated with the generic land-use management support system presented by *Fürst and others* in the last article of the Special Issue. This system can be used to combine multiple indicators, model output and end-user needs in a flexible way.

The first article by *Volk and others* deals with the progress with decision support systems in landscape and river basin management. They analyzed the benefits and shortcomings of the recently developed decision support systems (DSS) FLUMAGIS, Elbe-DSS, CatchMODS, and MedAction. The analysis focuses on (i) application area/ decision problem, (ii) stakeholder interaction/users involved, (iii) structure of DSS/ model structure, (iv) usage of the DSS, and (v) the most important shortcomings. On the basis of this analysis, they formulate four criteria that they consider essential for successful use of DSS in landscape and river basin management. The efficiency and applicability of these approaches is discussed and suggestions are presented to overcome existing problems. *Wolfslehner and Seidl* review the state of the art in forest ecosystem modeling and multicriteria decision analysis in the context of forest management planning. They identify two major challenges in a harmonized application of forest ecosystem models and multicriteria decision analysis (i) the design and implementation of an indicator-based analysis framework capturing ecological and social aspects and their interactions relevant for the decision process, and (ii) holistic information management that supports consistent use of different information sources, provides meta-information as well as information on uncertainties throughout the planning process. *Janssen and others* present a generic, integrated bio-economic farm model with its linkage to other models at field, regional and market scales. They assess with their models the socio-economic and environmental effects of policies on farm management and production.

In the following articles, some examples and case studies are presented, which analyze and discuss options and restrictions in land-use management support. To support management decisions, a set of suitable indicators is required and local information must furthermore be up-scaled to a landscape level. *Zirlewagen and v. Wilpert* demonstrate how to scale up ecological processes in order to better supporting their integration in forest management decision-making processes. The issue of which indicators can be considered as relevant for management support under changing environmental decisions is raised by *Fürst and others*. They introduce a screening method for better integrating the state and impact of environmental pollution in sensitive forest management decision-making processes. *Moravčík and others* discuss a model for the assessment of forests according to the degree of their naturalness. They considered the degree of forest naturalness as a basic criterion for the determination of the nature-conservation value of forest ecosystems. They identified the (i) possibility to restore and (ii) the possibility to improve the naturalness of less natural forest ecosystems, (iii) the occurrence of the endangered species, and (iv) the occurrence of other natural values as further decision-making criteria.

Three contributions by *Lorz and others*, *Vuletic and others* and *Fürst and others* illustrate, for a case study in Central and South-Eastern Europe, how environmental and societal parameters and dynamic development of landscapes, environment and society can be integrated into adaptive management support tools required by planning.

Natural and socio-economic conditions are compared for Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Germany, Serbia and Slovenia as a basis to interpret differences and similarities in stakeholder preferences for decision and management support tools. Results from surveys of forest management relevant stakeholders are used to define a common understanding in best practices in management support. Conclusions and recommendations are made for country-specific policies that consider international policy processes and experiences of other countries.

One of the greatest challenges in land-use management decision support is the integration of locally or regionally specific information. Such knowledge has to be integrated into a generic framework, where the input delivered by sectoral models, statistical data, monitoring information or expert knowledge has to be compatible to the information needs on the landscape level. A precondition for this procedure is a hierarchical evaluation and interpretation approach, which moderates between different levels of detailedness and complexity of information for decision making. *Fürst and others* present a system that combines a cellular automaton based modeling approach for simulating land-use changes with GIS functionalities for integrating different land-use change scenarios and a multicriteria evaluation approach. Model outcomes, statistical data and monitoring information are used as a knowledge base to describe the impact of different land-use types and land-use practices on a set of selected ecosystem services. Knowledge gaps are filled by a stepwise integration of regional expert knowledge and stakeholder perception. An exemplary application case in developing a regional climate change mitigation strategy leads to the conclusion that the evaluation process and results have high regional acceptance and that the results of simulated different land-use scenarios are considered as reliable by the planning actors.

Conclusions

The articles presented in this special issue cover a broad variety of integrated land-use management support tools on different scales, from DSS development and application in river basin and landscape management, to integrated bio-economic farm management tools, to forest ecosystem analysis, modeling and management, and regionally specific adaptive land-management tools. Concluding from these articles, and several other studies (Alkemade and others 1998; Harremoës and others 2001; McCown 2002; Parker and others 2002; Uran and Janssen 2003; Giupponi 2007; Van Delden and others 2007; Van der Sluijs 2007; Voinov and Gaddis 2008; De Kok and others 2008; Hewett and others 2009), an integrated land-management system that is able to cope with the present and future multifaceted challenges should fulfill the following preconditions. It should:

- be able to deal with discontinuity in information and datasets and bridge information gaps through active integration of scale-appropriate (local, regional) experience from experts and stakeholders;
- create a standardized list of indicators, which supports customizable indicators applicable on local to regional level that are consistent with the generic list in the sense of a nested approach;
- support the user on structuring the decision-making process and apply an appropriate conceptual approach (modeling vs. expert systems);
- support participation processes in generating decisions, management options and system understanding by means of user-friendly communication approaches such as visualization instead of simply presenting tables or parameter values;
- help to develop, compare and evaluate alternative management options (on the basis of a pool of options);
- help to assess the efficiency and trade-offs of possible management strategies on the basis of available information (data and experience);
- assist different stakeholders or stakeholder groups to balance and estimate their preferences.

One single tool that fulfils all these preconditions might not yet exist and remain a vision. But the articles presented in this special issue showed that there are already tools available that bundle some of these features. They force the development in this direction and revealed still existing shortcomings. This might improve the acceptance of such tools in land-use management planning and decision processes. The main objective of this process has to be the support of sustainable land-use management to overcome the still valid findings of FAO (1999):

"Planning and management of land resources are integral parts of any rural development programme as well as many development programmes with both rural and urban components. Land use does not consider agricultural uses only but also encompasses natural areas, forests, watercourses and urban areas among others. Land-use planning has often had negative connotations because it was traditionally associated with top-down procedures. […] Conventional land-use planning has frequently failed to produce a substantial improvement in land management, or to satisfy the priority objectives of the land users. As a result, rural development programmes have had mixed success in meeting production and conservation aims."

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#6 Fürst, C., König, H., Pietzsch, K., Ende, H.P., Makeschin, F. (2010c): **Pimp your landscape - a generic approach for integrating regional stakeholder needs into land-use scenario design and sustainable management support**. Ecology and Society 15(3): 34, 25 pp.

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Research, part of a Special Feature on Landscape Scenarios and Multifunctionality – Making Land Use Assessment Operational

Pimp Your Landscape - a Generic Approach for Integrating Regional Stakeholder Needs into Land Use Planning

Christine Fürst [1], *Hannes König* [2], *Katrin Pietzsch* [3], *Hans-Peter Ende* [2], *and Franz Makeschin* [1]

ABSTRACT. This article introduces *Pimp your landscape*, a tool that was developed for evaluating the effects of changes in land use patterns. The main application field is to support interactions and communication among actors in spatial planning. With this tool, different land use pattern alternatives can be visualized in a short time, and their impact on land use services can be evaluated immediately. Also, spatial training and environmental education with regard to sustainable land use management can be supported. The tool was developed in an iterative process, in close cooperation and over intensive exchanges with end-users. A resulting feature is the provision of two different modi oriented on the professional background and skills of the users. The biggest advantage of *Pimp your landscape* is the simple entry and handling. However, the system also offers the possibility to go in-depth and work with complex rule sets. The presented paper introduces the development background and development process of *Pimp your landscape* and describes the tool's resulting concept and actual usage. Finally, possible constraints of the use of the system and potential workarounds are discussed.

Key Words: *Evaluation of land use pattern changes; generic approach; land use management support; rule setting options; spatial planning; user requirements analysis; visualization of land use pattern changes*

INTRODUCTION

The status and functioning of landscapes are affected by political, economic, and demographic frame conditions (Schneeberger et al. 2007). New or modified environmental challenges are occurring due to worldwide climate trends, changing economies, and increasing societal needs as in, for example, Eastern Europe or the *BRICs*. *BRICs* is an acronym that refers to the fast-growing developing economies of Brazil, Russia, India, and China (Wilson and Purushothaman 2003). Furthermore, single land use types at the landscape level, such as forest ecosystems, are often characterized by a severe disturbance of their natural dynamics and by the fast development towards a new balance that likely has low stability and resilience (Dorren et al. 2004, Wilby et al. 2006). This dynamic development affects the fulfillment of socially requested functions, goods, and services, and must be considered in landscape planning (Bengtsson et al. 2000, Jessel and Jacobs 2005). In European landscapes, competing planning targets from directives such as Natura 2000 (including Species Protection Directive 79/409/EWG and Habitat Protection Directive 92/43/EWG), the European Union (EU) Water Framework Directive (2000/60/EG), the EU Drinking Water Directive (98/83/EG), Environmental Pollution/IPCC Directive (96/61/EG), NitrateDirective (91/676/ EWG), Waste Water Directive (91/271/EWG), and the Soil Protection Strategy form additional sources of conflicts, especially when the prioritization of respective functions and services is demanded (e.g., Parker et al. 2008). Most of the resulting environmental or land management-related problems can be characterized by generalizable processes and temporal-spatial patterns (With and King 1997, Rounsevell et al. 2006b, Schmit et al. 2006, Gardner and Urban 2007). Differing regional and trans-

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regional patterns are resulting from the local, regional, and national differences in the socioeconomic targets of landowners and land users with regard to ecosystem protection and resource production.

A need to design multifunctional landscapes can be identified. Multifunctional landscapes ensure, for example, flood prevention and an appropriate drinking water supply, provide space for natural biodiversity and infrastructural development, and enable protection and production targets to be met at the same time (Haigh et al. 2004, Rounsevell et al. 2006a, Wilby et al. 2006). In terms of multifunctional land use, Wiggering et al. (2003) stress three points that are relevant for successful rural planning: (a) a demand- and goal-oriented identification of land use services, (b) a participative character of negotiations over possible land use combinations involving all relevant groups, including the scientific community, and (c) an iterative character of the decision-making process, which enables uncertainties to be tolerated on the one hand and adaptation to emerging information and knowledge on the other.

As a result, contemporary land use management requires dealing not only with complex questions but also with various needs of different actors or actor groups involved in the planning process (Letcher and Giupponi 2005, Niemelä et al. 2005, Dragosits et al. 2006, Kallioras et al. 2006). Therefore, there is a demand for instruments that are able to deal with challenges such as the fragmentation of information and missing data communication standards, and that also allow for complex knowledge and experience management (Wiggering et al. 2006, Mander et al. 2007, Van Delden et al. 2007). The concept of land use functions (LUFs) as developed in the EU funded Integrated Project SENSOR (Helming et al. 2008) considers such complex demands. The LUF framework focuses on functions, goods, and services that are provided by different land use types and that address the most relevant economic, environmental, and societal issues of a region in an integrative way. The LUF framework can be used for sustainability impact assessment at the regional level in an integrated and balanced way (König et al. 2010, Uthes et al. *in press*). The LUFs framework makes it possible for policy makers, scientists, and stakeholders to identify functions, which are reduced or enhanced under various scenarios of land use change, and to explore the trade-offs between them (Pérez-Soba et al. 2008, Schößer et al. 2009). The LUFs framework can be adapted and modified for visualizing and communicating possible impacts of land use changes to the multifunctionality of regional landscapes.

Approaches to developing environmental decision support systems or to combining multi-criteria analysis with modeling and simulation tend to integrate a broad information base and increase user-friendliness by sophisticated participatory approaches (Walker 2002, Mendoza and Prabhu 2005, Matthies et al. 2007). However, Uran and Jansen (2003) point out that there is a risk that the use of such systems is too complicated for a nonprofessional end-user, and that their application area is thus restricted to scientific purposes and professional users.

With these considerations taken into account, the software *Pimp your landscape* was developed in the frame of the INTERREG-III-a project *IT-REG-EU* (Integrated Trans-Regional Land use Decision-Support in the Euro Region Neisse). The software was conceived as an online platform for visualizing and communicating complex interdependencies between land use pattern changes and land use services. The tool supports the participatory development of regional land use change scenarios by strengthening the integration of regional stakeholder needs in land use planning conflicts between forestry, water management, nature protection, and tourism (Fürst et al. 2008, 2009).

The objective of *Pimp your landscape* was to use a generic approach to simulate interactions and processes at the landscape level, and to translate them into rule systems, which can easily be adapted to variable regions and application cases (e.g., Holzkämper and Seppelt 2007). The name *Pimp your landscape* was chosen to intrigue end-users and to motivate them to test the tool. This paper introduces the methodological background and development process of *Pimp your landscape*, and describes the resulting concept and usage of the tool. Finally, possible constraints and how to deal with them are discussed.

METHODOLOGICAL BACKGROUND AND DEVELOPMENT PROCESS OF PIMP YOUR LANDSCAPE

Development background, user requirements analysis, and development process

The regional development background of *Pimp your landscape* was characterized by border-crossing land use management and planning conflicts, which were studied as a test in the Euro Region Neisse. This region is situated in the border area between the Czech Republic, Germany, and Poland. Multiple stakeholder groups from forestry, water management, nature protection, and tourism are forced to cooperate for the realization of EU directives such as Natura 2000 and the EU Water Framework Directive. However, these groups also compete by addressing the same areas for different land use targets. Thematically oriented expert groups (EUREX working groups) in traffic, economy, tourism, water, forestry, crisis management, health, history, statistics, and education form the most important platform for exchange and discussion. Representatives of these working groups were consulted for the conception and development of *Pimp your landscape*.

The development process of *Pimp your landscape* was conceived as an iterative approach. Figure 1 shows the different development steps, including the applied methods, the number of involved end-users, and experts and the outcome for each subsequent step. At the beginning of the development process, 47 experts from the Czech Republic, Germany, and Poland were contacted based on recommendation of the common office of the three-country council of Euro Region Neisse. The recommended experts represented the most important stakeholder organizations in regional resource management and regional planning, and were expected to contribute their experience to the conception of the intended software. Fifteen experts did not have enough time to contribute, but 32 experts confirmed their participation. The confirmed participants came from forestry (47%), nature protection (33%), water management (10%), and regional planning, including tourism (10%). Twenty-one experts who were involved in the first step also participated in the live test. Additional test persons were involved in the second test run based on recommendation of the original participants. Only the persons in step IV (the application phase) were totally different, as the system was tested by them in the context of follow-up activities. These follow-up activities are not described in detail because they did not influence the concepts and results presented here.

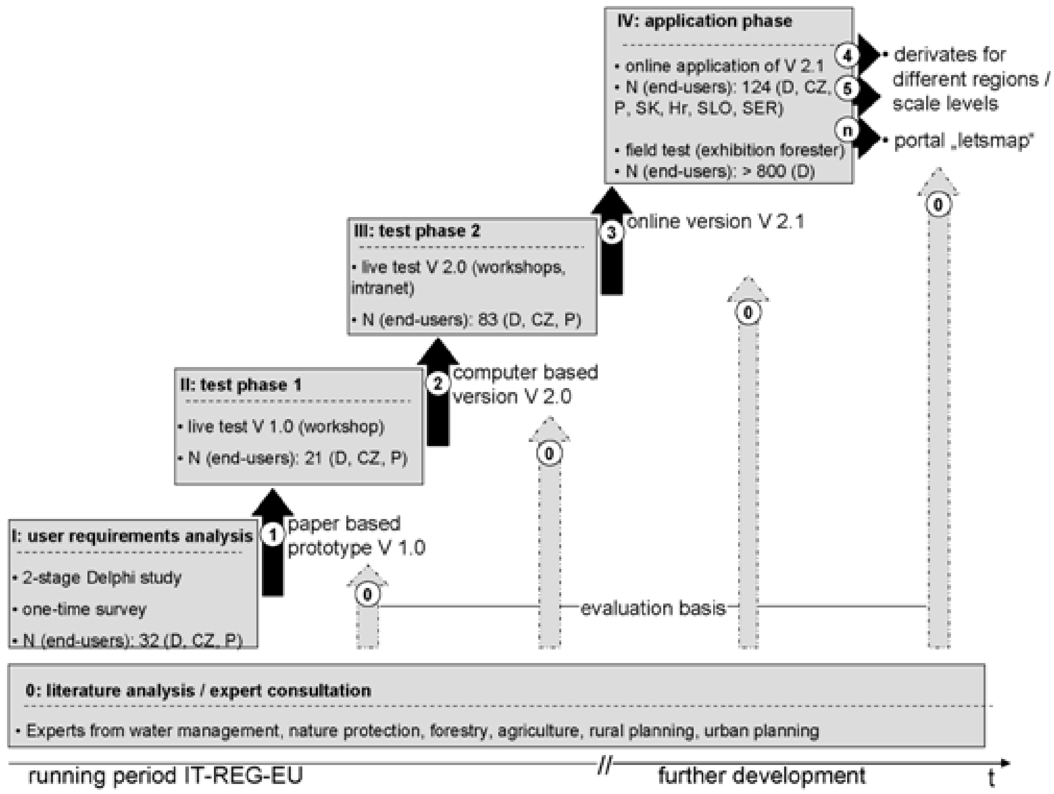
The software conception began with a Delphi study-based user requirements analysis on how to design an optimal management tool (Dalkey and Helmer 1963, Turoff and Linstone 1975, Cooke 1991, Scholles 2001). In contrast to opinion polls, which use a random choice of participants and lack opinion feedback, the Delphi method is thought to obtain consensus among individuals who have special knowledge of an issue of interest (EVALSED 2003, Schmidt-Thomé 2005). Van Paassen et al. (2007) use the approach to develop computer models that facilitate the capability of learning about sustainable land use in rice-cultivating regions. White et al. (2004) developed an empirically based area-type model with the assistance of the Delphi method. Regarding the regional frame conditions under which *Pimp your landscape* was developed, the method was considered appropriate to address the experts in the EUREX working groups. A further advantage is the anonymity of Delphi participants, which allows them to interact, rethink, and compare their thoughts in a “non-threatening forum” without being influenced by each other’s opinion (Miller 1993).

In the first round of the Delphi study, the following questions were posed (in each participant’s respective national language):

(A1) What kind of information sources are you generally using to prepare interdisciplinary planning decisions?
(B1) Which tools are you using to visualize the planning process and to support your decision?
(C1) What do you think an optimal support system should look like for it to prepare the necessary information and support you as a decision maker?

For each question, a set of pre-selected alternatives was offered (Table 1). The participants were asked to evaluate the alternatives on a scale from 1 (= always/most desirable) to 6 (= never/most undesirable). Further alternatives could be proposed by the participants and were ranked on the scale from 1 to 6. In round 2 of the Delphi study, only question (C1) was repeated.

Fig. 1. Development process of *Pimp your landscape*. Most working steps overlapped to ensure an intensive feedback between tests and technical development.



In a subsequent step, the Delphi study participants were asked to examine some exemplary tools and give their impressions on desirable design features. The analysis was designed as one-time survey (Borg and Gall 1989) and was in the form of an online questionnaire. The tools that the participants were asked to test were Cardogis, as example of a user-friendly Geographic Information Systems (GIS)-based solutions (www.cardogis.com), Lenné3D, as an example of visualization tools (www.lenne3d.com), Meascope, as an example of landscape management support in agriculture(www.mea-scope.eu), and SIAT as an example of a complex impact assessment and management support system (www.ip-sensor.org). Test examples and information on the tools and the underlying methods were presented on the webpage of the online questionnaire.

Again, a set of standardized alternatives for answers was offered, including the option of additional free comments (Tab. 1b). The following questions were posed:

(A2) Which are the most important application fields you see being supported?
(B2) Which features should the development focus on?

Based on the results of these two analyses and some freelanced ideas provided by the participants, a prototype of *Pimp your landscape* (V 1.0) was designed. This prototype was a paper-based version of the later system, which was tested to learn more about possible user habits. Testing of the prototype was carried out in a workshop. The participants were asked to simulate with the paper-based tool a typical communication and negotiation process in regional planning from the point of view of their professional experience in their sectors. In the simulated negotiation process, different land use pattern

Table 1. Overview of the results of the Delphi study.

Questions and alternatives	Evaluation result	Ranking
(A1) What kind of information sources are you generally using to prepare interdisciplinary planning decisions?		
• textbooks, journals, other written information sources (handbooks, guidelines)	2.3 (32)	1
• oral information (consultation of experts and colleagues)	2.3 (32)	
• institutional information systems	2.3 (32)	
• web-based information/online portals	2.4 (32)	2
• other (newsletters, newspapers)	3.0 (6)	3
(B1) Which tools are you using to visualize the planning process and to support your decision?		
• standardized Office applications (spreadsheets, calculator, etc.)	1.7 (32)	1
• Geographic Information Systems	2.0 (32)	2
• (interactive) database applications	2.1 (30)	3
• maps and monitoring data (either in ditigal or printed form)	2.3 (32)	4
• institution specific software solutions (calculation programmes, visualization, etc.)	2.6 (28)	5
• key figures, operating figures	2.7 (29)	6
• handbooks, written guidelines	4.0 (6)	7
(C1) What do you think an optimal support system should look like? (Delphi round I)		
• online portal including expert system and online consultation	2.0 (32)	1
• specialized/expert information system	2.2 (32)	2
• collection of spreadsheets and key figures	2.7 (32)	3
• management software for free download	2.8 (32)	4
• decision schemes usable under standardized Office applications	3.0 (32)	5
• (digital) handbooks including (digital) decision tree(s)	3.5 (32)	6
(C1´) What do you think an optimal support system should look like? (Delphi round II)		
• online portal including expert system and online consultation	2.0 (32)	1
• specialized/expert information system	2.2 (32)	2
• collection of spreadsheets and key figures	3.2 (32)	3
• decision schemes usable under standardized Office applications	3.2 (32)	3
• management software for free download	3.5 (32)	4
• (digital) handbooks including (digital) decision tree(s)	4.0 (32)	5

alternatives were proposed, evaluated, and discussed according to the divergent interests of the planning actors. The term “land use pattern” was used in the development of *Pimp your landscape* to express the mosaic of different land use types as they are classified in the context of CORINE Land Cover (CLC) 2000 or other land cover classification standards, for example, on a national level.

The experience using the prototype and desired improvements of the basic approach were analyzed in a feedback round. The results of this test formed the basis for finalizing the development profile for *Pimp your landscape* version V 2.0.

Several series of user tests were conducted in workshops and meetings as a means of refining the system and identifying development needs and technical weaknesses. The test series focused on questions regarding an optimal user interface and user support. Furthermore, the need for the system to correspond to different educational backgrounds and user skills was identified. The resulting online version V 2.1 provides different modes of complexity; only the version with the highest level of complexity (scientific version) is presented in this article.

Subsequent tests revealed that the original approach to evaluating land use changes based only on information on land use types was too simple to reflect the complexity of the system landscape. This led to the development of a rule-based system concept, which also considered the question of neighborhood relationships between land use types, spatial restrictions, the impact of the localization of a land use type in the landscape, and temporal dynamics. Expert consultation and additional literature analysis are continued permanently for referencing the evaluation basis to prevailing studies and to fit the system to other regions.

A follow-up version of *Pimp your landscape* has been adapted for developing regional climate change mitigation strategies in the frame of the REGKLAM project (www.regklam.de) for the metropolitan areas of Leipzig-Halle-Bitterfeld and Dresden (Fürst et al., *in press*). An application for the development of forested regions has been tested and prepared for implementation in e-learning in the frame of the Leonardo da Vinci project TrainforEducation (http://foreducation.nlcsk.sk/de/index.html). Finally, the tool and derivatives were integrated into a web portal (www.letsmap.de), which is under development for different user groups, user rights, and use cases.

Land use classification and evaluation approach

Pimp your landscape intends to use a generic approach for the evaluation and visualization of land use changes regarding environmental, economic, and social services. This requires the definition of a reference base for the land use classification, which ensures comparability between different countries, and between different regions within the countries. Furthermore, the experiences with the test subjects revealed that great attention should be paid to the development of a generic concept for the evaluation of the land use pattern changes with regard to their impact on land use services.

For this study, land use types were defined on the basis of the CLC 2000 classification because it was the only digitally available transnational planning basis at Euro Region Neisse. Apart from this study-specific convention, *Pimp your landscape* can also import other kinds of digital data sets provided they are in vector format, as a shape or a text file. CLC 2000 offers many land use types, which were not all relevant in the model region. As a result, and in agreement with the participating experts, only the ten most important land use types were considered in the presented study.

With regards to the evaluation of land use change impacts, literature analysis was used to obtain information on comparable studies, whose outcomes can be transferred. Meanwhile, expert consultation was conducted to integrate unpublished regionally available data and information, and to fill some knowledge gaps where the literature analysis did not provide sufficient information. The experts consulted were those who participated in the Delphi study, and scientists in the fields of catchment area management and landscape aesthetics.

The evaluation idea is based on the LUFs framework (Perez-Soba et al. 2008, Schößer et al. 2009) but was modified for the purposes of this study. Based on the discussions at the regional workshops, the four regionally most important land use services were selected for Euro Region Neisse. The term “services” is used because the evaluation refers to appraisable landscape benefits. Taking the second service “ecology” as an example, the discussions revealed that possible alternatives, such as “biodiversity,” “species diversity”, or “habitat quality”, were considered too narrowly defined and that the participants preferred a more holistic view on landscape services. The impact of each land use type on these services was evaluated as follows:

I. water quality with regard to the impact of a land use type on the nitrogen output as an indicator for drinking water quality. Expert consultation was used to put the different land use types in relation to each other for the scale level “region.”

II. ecology with regard to the impact of a land use type on the regionally typical species richness. Administrative guidelines on the economic value of a land use (biotope) type were consulted (SMUL 2003). These guidelines are used for defining the extent of compensation measures for biotope losses by infrastructural measures.

III. economy with regard to the contribution of a land use type to income and taking into consideration the regionally relevant purchase prize relations. Statistical characteristics for land use type specific taxes, revenue (€ / ha x a), and purchase prices were used (obtained from data of the statistics agency of Saxony, www.statistik.sachsen.de). This information was complemented by expert consultation for land use types for which no sufficient database was available (wetland, water bodies).

IV. aesthetics with regard to the contribution of a land use type to the aesthetical value of a landscape. Aesthetics was used as a proxy for the touristic value of the region. Regional studies on respective preferences of tourists were not available, but tourism was considered the most important landscape-related issue in the region. Therefore, in the examples in the Results section, the term “tourism” is used, but this is based on the aesthetic value of the landscape. Expert opinion in combination with some literature on the aesthetic value of landscape elements and structures (Bourassa 1991, Wöbse 2003, Herrington 2008) were consulted.

To correspond to the demands of a generic evaluation concept and to achieve comparability between the different land use types and their services, a scale from 0 (= most negative effect) to 100 (= most positive effect) was introduced. The indicators and consulted knowledge sources were used to rank the land use types according to their impacts on this relative scale (Table 2). For upscaling the evaluation to the regional level, a weighted mean was calculated for each land use service by summing the values of each cell for the singular land use services and dividing the sums by the total number of cells. To exclude any influence of the evaluation result by impact factors such as cell size, the latter was fixed to 100 x 100 m².

RESULTS - USER REQUIREMENTS AND SYSTEM CONCEPTION

User requirements

The Delphi study showed that various kinds of information sources are used for knowledge mining without particular preference for a specific source (question A1). Information from publications and the consultation of colleagues or experts are used as extensively as web-based information and personal and institutional experiences, which are collected in sectoral information systems (Table 1).

In the planning and decision process, computer-based tools are clearly preferred to paper-based tools such as handbooks or written guidelines (question B1). Standardized Office applications, Geographic Information Systems, and interactive database applications are the most preferred instruments, followed by planning materials such as maps and monitoring data and institution specific planning software. Collections of key figures are still used for orientation, while handbooks and written guidelines were clearly ranked in last place (Table 1).

Preferences for an optimal support system focused on online portals and expert systems, while other alternatives such as a collection of spreadsheets and key figures, software or decision schemes and handbooks were ranked lower (question C1). Compared to the results of the first Delphi study round, the participants ranked online portals and

Table 2. Overview of the results of the one-time survey.

Questions and alternatives		Number of answers†	Ranking
(A2) Which are the most important application fields you believe need to be supported? Please clarify.			
• other: communication and conflict negotiation in participatory processes		15	1
• landscape management planning (intersectoral)		11	2
• policy support/consulting		11	
• impact assessment/estimation of potentials and risks in planning		7	3
• operational management and decision support (intrasectoral)		3	4
• other: further education and training		3	
(B2) On which features should the development focus?			
output type	• qualitative results (visualized results, e.g., maps, diagrams, trends for different planning alternatives)	21	1
	• quantitative results (data (sets) or indicator sets as output to evaluate planning alternatives)	14	2
user insight into results generation	• free design of decision and management planning alternatives, user can generate rules and criteria and modify the evaluation basis	18	1
	• modeling based results/simulation of landscape development, user input restricted to environmental data	12	2
	• multicriteria decision making (MCDM), user input: decision criteria and data, optional choice between different MCDM methods	4	3
style of user guidance to decisions	• visualization of the relative benefit of different alternatives by using maps and information on positive/negative trends	17	1
	• Geographic Information Systems-oriented tool, which allows user to visualize planning alternatives and integrate multiple environmental information in decisions but is not too complex in handling and focuses on evaluation of scenarios	16	2
	• comparison of different planning alternatives by (selected) indices	11	3
	• proposition of the “best” alternative (decision making)	7	4
	• decision tree	5	5

†multiple answers were permitted; consequently, the number of answers given by the 32 participants in the study is > 32

expert systems even more highly in the second round (question C1') (Table 1).

Table 1 presents the results of the two Delphi study rounds, including the originally proposed alternatives and additional comments and propositions by the participants, which are italicized. The evaluation results are displayed as weighted means calculated by the number of responses and the ranking given to each response alternative. Numbers in brackets give the number of responses.

The one-time survey gave information on the most important application fields for which the participants of the study expect improved support (question A2). The application field communication and conflict negotiation was ranked highest, followed by support in intersectoral planning processes and policy support. Impact assessment and decision support in intrasectoral planning were ranked lower. A few participants also proposed that management support systems be used in education and training (Table 2).

Considering the most important features the development should focus on (question B2), a trend could be identified with regard to qualitative information (output type) and high transparency in the way in which results are produced (user insight into results generation). The users voted for tools in the style of Geographic Information Systems, which focus on the visualization of planning alternatives and their effects (style of user guidance to decisions) (Table 2).

Table 2 provides information on the results of the one-time survey on envisaged application areas and demanded design features. Propositions by the participants are again italicized. The number of responses and the rankings are given. The participants had the option of choosing multiple answers.

Finally, in discussion with the Delphi study participants, a commonly accepted profile of the envisaged tool was defined that addresses the following generic attributes and specific features:

(i) An optimal support system should ensure a broad accessibility for users at any time and any place. A web-based solution was demanded.
(ii) The tool should offer the possibility to iteratively integrate experience from case studies and regional experts as well as upcoming scientific results into its knowledge base in terms of a learning system. The need to orient support as best as possible to real-world conditions and to the most recent knowledge was highlighted.

- As a precondition for broad acceptance and use, an interactive and self-explanatory user interface is expected. It was recommended that this interface be kept as simple as possible to ensure its suitability even for people who are not very familiar with the use of computers and electronics. This includes easy user guidance on how to adapt the evaluation to one's own experiences and upcoming knowledge. Information on the effects of what has been changed was expected to be available in real time.
- Based on the experiences from testing different tools and the prototype of *Pimp your landscape*, the following specific features were demanded by the test participants: (a) high ability to "design" the landscape and to introduce and modify planning rules, (b) easy handling of landscape changes in the system "by mouse click" without the necessity to learn a special programming language, and (c) transparency of the evaluation results and possibility to modify the evaluation basis.

In summary, an optimal solution was expected to be "a system in which different actors involved in planning decisions can share and exchange their planning propositions and which delivers generalizable conclusions on the effects of the planning alternatives for regionally important landscape services."

Specifications for the system conception

To address the user needs described in (*Results–User Requirements and System Conception: User requirements*), the software had to enable user-driven changes in the land use pattern by mouse click. Furthermore, it became necessary to evaluate the impact of the land use pattern changes on the most important land use services under consideration of complex interactions between various land use types and the related environmental conditions. Land use pattern changes are defined as

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the conversion of (a) single land use types into another land use type, or (b) all land use types in a part of a region into a specific land use type. The first, (a), reflects regional planning measures such as the afforestation of agricultural sites or the conversion of coniferous forests into mixed forests; (b) reflects planning measures such as the establishment or enlargement of a settled area in a region. Therefore, the continuous problem "landscape" must be divided into spatially distinct units that can interact and communicate with each other and to which different attributes can be assigned.

Pimp your landscape was aligned with the approach of a cellular automaton with a Moore neighborhood (nine-cell neighborhood with range r = 1: http://mathworld.wolfram.com/MooreNeighborhood.html). According to Cochinos (2000), "a cellular automaton is a discrete dynamical system. Each point in a regular spatial lattice, called a cell, can have any one of a finite number of states. The states in the cells of a lattice are updated according to a local rule. That is, the state of the cell at a given time depends only on its own state one time step previously, and the states of its nearby neighbors at the previous time step. All cells in the lattice are updated synchronously. The state of the lattice advances in discrete time steps."

Cellular automata were introduced by Ulam (1952), and their potential to support the understanding of the origin and role of spatial complexity was highlighted by Tobler (1979). The original cellular automaton concept has been adapted for modeling urban structures and land use dynamics (White and Engelen 1993, 1994, White et al. 1997, Barredo et al. 2003), regional spatial dynamics (White and Engelen 1997), and the development of strategies for landscape ecology in metropolitan planning (Silva et al. 2008). Nowadays, cellular automata are broadly used to simulate the impact of land use (pattern) changes and landscape dynamics (e.g., Soares-Filho et al. 2002, Holzkämper and Seppelt 2007, Yang et al. 2008, Moreno et al. 2009, Wickramasuriya et al. 2009).

Pimp your landscape has adopted some properties of the cellular automata concept in land use modeling but has also modified some aspects. The cell is the smallest spatial unit in the system with invariable size (actually 100 x 100 m²) and interacts with its neighboring cells in accordance with certain rules. Contradictory to the original concept of a cellular automaton, each cell can have multiple attributes as introduced by Couclelis (1997). The land use type is the most important cell attribute and the only one that is updated. *Pimp your landscape* does not automatically update all cell states on the basis of rules, but the user has to decide (by mouse click), at which point in time he wants to change a cell or a part of the region. Rules for restrictions and for evaluating the effects of updating the land use types are explicitly defined by the user (*Results– User Requirements and System Conception: Rule setting options*) and consider the cell state, the states of neighboring cells, cell attributes such as environmental data, the presence or absence of linear (e.g., streets, rivers) or point-shaped elements (e.g., power plants), and thresholds for the maximum or minimum share of a land use type. User-driven and nonautomatic updating was chosen to increase the transparency of the outcomes of the evaluation, as the user can then directly experience the effects of each change that is being carried out. A better term to reflect the way in which *Pimp your landscape* is working would probably be "cellular semiautomata."

Evaluation results

Literature analysis and expert consultation was used to create an evaluation table that ranks the impact of each regionally important land use type on the most important land use services on a scale from 0 to 100. Table 3 shows as an example the resulting regional evaluation table for Euro Region Neisse. This table is exclusively valid for the considered model region. For other regions, the considered land use types and services and the related evaluation must be adapted on the basis of regional knowledge sources and experiences.

The evaluation table forms a major steering mechanism for the user, who can change and adapt this table according to regional demands, existing knowledge, and consulted experiences. A special user interface allows the user to generate a stepwise evaluation, starting with the selection and description of the land use types. CLC 2000 is available as a standard set, but a user-specific set can also be introduced. This step is followed by the selection of the land use services. The LUF set is available as a standard set, but again, a user-specific set can also be introduced. After having finished these two steps, a matrix is displayed, where values from 0 to 100 have to be entered for each land use

Table 3. Exemplary evaluation table for the Euro Region Neisse.

CORINE Land Cover 2000 land use types	Values of the land use types for the land use function			
	Water quality	Economy	Ecology	Aesthetics
urban areas	0	100	0	0
industry	0	100	0	0
agriculture	20	80	30	20
fruit trees and vegetables	30	75	35	40
pastures	60	60	35	50
deciduous forests	80	30	100	80
coniferous forests	50	40	60	60
mixed forests	80	35	90	90
natural grassland	70	5	100	90
wetlands and waterbodies	100	5	100	100

type – land use service combination. In this matrix, the maximum values must be entered, which a land use type can adopt considering its impact on a land use service in the specific regional context: for the application of the system and with regard to the data basis for the evaluation, it was necessary to refer to planning units with practical relevance. Therefore, *Pimp your landscape* refers to concrete regions whose borders are at the moment predefined (set of model regions). A region is understood to be a spatially confined area, and is classified by its land use pattern (mosaic of land use types, e.g., forested regions, agricultural regions, urban regions, etc.) and additional environmental factors (climate zones/geo-zones). Land use pattern and environmental factors determine the maximum value of a land use type considering its contribution to the provision of land use services. As a result, the transfer of an already developed evaluation and rule set from one region to a comparable one is possible.

The rules described in the next section were built on the evaluation table.

Rule setting options

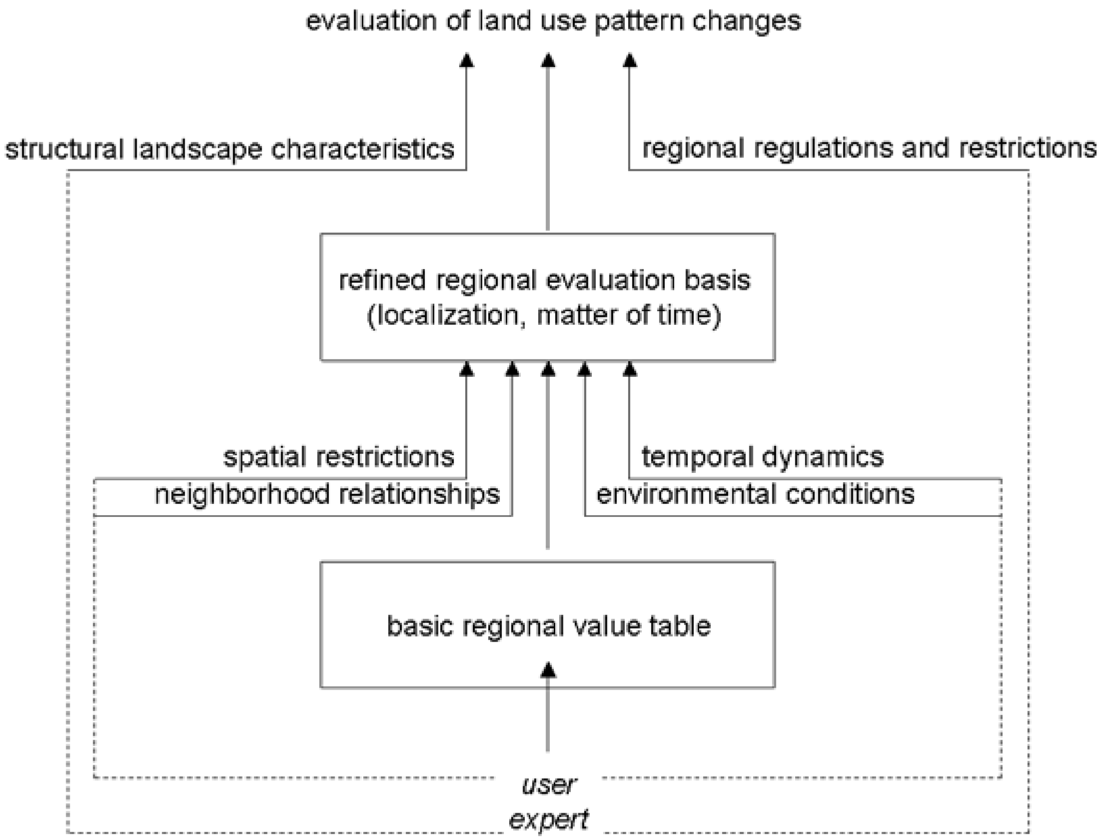
A number of rule-setting routines was implemented in the system. These offer the opportunity to define in detail the interactions between neighboring land use types and the impact of environmental frame conditions on the cell-specific values of a land use type for a land use service. Furthermore, planning restrictions can be described by these rule-setting routines (Fig. 2).

Each rule must be saved with a name and must be documented by a short description. Once a rule is established, it can be activated or deactivated. A rule is always valid for the region where it was established and is therefore based on the region-specific evaluation table. For use in other (comparably classified) regions, the evaluation table and the rule systems can be exported. The following rule setting options are given:

I. Impact of environmental frame conditions

I.1 Based on the evaluation table, the user can specify if and to which percentage cell attributes

Fig. 2. Connection between value table, rule sets, and evaluation results in *Pimp your landscape*.



such as geological and topographical data, climate data, etc., reduce the value of a land use type for a land use service. Note that in the evaluation philosophy of *Pimp your landscape*, the basic value of a land use type for a land use service represents the maximum in the regional context. Cell attributes can only reduce this maximum value. The specific local situation of a cell within a region can thus be integrated in the evaluation and helps to provide a more realistic appraisal of the impact of changes in land use patterns. An example is the economically relevant productivity of agricultural or forest areas as being dependent on the height above sea level (length of the vegetation period), the soil potential, and the available annual precipitation.

I.2 Furthermore, the user can define whether one of the above-mentioned cell attributes restricts the possibility of converting a land use type into another (see I.1). In this rule-setting option, two aspects are integrated: (a) the probability that an environmental factor limits the conversion of a land use type into another, and (b) considerations of regional planning restrictions that might forbid the conversion of one land use type into another. An example is (a) the probability that badlands can be converted into forests or agricultural sites as dependent on the soil type or the mean annual precipitation. Steep slopes in mountainous areas can serve as an example for (b), as forests should be kept there to protect the site (protection forests).

II Interactions between cells

II.1 In this rule-setting routine, the user has the option of specifying if and at which percentage the value of a land use type for one (or several) land use service(s) is decreased by the neighborhood to another land use type. In the simplest case, two cells of the same land use type are in direct proximity.

As a result, no mutual impact is assumed. In the case that two differing land use types are neighbors, their original value for one (or several) land use service (s) might decrease. As an example, the value that is assumed for an agricultural site in terms of its economy can be reduced by its proximity to a forest due to its shadowing effects. At the same time, the economic value of the forest might increase due to its proximity to an agricultural site providing nitrogen deposition. Following the model of a Moore neighborhood, different neighborhood types are considered. A longitudinal neighborhood has a full impact, whereas the impact is reduced as a commitment to 25% of the full value in the case of the diagonal proximity of the cells.

II.2 Furthermore, the user can define whether a neighborhood restricts the possibility of the conversion of a land use type. This rule-setting option reflects planning restrictions that might occur. As an example, it might be forbidden to establish a dump site in the neighborhood of a settlement.

III Interactions between cells and linear or point-shaped elements

III.1 The user can specify if and at which percentage linear or point-shaped cell attributes reduce the value of a land use type for one or several land use services. In the case of point-shaped elements, the user must specify the spatial distance up to which this impact is valid. This is the only case where the Moore neighborhood with range r = 1 is modified. An example is the impact of a power plant, for which a deposition gradient must be defined. The spatial distance and the number of neighbors that are affected in each direction are simply defined by freehand delineation on the map. The gradient can be centric or irregular, even with an excentric localization of the point-shaped element. Within the gradient, a linear decrease of the impact is assumed starting with the highest impact on the original values of the land use types at the cells nearest to the point-shaped element.

III.2 In addition to the rule-setting option described in II.2, the user can specify whether the existence of and neighborhood to linear elements, such as rivers or roads, restricts the conversion of a land use type into another. “Existence of” addresses the cells that have a river or road as an additional cell attribute; “neighborhood to” addresses cells that are situated next to a cell with such an attribute. As an example, the clearing of forests along rivers can be forbidden and reflects the planning restriction to protect floodplain forests.

IV Further rule setting options reflecting planning restrictions

IV.1 A basic characteristic of a cellular automaton is the transition probability of the original status of a cell into another status. Independent from the yet-described impact of the neighboring land use type (II.2), the user can specify which land use type is basically allowed to be converted into another. This reflects again two aspects: (a) the (natural) probability that a certain land use type can be converted into another, and (b) the considerations of regional planning restrictions, which might forbid the conversion of one land use type into another. An example for (a) is the conversion of a settlement into a forest; an example for (b) is the conversion of a deciduous forest into a coniferous forest.

IV.2 To support the complex considerations in regional planning, the user can also specify development thresholds and development trends. The minimum and maximum share of a land use type with reference to the total number of cells can be defined. Additionally, the user can decide whether the actual share of a land use type can only be increased or decreased or must be kept. This reflects planning aspects with regard to the character of a landscape. As an example, it might be desirable to keep the character of a cultural landscape with a share of 30–40% of forests, 50–60% of agriculture, 5% of water bodies, and a maximum of 5% of noncontinuous urban areas. In this case, only the location of the different land use types could be changed, but a warning message would signal whether one of the thresholds is exceeded. In progress is a complementary option to decrease the value of a land use type for one or several land use services as a function of these thresholds.

IV.3 Finally, the user can also set minimum or maximum thresholds for the land use services on a scale from 0 to 100. This offers the option to reflect political targets in planning, such as keeping biodiversity or water quality at a certain level.

V. Impact of time on the evaluation result

The value of a land use type for one or several land use services might depend on its development stage.

An example is the afforestation of former agricultural sites: at least one forest stand life is necessary until the full quality of the forest ecosystem is reached in terms of drinking water quality, typical species richness, and economically relevant production. The consideration of a time dependent value of land use types for land use services is also important for evaluating land use pattern changes for climate change scenarios with different speeds and intensity of changes over time. The user can decide for which land use types such trends apply, and must define first which time periods should be considered in the evaluation and next the time-dependent value of the land use type for the land use services, for which temporal trends are relevant.

The different rule-setting options can be used singularly, or several rules can be combined and saved as a complex rule set. An example of a complex rule set is the translation of multiple planning restrictions derived from EU directives such as Natura 2000 or the EU Water Framework Directive. The possibility of combining rules enables the comparison of the functioning and effects of competing directives or planning restrictions.

The rules impact the possible land use pattern changes in different ways: (a) the evaluation result is dependent on the rules I.1, II.1, III.1, and V (and in future also IV.2); (b) the number of land use types that are displayed in a selection box when clicking on a cell can be limited by rules I.2, II.2, III.2, and IV.1; and (c) warning messages are given if thresholds defined in rules IV.2 and IV.3 are broken.

Technical realization and usage of the system

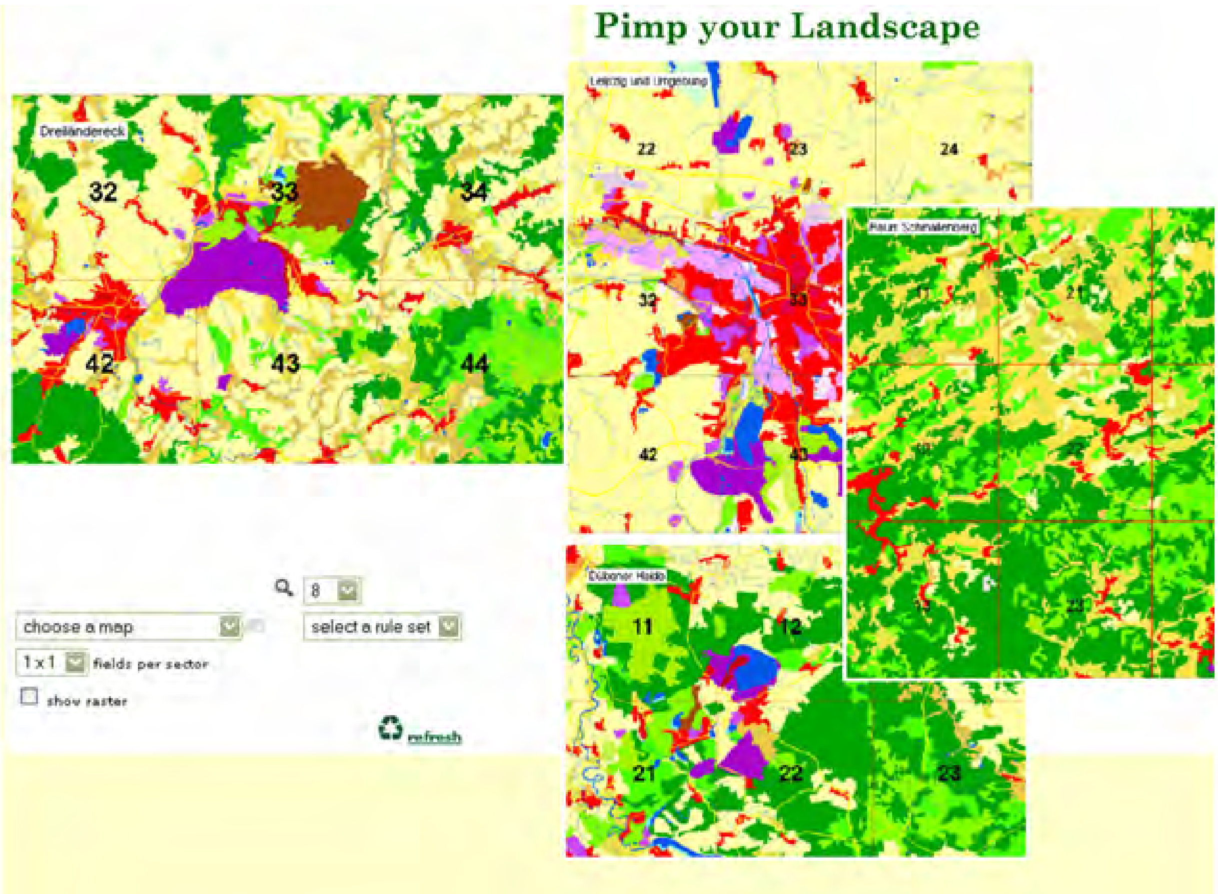
Pimp your landscape (V 2.1) was developed as an online tool. Information on land use patterns was based on CLC 2000 maps with a spatial resolution of 100 x 100 m² (= 1 cell). This resolution was chosen because it is the highest resolution possible with CLC 2000. Roads, highways, railways and water bodies are displayed as linear elements, which are extracted from 1:100 000 topographic maps. Additional attributes such as geology/soil type, topography, and climate data can be imported in the form of vector data (text or shape file) as an information layer, which is valid for the total region. If no relevant information is available, these cell attributes can also be defined manually for each cell or for an area comprising several cells. To avoid the user's confusion as a result of information overflow, only land use pattern and infrastructural elements are displayed as maps at the front end, while information on the additional attributes is displayed as pop-up window when the cursor hovers over a cell.

One of the major development challenges involved combining of permanent map details (existent infrastructural elements, environmental attributes) and modifiable map details (land use types, additional linear or point-shaped infrastructural elements) without using GIS functionalities, which are highly complex and time demanding. Each cell must contain geo-referenced information about the major land use types and the presence or absence of other attributes. A color code management enabling the identification, administration, and allocation of colors to each cell was thus introduced. A map-management module supports the relation of the CLC 2000 land use maps and the attributes from the other information layers to the same scale without distortion. The described data aggregation technology allows for an optimized loading time of the maps and for the fast actualization of the land use pattern and the insertion of linear or point-shaped elements per mouse click. Additionally, zoom functionality is supported, which helps users adapt the user interface optimally to their technical facilities (screen size). The possibility of working with different raster sizes from 1 x 1 (= basic resolution of 100 x 100m²) up to 16 x 16 and with a freehand mode for enabling large-scale changes is another result of this special aggregation technology.

Figure 3 shows the home page of *Pimp your landscape*. The maps displayed on the user interface are divided into 10 x 10 km sections and transferred into gif format to reduce the transfer time to the end-users' browsers. The user is asked to zoom into regions – that is, to select a part of the region that he/she wants to work on, by mouse click. This was done for practical reasons, as tests showed that users are not able to work on more than 2500 to 3000 cells simultaneously. It is also possible to upload a map together with environmental data sets, which are available as a text or shape file in a resolution of 100 x 100 m² (without illustration).

Figure 4 shows the actual user interface of *Pimp your landscape*. For each of the 100 x 100 m² cells, the dominant land use type is displayed.

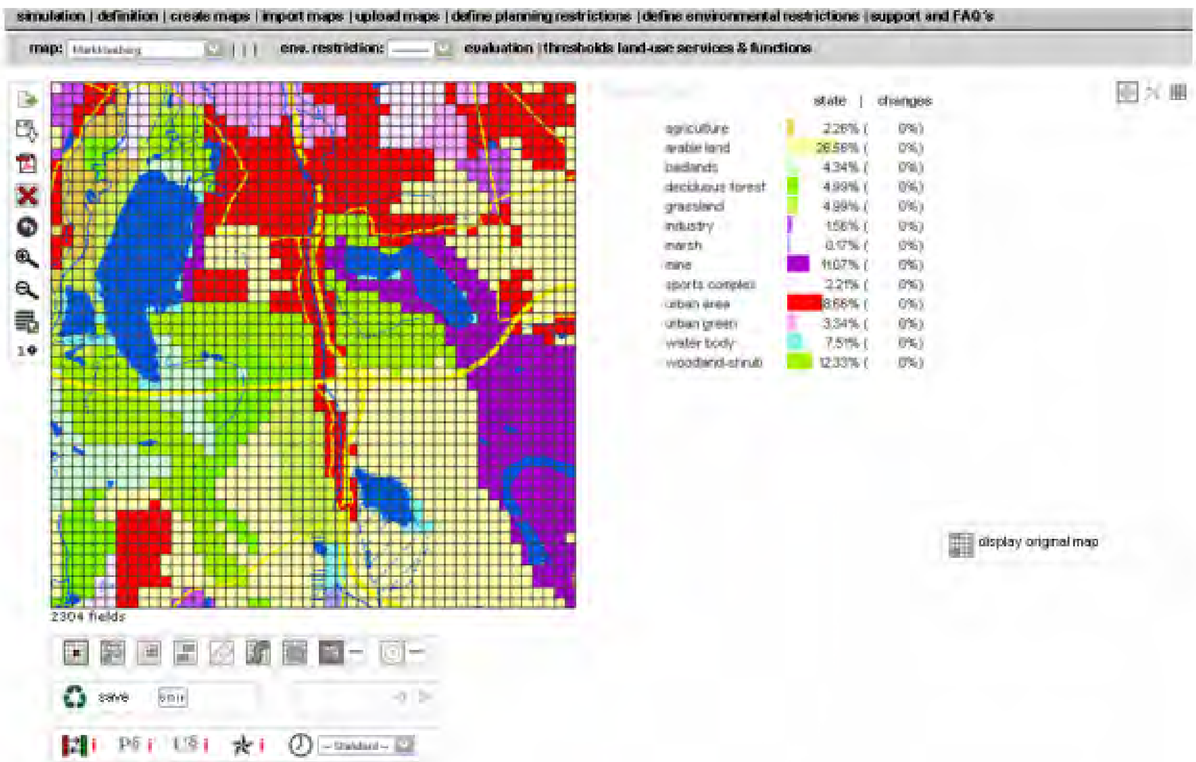
Fig. 3. Home page of *Pimp your landscape*, displaying some of the model regions, which are already integrated into the system.



After having selected a region and the related data sets and having specified the rules in the menus above the map, the user is offered multiple tools to modify the landscape, which are shown by icons. The icons below the map, from left to right, allow for changing the land use types cell-wise, for changing a sector marked by a freehand delineation, for changing all cells of a certain type, which are neighbored at a stretch, and for changing all cells of a certain land use type for the whole map. A new land use type is assigned by a pop-up menu, which displays the available land use types. A click on the desired land use type (e.g., coniferous forest) makes the intended change.

The fifth icon below the map allows for delineating streets with different sizes (highways, main roads, small roads, etc.). Different classes of streets according to their size and traffic intensity can be selected from a pop-up menu, and the impact on the land use services must be specified by the user for each of the classes. The sixth icon gives the same opportunity for rivers. The seventh icon enables the delineation of water bodies. The eighth icon allows the user to zoom into a part of the map and to compare the evaluation results, which are displayed in a star diagram (faded out in the illustration) for the total map and for the selected zoom area. This feature helps one to better understand local effects, for example, such as those associated with the introduction of a motorway junction or the introduction of a dumpsite. It is also possible to switch between different zoom areas, for example, to test the effects of introducing a dumpsite or motorway junction at alternative localizations in the map. The last icon below the map allows for drawing

Fig. 4. User interface of *Pimp your landscape*.



a point-shaped element in the map and to define its impact gradient. The icons in the row below this provide the opportunity to save the results of the simulation and to receive information on the rule sets that are introduced and activated. The clock icon provides the opportunity to activate a menu, where values of the land use types for one or several land use services can be defined as dependent on different time slots.

The tool bar on the left-hand side of the map from top to bottom includes icons for exporting the final results of the simulation as a text or shape file and for saving them as a pdf file. The fourth icon allows the user to reset the simulation. The fifth icon activates the replay of all movements so far, and can be interrupted to restart the simulation at a move that might have led to undesired results. The two icons below that allow the displayed map size to be enlarged or reduced. The next-to-last button activates or deactivates the display of the raster, and the last icon allows the displayed raster size to be changed. This is thought to be useful in cases where a user wants to convert larger parts of the map with homogenous cells. It does not affect cells sized 100 x 100 m^2.

A legend, which can be activated by mouse click, informs the user about the colors of the land use types and their regional value on a relative scale from 0 to 100. For the displayed map, a statistic of the land use types can be displayed (right-hand side of the map), or evaluation results can be displayed in a star diagram or a trend table that gives the numbers and shows the trends for the land use services as indicated by arrows (icons on the right-hand side of the statistic). The numbers, which are displayed in the star diagram and the trend table, are the weighted mean values for each land use service (*Introduction*).

To support the visual comparison of the original landscape and the simulation result, the original situation can be displayed in parallel to the map by clicking the "display original map" icon on the right-hand side of the map. The figure that is displayed cannot be changed by the user, but its position can be moved with the mouse to avoid obscuring the diagram, trend table or land use type statistic.

DISCUSSION

Complexity versus simplicity - advantages and disadvantages

Systems for supporting spatial management decisions were developed in the frame of many projects. The application fields they cover range from sectoral management support in forestry up to integrated water resources and complex environmental management approaches (Matthies et al. 2007, Burstein and Holsapple 2008*a*, 2008*b*, Reynolds et al. 2008). However, a major criticism of these systems is their high complexity, which provides an abundance of information far beyond what is really used by managers or even policy makers (Uran and Janssen 2003, Van Kouwen et al. 2008). Meanwhile, the need to pay greater attention to end-user needs and to the requirements of particular applications of a tool is widely recognized (Giupponi 2007). Mendoza and Prabhu (2005) and Parker et al. (2008) have identified the human aspect and especially communication as central criteria for the development of successful system solutions. Communication in this context must comprise both the internal communication between the developers and the external communication with end-users. How does one evaluate *Pimp your landscape* with this background in mind?

Pimp your landscape was conceived as an instrument to visualize the effects of changes in land use pattern and to quickly provide information on possible positive or negative trends. The intention is to support a better understanding of the effects of spatial planning measures at the landscape level. *Pimp your landscape* allows for the flexible consideration of different land use change scenarios and the quick visualization of possible side effects and trade-offs. The tool can easily be adapted to any region considering the land use services to be integrated, the digital data (maps) to be used, and the available evaluation basis and rule sets to be introduced. Consequently, the original aim to realize a generic system approach, which can be adapted to variable application cases, was achieved. (Holzkämper and Seppelt 2007).

One of the main development targets of the tool is to deliver a basis for exchange, discussion, and conflict solution between different actors or actor groups in regional planning. The system conception, its development, and the configuration for its application fields is driven by end-user demands from the beginning on. This was done especially with regard to the criticism about spatial support systems highlighted by Uran and Janssen (2003).

The intention to build the system development basically on the users' point of view led to some problems. A problem was to concretize the user demands because the participating experts in the Delphi study were not very familiar with existent and available solutions and thus could not always specify in detail what they really understood to be an optimal solution. Therefore, the one-time survey was added, and the experts were offered the opportunity to have a look at existing solutions and to test them. A problem in the user-driven development was that users could not or were not willing to spend much time testing different solutions, and their answers thus remained partially superficial. In consequence – and diverging from the original intention of a completely user-driven approach – the initial system specifications had to be proposed by the developers and had to include their experiences (and probably preferences). Communication within the development team, with the end-users, and also with scientists working in the field of developing support systems at different scale levels was an essential element in the development of the software. In particular, exchange with other scientists, with regard to experiences with user-driven software development, will increase in the future as a result of lessons learned from the development process so far.

User needs with regard to new knowledge and their being addressed by simplified answers and scientific progress are currently unmatched. A precondition for a successful support tool is the strict orientation on the knowledge background and skills of the later user (Diez and McIntosh 2009) and the transparency of the results (Malczewski 2004). Therefore, it was considered essential to keep the evaluation approach and the output on the effects of land use pattern changes as simple as possible. In consequence, *Pimp your landscape* is not based on coupled models and gives a very simple set of feedback to the user. The evaluation results represent highly aggregated information corresponding to the demands of decision and policy makers (Hartono et al. 2007). The selected approach of a cellular (semi)automaton provides a useful instrument to consider complex interactions at the landscape level (Holzkämper and Seppelt 2007, Silva et al. 2008), but it is also useful to make them more transparent for the user.

With regard to the manifold evaluation approaches and results in environmental impact assessment (Perez-Soba et al. 2008), the applied approach of using a combination of literature analysis and expert consultation for the evaluation basis and to reference the impact of land use types on all land use services on a scale from 0 to 100 runs the risk of presuming the accuracy and simplicity of answers that, in fact, do not correspond to the complexity of real-world conditions.

The analysis of appropriate knowledge sources and indicators for the evaluation has also revealed a severe problem: when bundling experience-based expert knowledge and knowledge from publications on the impact of different land use types on landscape services, an incredibly high number and variability of indicators and indicator sets were found for the effects of each single land use type on the land use services (e.g., Repetti et al. 2006). Furthermore, indicators and indicator sets do not deliver in any case a sound basis for comparing different land use types and achieving an integrative evaluation at the landscape level (Yli-Viikari et al. 2007, Wijewardana 2008). This required an intensive selection process and complicated referencing of the land use impacts on the described scale from 0 to 100. A possibility would have been to directly display the indicators or indicator sets as feedback for the end-user. However, this endangers the comprehensibility of the results for users, in this case especially the non-professional ones (e.g., Janssen et al. 2006). The relative ranking of land use types also has another advantage over the direct display of indicators. When using a set of indicators and knowledge sources for each land use type and service, the ranking becomes more stable over time compared to each single indicator (compare e.g., Lindeijer 2000). On the other hand, the chosen referencing of the results on a relative scale might reduce the transparency of the results. A solution corresponding to both needs, the quick estimation of positive/negative trends and more detailed information on the underlying indicators and indicator sets is planned to be implemented soon.

Another possible constraint faced in the acceptance and use of *Pimp your landscape* is a missing interface for land use type specific or landscape-related models. The reasons for this are that analyses of existing systems and modeling approaches have shown that the availability of models for all land use types that consider multiple effects on different land use services is not ensured (e.g., Rossing et al. 2007). Furthermore, models of different land use types often work at different scales, which complicates their linking in a landscape level-oriented system. Models are often hyper-parameterized, which confines their use to regions that were originally developed. Last but not least, few models cover the interactions between land use types in a landscape context (e.g., Lambin et al. 2000, Roetter et al. 2005, Verburg et al. 2006). As a result, *Pimp your landscape* was conceived as open platform, which supports the integration of knowledge gained from modeling results but also offers the possibility of compensating missing knowledge with experiences and expert knowledge-based estimation. The future direct linking to models, however, is not excluded.

To validate the results of *Pimp your landscape*, a comparison with spatial modeling approaches is in preparation in the context of the project REGKLAM (www.regklam.de), and focuses first on the water quality, economic, and (in development) soil protection (erosion risk) land use services. The consideration of landscape structure indices in the evaluation results is actually integrated into the validation of the outcomes for services such as ecology (diversity) and aesthetics. As a result, comparison with the outcomes of other approaches has not yet begun.

The presented options to specify rules and thresholds are intended to partially compensate for the missing link to models. However, in discussion with the test persons, two criticisms occurred: the intention to provide great flexibility to the user in adapting and defining unique rule sets demands, at least at the beginning, a time-consuming adaptation of the system, despite the offer that predefined evaluation tables and rule sets for some model regions are iteratively integrated into the system and are made available for the users. The other criticism is the possible misuse of the software by inaccurate rule settings, which might produce incorrect results.

These criticisms are valid, and they restrict the free use of the software without accompanying scientific support. Furthermore, user groups are specified with differentiated rights to adapt and configure the knowledge base and restrictions.

CONCLUSION AND OUTLOOK

Pimp your landscape supports the testing, visualization, and evaluation of the effects of changes in land use patterns, which result from spatial planning measures. The advantage of *Pimp your landscape* is its simple entry and online handling with low technical requirements with regard to end-users' technical facilities (Seffino et al 1999, Tang and Waters 2005). In fact, a widely available set of maps based on CLC 2000 and geographical, topographical, and climate data sets is used as a standard. For each new region, these data sets can easily be imported into the system's map management module. A possible extension to CLC 2000 would be offered by the GEOLAND data sets (Willemen and Kooistra 2004), which so far are available for only some regions. The vision for future development, however, is to link *Pimp your landscape* with open access map material or satellite data (e.g., Google Earth). A link to OpenStreetMap is already realized, and even the option to overlay the maps with orthophotos is tested.

The system also offers the user the possibility to go in-depth, specifying complex planning restrictions and testing variable planning measures. The main application fields of the system are training and education in understanding the effects of spatial planning measures and the interactions of different land use types at a landscape level. Furthermore, the software can be used for the initial estimation of possible positive or negative consequences of planning measures at the landscape level. Last but not least, *Pimp your landscape* also supports the stepwise identification of possible planning corridors for infrastructural planning by delivering a forum of exchange and discussion between different actors in spatial planning.

The development of *Pimp your landscape* with user requirements analysis, test series, and feedback rounds is ongoing in a number of projects on the national and EU-wide levels. Different application fields are currently being tested. On a microscale level, *Pimp your landscape* is used to design together with regional citizens ways of using and developing former opencast mining areas in the vicinity of Leipzig. Another application area on a microscale level is to test together with farmers alternative scenarios of land consolidation measures in the catchment area of a drinking water reservoir. On a meso-scale level, the system is used to test the effects of different land use pattern alternatives under a climate change scenario to develop a mitigation strategy for the metropolitan region of Dresden. Furthermore, the software is applied in Brazil to moderate land use management conflicts in the vicinity of the capital city of Brasilia. The system is also used for the education and training of land use managers in the context of a Leonardo da Vinci activity in Austria, Czech Republic, Germany, and Slovakia.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol15/iss3/art34/responses/

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Pimp Your Landscape: A Tool for Qualitative Evaluation of the Effects of Regional Planning Measures on Ecosystem Services

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Abstract The article presents the platform "Pimp your landscape" (PYL), which aims firstly at the support of planners by simulating alternative land-use scenarios and by an evaluation of benefits or risks for regionally important ecosystem services. Second, PYL supports an integration of information on environmental and landscape conditions into impact assessment. Third, PYL supports the integration of impacts of planning measures on ecosystem services. PYL is a modified 2-D cellular automaton with GIS features. The cells have the major attribute "land-use type" and can be supplemented with additional information, such as specifics regarding geology, topography and climate. The GIS features support the delineation of non-cellular infrastructural elements, such as roads or water bodies. An evaluation matrix represents the core element of the system. In this matrix, values in a relative scale from 0 (lowest value) to 100 (highest value) are assigned to the land-use types and infrastructural elements depending on their effect on ecosystem services. The option to configure rules for describing the impact of environmental attributes and proximity effects on cell values and land-use transition probabilities is of particular importance. User interface and usage of the platform are demonstrated by an application case. Constraints and limits of the recent version are discussed, including the need to consider in the evaluation, landscape-structure aspects such as patch size, fragmentation and spatial connectivity. Regarding the further development, it is planned to include the impact of land management practices to support climate change adaptation and mitigation strategies in regional planning.

Keywords Land-use planning · Land-use management · Environmental planning · Planning support · Evaluation of planning measures · Ecosystem services · Cellular automaton

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Introduction

Spatial planning is continuously confronted with the challenge to (1) integrate conflicting demands and interests stemming from the multiple functions that landscapes have to fulfill, (2) consider complex socio-economic and environmental impacts on land-use development, and (3) evaluate various interactions and trade-offs between different land-use types (Parker and others 2008). These problems have to be tackled on different scales (Müller 1992; Steinhardt and Volk 2003; Volk and others 2008; Rossing and others 2007): On the micro-scale the impact of small scale planning and management measures on soil, water, or biodiversity must be considered, e.g., forest conversion or establishment of habitat or species protection areas. Studies on the micro-scale level are very important as they provide the data needed to parameterize larger scale modeling exercises, to understand relevant biophysical processes and to deliver thus the base for assessing the impact of land-use changes. Process-based models and simulators, such as forest growth simulators, can be applied at this level (e.g., Crookston and Dixon 2005; Pretzsch and others 2002). However, these models give evidence of, for the most part, a lack of an interface to the meso- or macro-scale, which impedes an evaluation of the environmental impact and interaction of regional land-use pattern changes (Bragg and others 2004). On the macro-scale, the focus is more on impact assessments of policies and large-scale development strategies, such as large scale effects of global change (Le and others 2008; Helming and others 2008).

Hence, the meso-scale level must be considered as the most important scale for spatial planning and different fields of environmental management. For instance, in river basins, land-use patterns and land-management strategies are used as an instrument to improve flood-plain ecology, soil protection, and river as well as groundwater quality (Steinhardt and Volk 2003; Gaiser and others 2008; Volk and others 2008). On the meso-scale level, the overall principle of sustainable development needs to be diversified into spatially differentiated objectives and standards for future landscape development. This represents the main task of multi-functional land-use management including the principles of ecosystem services and public participation (Constanza and others 1997; Petry 2001; Mendoza and Martins 2006; Hein and others 2006). The formulation of planning and management objectives on the meso-scale is no longer the preserve of a few specialized experts; rather it is the outcome of discussions among planners, politicians, land-users and the concerned public, who form a heterogeneous group of stakeholders with different interests and demands (Petry 2001; Hirschfeld and others 2005; Newham and others 2006; Volk and others 2008, 2009; Rosa 2008). Such processes demand approaches that support moderation and the inclusion of expert knowledge in consensus building (Higgs and others 2008; Lennertz and others 2008).

From a technical perspective, the implementation of spatial and environmental planning strategies is faced with problems, such as different data parameterization standards, missing spatial information regarding relevant environmental or socio-economic factors, or uncertain information concerning their future development (Verburg and others 2009). The lack of suitable data inhibits the transfer of existing management and decision-support tools from one study area to another. With regard to implementation in practice and applied research, the application of existing management or decision-support systems is mostly impaired by their complexity and the large number of generated scenarios. This complicates their usage for the planner, who has to evaluate and forecast the effects of planning measures in a transparent manner (Uran and Janssen 2003; Matthies and others 2007; Volk and others 2009). Hence, simple methods which follow a qualitative approach to the evaluation of planning measures might be a bridge between science, policy, the interested public and planning practice and a basis for later more detailed, quantitative analysis.

The described considerations emphasize the need for solutions to "squaring the circle" of multiple problems and challenges which regional spatial and environmental planning are facing (Fürst and others, in press). The Special Issue of the Journal on Environmental Management attempts to fill this gap and provide a much needed state-of-the-art collection of problems and solutions in spatial and environmental research, planning and management.

Potential solutions must fulfill the following basic requirements (Alkemade and others 1998; Harremoës and others 2001; Parker and others 2002; Uran and Janssen 2003; Malczewski 2004; Giuponni 2007; Van Delden and others 2007; Van der Sluijs 2007; Voinov and Brown Gaddis 2008; De Kok and others 2008; Hewett and others 2009):

- support understandable impact assessments of (alternative) planning measures on multiple ecosystem services on different spatial scales;
- support decision makers in developing alternative and understandable land-use scenarios ("what happens if");
- address and define user groups, and respect their specific demands;
- supply appropriate data (with the options of including expert knowledge and integrating additional data in an iterative way without losing robustness).

This article presents a method that takes the above mentioned requirements into account. It introduces the platform "Pimp your landscape" (PYL), which was originally developed to support participatory and group communication processes on meso-scale level (Fürst and others 2008). The name "Pimp your landscape" was based on a famous TV show called "Pimp my ride" and expresses the original concept of PYL to give the user the full creative freedom to design the landscape according to his (or her) own ideas and to get real-time feed-back on what these ideas mean for the balance of regionally important ecosystem services.

The presented version has been adapted to the needs of the REGKLAM project (www.regklam.de). In this project, PYL aims to support regional planners by the evaluation of environmental effects of climate change mitigation strategies. Different land-use scenarios are compared with regard to their impact on ecosystem services and their ability to mitigate undesirable development trends under climate change in the Dresden region (Federal State of Saxony, Germany).

PYL is conceived as an online-platform and focuses on a qualitative evaluation (initial estimate) of planning-measure effects on regional environmental and economic factors. The measures can be simulated (a) by modifying the mosaic of land-use types, (b) by establishing non-cellular infrastructural elements (see chapter 2, section technological and scientific approach). The environmental and economic factors or ecosystem services which are integrated into the impact assessment are specified by the user.

Integrative services, which are addressed within the REGKLAM project, are (a) human health and well-being (related to the provision of drinking water and clean air), (b) aesthetic value (related to the attractiveness of the region for short distance tourism and recreation), (c) ecological functioning (related to species and structural diversity in comparison to the natural potential vegetation and ecosystem types), (d) bio-resource provision (related to the provision of biomass, food and timber), and (e) climate change mitigation (related to the mitigation of drought, erosion and flooding). Factors which were included for other application cases, addressed specific land management aspects, such as Nitrate output, Carbon storage or revenue from biomass harvesting.

The users could be regional planners or experts from different sectors that are involved in regional planning processes. Regarding the evaluation process, see chapter 2, section evaluation procedure.

The article (a) introduces the technological and scientific approach of PYL (chapter 2), (b) presents user interface and usage of the platform by an exemplary application case (chapter 3), and (c) identifies constraints and limits of the recent version (chapter 4). Finally, an outlook for further development is given.

Materials and Methods

Technological and Scientific Approach

PYL has three main objectives. First, it aims at the support of planners by an initial simulation of alternative land-use scenarios and by an initial evaluation of possible benefits or risks for regionally important ecosystem services. Regionally important means that these services are specified and selected by stakeholders involved in the evaluation and planning process (see chapter 2, section evaluation procedure). Second, PYL supports an integration of information on environmental and landscape conditions, such as climate data, pedological/geological and topographical data into the impact assessment. Third, PYL supports the integration of different impacts of planning measures on ecosystem services.

To achieve these objectives, a technological approach was chosen that is based on a 2-D cellular automaton. A cellular automaton is a discrete dynamic system. Each point in a regular spatial lattice, called a cell, can have any of a finite number of states. The states in the cells of a lattice are updated according to a local rule. That is, the state of the cell at a given time depends only on its own state one time step previously, and the states of its nearby neighbors at the previous time step. All cells in the lattice are updated synchronously. The state of the lattice advances in discrete time steps (Cochinos 2000).

2-D cellular automata for the simulation of spatial structures were first introduced by Ulam (1952). Tobler (1979) discovered their potential to support the understanding of the origin and role of spatial complexity. Cellular automata can be used to model urban structures and land-use dynamics (Barredo and others 2003; White and others 1997, 2004; White and Engelen 1994, 1993), regional spatial dynamics (White and Engelen 1997), or the development of strategies for landscape ecology in metropolitan planning (Silva and others 2008). Nowadays, cellular automata are broadly used to simulate the impact of land-use (pattern) changes and landscape dynamics (e.g., Moreno and others 2009; Wickramasuriya and others 2009; Yang and others 2008; Holzkämper and Seppelt 2007; Soares-Filho and others 2002).

In accordance with the cellular automaton approach, the smallest unit within the system is a cell, which represents in PYL an area of 100 $\times$ 100 m^2. This cell size was chosen, as it represents the greatest possible spatial resolution of the selected CORINE 2000 land-cover classification. Each cell interacts rule-based with its neighboring cells. A cell can only be attributed with one land-use type. Land-use types with only small share within a cell are attributed automatically to the dominating land-use type. Smaller elements such buffer strips are not considered as this information is not provided by CORINE land-cover 2000. With regard to proximity effects, a Moore neighborhood (nine-cell neighborhood with range $r = 1$, see, for example, Georgoudas and others 2007) is used. It is one of the two most commonly used neighborhood types, the other one being the 4-cell von Neumann neighborhood. The Moore neighborhood type was selected for PYL as it enables to consider the impact of each neighboring cell, even of the corner cells. Rules for enabling or restricting the transition of one land-use type into another as well as for evaluating the effects of updating the land-use types are explicitly defined by the user (see chapter 2, section specification of rules). The rules take into consideration the cell state, the states of neighboring cells, cell attributes, such as environmental data, the presence or absence of infrastructural elements and thresholds for the maximum or minimum share of a land-use type (Fürst and others 2010a, see also chapter 2, section specification of rules).

The demand to integrate variable environmental parameters in addition to the land-use type as a basic attribute of a cell made it necessary to modify the original concept of a cellular automaton. The platform was complemented by some features of a Geographical Information System (GIS). These features enable the import and overlap of different information layers and the assignment of different attributes to the cells (White and Engelen 1997; Couclelis 1997). Additionally, features were introduced that enable one to "draw" non-cellular infrastructural elements into the maps. These can be linear elements (e.g., roads or rivers), irregular spatial elements (e.g., water bodies) and point shaped elements with a spatial impact gradient (e.g., (chemical) industrial factories or power plants). In this latter case—as an exception—the Moore neighborhood is modified for a consideration of proximity effects, whose spatial extent (range >1, direction) can be defined by the user, e.g., on the basis of knowledge on deposition gradients and range (Fürst and others 2010b). The irregular spatial elements are handled in the same manner as the land-use types, whereas the linear and point shaped elements are handled as cell attributes. The linear elements can be classified into different categories according to their size and, in the case of roads, according to their status (local, regional, national) and use intensity. This differentiation into categories has been taken into consideration in the evaluation results and supports the formulation of the rules.

A major contrast to cellular automata is that PYL does not automatically update all cell states on the basis of local rules, which specify the transition probabilities. In our case, the user has to configure rules that determine if a land-use type is allowed to be converted (transition probability = 1) or not (transition probability = 0) into another land-use type (see chapter 2, section specification of rules). The user decides by mouse click at what time he (or she) wants to change a cell, a part of the region or insert a linear, irregular or point-shaped infrastructural element. Changes however, which do not conform to the previously configured rules are automatically blocked. This user-driven and non-automatic updating was chosen to provide transparency to the evaluation outcomes: the user receives an evaluation result, which does not contain mixed information between an active planning decision and otherwise determined transitions of land-use types. The user can exclusively experience the effects of each change that he (or she) wants to have simulated by the system.

The basic input dataset of PYL are "CORINE land-cover (CLC) 2000" maps or comparable land cover maps (biotope type/land-use type maps). Geo-pedological, climatic or topographic information is imported as geo-referenced information layers. In the system, these data layers are overlapped with the land cover maps. Their information can then be assigned to the cells as additional attributes.

Evaluation Procedure

The evaluation procedure in PYL is based on an iterative process (Fig. 1), which includes the following steps:

(i) Identification and selection of regionally important land-use types, infrastructural elements and ecosystem services. The land-use classification standards of CLC 2000 and the nine ecosystem services (or landscape functions (LUF)) set described by Perez-Soba and others (2008) are available as initial settings. According to Perez-Soba and others (2008) LUF's are the goods and services provided by the different land-uses, which characterize the most relevant economic, environmental and social aspects of a region. Mainly social land-use functions according to this concept are human health and recreation, provision of work, and cultural. Economic functions are residential and land independent production, land based production and transport. Environmental functions are provision of abiotic resources, support and provision of biotic resources and maintenance of ecosystem processes. The approach was chosen, as the underlying indicator system is well elaborated and was considered as valuable input and example for demonstrating to the PYL users how to come up with a sound regional evaluation base.

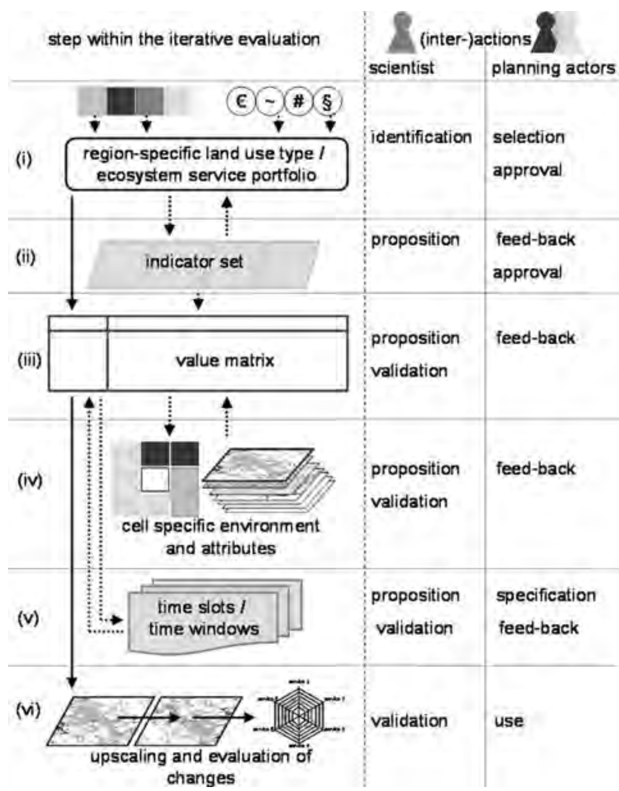

Fig. 1 Iterative evaluation procedure in PYL

The user can modify these initial settings or adopt completely different settings according to the regional application targets. In the example of the REGKLAM project, this step is carried out as a moderated process based on a number of workshops together with representatives of the regional planning administration and the sectoral experts involved in planning.

(ii) In the following, a set of (adapted) indicators is identified in co-operation with the planning actors who provide regional expertise and information on how to assess the impact of the land-use types and infrastructural elements on ecosystem services.

One of the most challenging questions at the regional level is the availability of research studies or monitoring results, which allow for assessing the impact of land-use types and land-use changes on ecosystem services. The 1:1 transfer of indicator-based approaches such as the LUF-approach of Perez-Soba and others (2008) might cause problems, because even available information is not always published or well documented and exploited. Also ownership structures might cause added issues, as information on private land-uses is less accessible than information on state-owned land (e.g., forests). Therefore, existing approaches such as the LUF concept are used as an example and "start kit", but must necessarily be adapted together with the regional planning actors. This applied a fortiori, as not only the indicators, but also the addressed ecosystem service set itself might vary in dependence from the regional context and planning questions.

As an example, for the adaptation of PYL to the REGKLAM study, a combination of indicators derived from regional statistical data (e.g., land prizes, tax revenue, average revenue from land-based production in agriculture and forestry, cluster characteristics for the economic wealth), measured and modelled indicator values (e.g., biomass production in forestry and agriculture) and scores assigned by stakeholders and experts in a multicriteria evaluation approach (esp. to evaluate the impact on human health and well being and the aesthetical value) were used (Koschke and others, accepted). Figure 2 summarizes the stepwise integration of multiple knowledge sources into the evaluation basis (steps 1–4) and the way that this basic information is subsequently processed (steps 5–10).

The indicators are used to rank the land-use types and infrastructural elements on a relative scale from 0 (worst case) to 100 (best case) according to their specific impact on the ecosystem services. The introduction of this relative scale aims to facilitate a balance of trade-offs between different ecosystem services to overcome two problems: (a) indicator sets for different land-use types are often assigned in a range of different scales and are expressed in variable dimensions (Fürst and others 2009). (b) Regional reference and transferability of published indicator sets [see Perez-Soba and others (2008)] are not given in all cases, and availability of regional data is often poor. Therefore, indicators are selected and weighted to include regional expert knowledge and to compensate for knowledge gaps. Scientific expert knowledge and results from literature analyses are used to make an initial proposal for appropriate indicators. As described before for the REGKLAM project, the final selection of the indicator sets was realized in a discursive process with the planning actors. Table 1 gives the ranking for the land-use types relevant in the REGKLAM project.

(iii) A value matrix is set up in the system that contains impact values of the land-use types and infrastructural elements for the ecosystem services. These values are considered to be the maximum in the

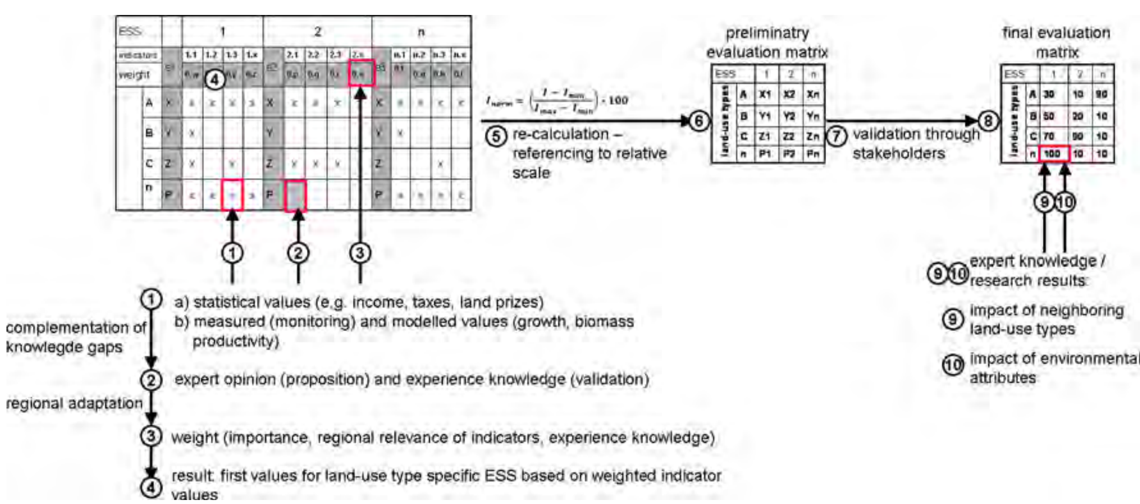

Fig. 2 Stepwise integration of different knowledge sources into the evaluation matrix

Table 1 Exemplary evaluation for the REGKLAM project (actual state, discussion ongoing)

CORINE 2000 land-cover classes	CC mitigation	Bio-resource provision	Ecological functioning	Economic wealth	Aesthetical value	Human health and well being
Continuous urban fabric	0	0	0	100	0	0
Discontinuous urban fabric	0	0	0	75	0	0
Industrial or commercial	0	0	0	100	0	0
Road and rail	0	0	0	75	0	0
Port areas	0	0	0	50	0	0
Airports	0	0	0	75	0	0
Mineral extraction sites	0	0	0	75	0	0
Dump sites	0	0	0	50	0	0
Construction sites	0	0	0	75	0	0
Green urban areas	0	0	0	0	25	25
Sport and leisure facilities	0	0	25	25	0	25
Non-irrigated arable land	25	100	50	50	25	25
Vineyards	25	25	50	25	50	25
Fruit trees and berries	50	25	50	25	50	50
Pastures	50	25	75	25	75	75
Complex cultiv. patterns	75	50	75	25	50	50
Annual + permanent crops	75	75	75	25	750	75
Deciduous forest	100	50	100	25	100	100
Coniferous forest	100	75	75	25	75	75
Mixed forest	100	50	100	25	100	100
Natural grasslands	50	25	75	0	75	75

specific regional context. As an evaluation principle, these values can only be reduced, e.g., by unfavorable site or climate conditions or negative impact by neighboring land-use types. The value matrix is of central importance within the evaluation concept, as all subsequent modifications of cell values are based on it.

(iv) The impact of environmental attributes and proximity effects on the cell values is set up in the form of rules. These rules specify to what percentage the regional maximum value of a land-use type or infrastructural element is reduced (see also Table 2). Proximity effects are assumed to occur only in a case where two different land-use types are neighbors. Following the model of a Moore neighborhood, different neighborhood types are considered. A longitudinal neighborhood has the full impact, whereas in the case of diagonal proximity of the cells, the impact is reduced as a convention to 25%. In the case of point shaped elements, the user must specify the spatial distance (gradient) up to which its impact is valid and up to which a percentage reduction in the original cell values should be considered. Within the gradient, a linear decrease in the impact is assumed starting with the highest impact (full percentage reduction) on the original values of the land-use types at the cells nearest to the point-shaped element. The gradient can be centric or irregular, even with an ex-centric localization of the point-shaped element.

Expert knowledge based on literature analysis is used to provide a first proposition of how to take into account environmental factors and proximity effects (Fig. 2). In the REGKLAM project, this proposition was intensively discussed with the planning actors, because especially with regard to proximity effects, there is little scientific knowledge about how to describe them precisely.

(v) Time dependent differences in the land-use type values are introduced to take into account ecosystem dynamics. The periods until a newly established land-use type or infrastructural element fulfils “fully” an ecosystem service are highly variable. As an example, a forest ecosystem takes at least one rotation period until it provides ecosystem services to the full extent. In contrast, industrial sites or settlements develop their full impact from the time they are established. In consequence, it is impossible to define a general and final point in time t_n on the landscape level for accounting changes of the ecosystem services

Table 2 Overview on the rule setting options in PYL according to the rule type, its meaning and application case and the group of persons, which determines the rule

Decisive attribute	Meaning and examples	Application area	To be determined by
A. Adaptation of the land-use type values to local (cell-specific) conditions			
Environmental attributes	Land-use type value can be reduced if environmental attributes are limiting (e.g., productivity at poor sites)	Correction of the land-use type values in dependence from local (cell specific) settings	Expert knowledge + regional stakeholder experiences
Neighboring land-use type	Land-use type value can be reduced if negative impact of neighbored land-use types occurs (e.g., shadowing effect of forests next to agricultural sites)		
B. Restrictions to transition from one land-use type to the other (forbidden/allowed moves)			
Environmental attributes	Land-use type cannot be converted into selected other types in dependence from limiting environmental attributes (e.g., deforestation at steep slopes)	Description of environmental protection regulations (e.g., soil protection)	Expert proposition + existing regulations/ directives + stakeholder decision
Land use type of the cell	Land-use type cannot be converted into selected other types in dependence from the starting type (e.g., conversion of deciduous forests into coniferous forests is forbidden)	Description of protection regulations (e.g., habitats protection directive) or "known" unlikelihoods (e.g., transition from settlements to forests)	
Neighboring land use type	Land-use types cannot be converted into selected other types in dependence from neighbored land-use types (e.g., interdiction to establish dump sites next to settlements)	Restriction of undesirable or unlikely conversion cases	
Infrastructural elements	Land-use types cannot be converted into other types in dependence from the existence of infrastructural elements such as roads, water bodies (e.g., interdiction to clear-cut forests along water bodies)	Description of protection regulations (e.g., EU Water Framework Directive) or conflicting conversion cases (e.g., new settlement area along highway)	
Thresholds for the portion of a land-use type	Minimum/maximum thresholds and development trends (increase/decrease/ remain equal) can be determined for selected land-use types (e.g., portion of dump sites should not be increased)	Expression of a vision on the regional development (character of the landscape, portions of the land-use types)	Stakeholder decision, which must be made in a discursive process
Thresholds for environmental services	Minimum and maximum thresholds can be specified for the ecosystem services (e.g., ecological value of a landscape should be kept or increased)	Expression of global targets in regional development/prioritization of services	

provision for land-use changes. Therefore, in PYL, time slots can individually be specified by the user regarding the type of planning measures (afforestation ⇔ establishment of a new industrial site) in the form of regular time slots of 10 years, for example, or related to the needs of sectoral planning in the form of irregular time windows of 10, 30, 50 and 100 years. As an example in the REGKLAM project, time slots of $t_n = 100$ years (year 2110), $t_n - 50$ (year 2060), $t_n - 70$ (year 2040) and $t_n - 90$ (year 2020) are used to evaluate the effects of land-use changes as compromise between short, medium term and strategic planning in agriculture, forestry and regional planning. The long-term time slots (2110, 2060 and 2040) are related to forest dynamics, as afforestation is one of the most discussed countermeasures to mitigate climate change effects. The short-term time slot is related to structural changes in agriculture (introduction of agroforestry systems, reduction in intensity of farming practices) and the planning horizon of regional planning. The time dependent modification can be done for all ecosystem services or only for selected ones. As in the previous case, an initial assessment was based on expert knowledge and discussions with the planning actors in the REGKLAM project. They decided upon the final time slots, land-use types and ecosystem services to be taken into consideration.

(iv) For up-scaling of the evaluation to the regional level, a weighted mean was calculated for each ecosystem service by adding up the values of each cell for the singular service and dividing the sums by the total number of cells. To exclude any influence of the evaluation result by impact factors, such as cell size, the latter was fixed to 100×100 m^2.

Specification of Rules

As a second element for the regional adaptation of the platform, PYL enables one to specify planning rules and restrictions (Table 2). These rules affect either (a) the evaluation results (see chapter 2, section evaluation procedure), or (b) the transition probability of a land-use type (see also Fürst and others 2010a).

The transition probability of land-use types (rules type b.) depends on initial land-use type, on proximity effects and on environmental factors. The fine tuning between the two possible cases “conversion is allowed” (transition probability = 1) or “conversion is forbidden” (transition probability = 0) is managed by the evaluation. Each conversion of a land-use type influences the value of the cell (impact on different ecosystem services). A conversion of a land-use type with high value for one or several ecosystem services into a land-use type with a low(er) value is in consequence “punished” by a worsening of the value(s) of the ecosystem service(s) on landscape level. It is assumed that “punished” changes are less probable because usually, planners want to keep or even improve the actual status of ecosystem services provision.

Table 2 resumes the rule setting options in PYL regarding their type (a. adaptation of the land-use type values to local (cell-specific) conditions, see also chapter 2, section evaluation procedure, or b. restrictions to transition from one land-use type to the other), their meaning and application area and the group or knowledge source, which decides upon how this rule is applied. While the evaluation related rules (rules type a.) must be based on expert knowledge complemented by stakeholder experiences, all other rules intend to express stakeholder decisions, the latter of course on the basis of existing (legal) regulations and expert knowledge (see chapter 2, section evaluation procedure, Fig. 1).

The single rules describing the dependence of the transition probability of a land-use type to initial type, proximity effects and environmental factors can be used singularly or they can be combined and saved as a rule set. This supports the translation of complex planning restrictions as they might be given in the framework of laws or EU directives. Here, the possibility of combining rules enables comparison of the functioning and effects of competing directives or planning restrictions.

Another aspect to be considered in landscape development are thresholds, which restrict the spatial extension of a land-use type, or which provide development trends to either conserve or evolve the character of a landscape. Therefore, PYL provides the opportunity to set thresholds for the minimum and maximum share of a land-use type as well as trends for its development (increase, decrease, unchanged). In the case that such a threshold is exceeded, a warning signal is given that, however, has no effect on the continued simulation run; rather, it merely informs the user. Finally, minimum or maximum thresholds for the ecosystem services can be introduced. This provides the option to reflect political targets in planning, such as keeping the ecological value or water quality at a certain level.

Results: Application of the Platform

A test area within the model region of the REGKLAM project was selected to present the applicability of PYL. The study area “Dresdner Heide” is actually characterized by bisection into an intensively settled and industrialized western part and a forested eastern part. The forested part is dominated by pure Scots pine stands. Figure 3 shows the start situation in the study area. The diagram left of the map displays the actual status of six ecosystem services, which were considered by the regional planners as relevant for the model region. These are (1) human health and well being (water and air quality), (2) economic wealth (income and provision of working places), (3) aesthetic value (intensity of recreation and tourism activities), (4) ecological functioning (richness in species and structures), (5) bioresource provision (provision of biomass and food) and (6) climate change mitigation (ability to mitigate the risk of drought, erosion and flooding). The red dots in the diagram show the minimum and maximum thresholds which were defined together with the planners. They indicate that the actual situation is not satisfying, as the minimum thresholds were not reached for any of the ecosystem services. Furthermore, a warning signal is activated, which indicates that the area for deciduous and mixed forests is too small; this originates from the regional plan.

In Germany, the regional plan is an administrative and political instrument of spatial planning and land-use management. It regulates for administrative planning regions the efficient placement of infrastructure and the spatial development of the land-use for ensuring sustainable regional growth. For the test area, the regional plan foresees a conversion of the Scots pine stands and an increase of deciduous and mixed forests to at least 30%.

Within the next 20 years it is expected that the urban area in the Dresdner Heide region will grow by using all disposable areas of other land-use types (which are not protected within the regional plan). This applies also for industrial sites. It is expected that in particular areas covered by forests will be used for urban and industrial growth.

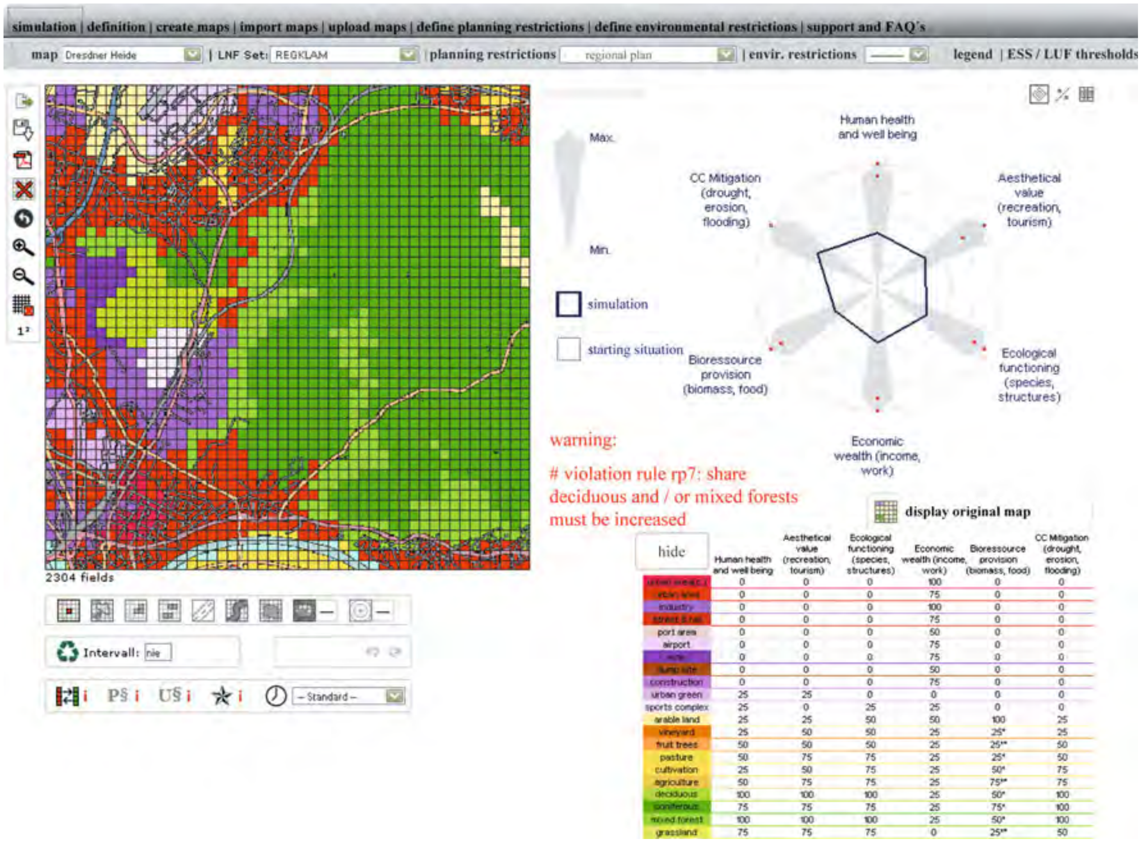

Fig. 3 Exemplary simulation run—starting situation in the study area "Dresdner Heide"

Taken from the regional plan, a conversion of a forest is only possible if the forest is situated directly in the neighborhood of a settlement and if at least one neighboring cell is not a forest, but any other land-use type. Furthermore, it is expected that within the urban area, a further congestion will take place which leads to a conversion of the land-use type "discontinuous urban area" into the type "continuous urban area". Figure 4 shows the effects of this scenario that was developed together with the planners as regards the parameter settings within the regional plan.

As a result, the diagram displays two lines. The bold line shows the results of testing the planning scenario and the dashed line represents the starting situation as a reference. Comparing both lines reveals that the provision of all ecosystem services will deteriorate with an exception for economic wealth. The question that the planners want to answer in such a situation is "what measures could at least compensate this situation or even contribute to an improvement?". The regional plan suggests as a possible measure a conversion of the dominating Scots pine stands in the eastern forested part of Dresdner Heide into deciduous forests with preference of European beech and oak. The simulation of this strategy (Fig. 5) shows that the services "aesthetic value" and "ecological functioning" would remain on the same level as at the starting situation without urban growth. The increase in the service "economic wealth" gained by urban growth will not be reduced by forest conversion: lower growth and yield of the mixed forests and longer rotation periods (oak) are expected be compensated by higher timber prices even for small dimension timber of beech and oak. The services "human health and well-being" would even be slightly increased compared to the situation at the start. In contrast, the services "bio-resource provision" and "climate change mitigation" would be even lower compared to the planning scenario with urban growth. The evaluation assumes in this case that the deciduous forest would provide less timber according to the regional valid yield tables, and that it would be less well-adapted to climate change. As a consequence, it could contribute, to a lesser degree, to mitigation of its effects.

To test the robustness of the conversion strategy, a moderate regional climate change scenario was introduced in the evaluation that assumes a reduction of the mean annual precipitation of 30% and an increase of the mean annual temperature of 2°C (Fig. 6; Table 3). This scenario was formulated on the basis of ongoing discussions in REGKLAM on the range until which forest management

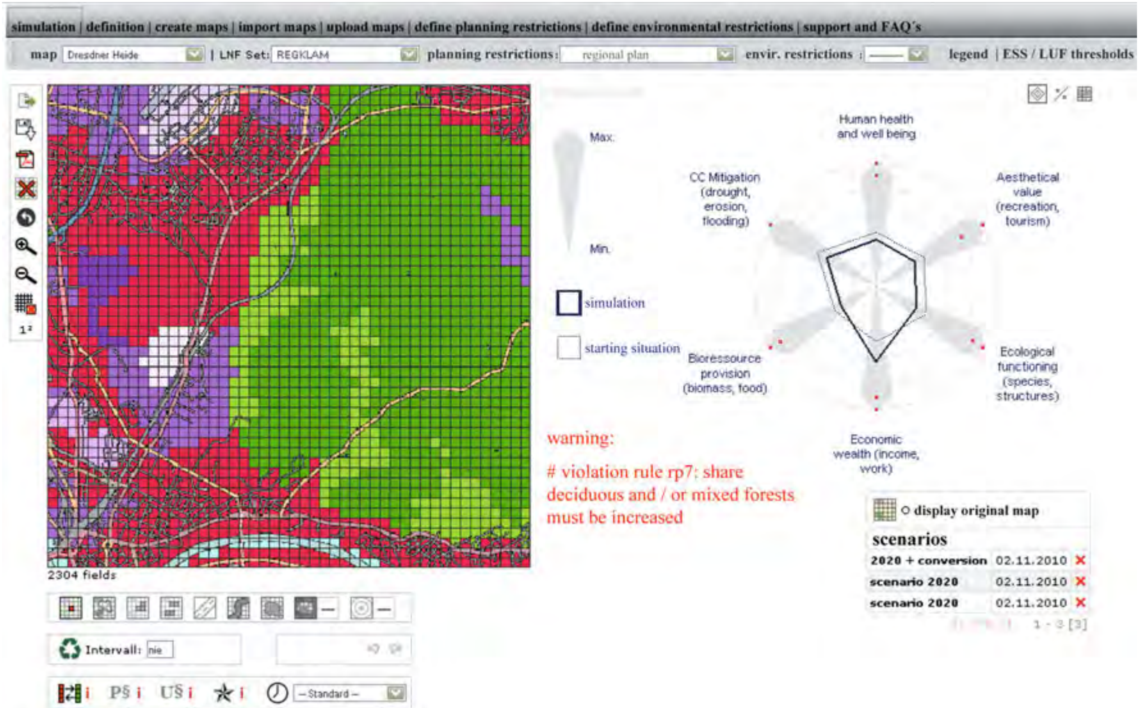

Fig. 4 Exemplary simulation run—effects of the planning scenario "urban growth"

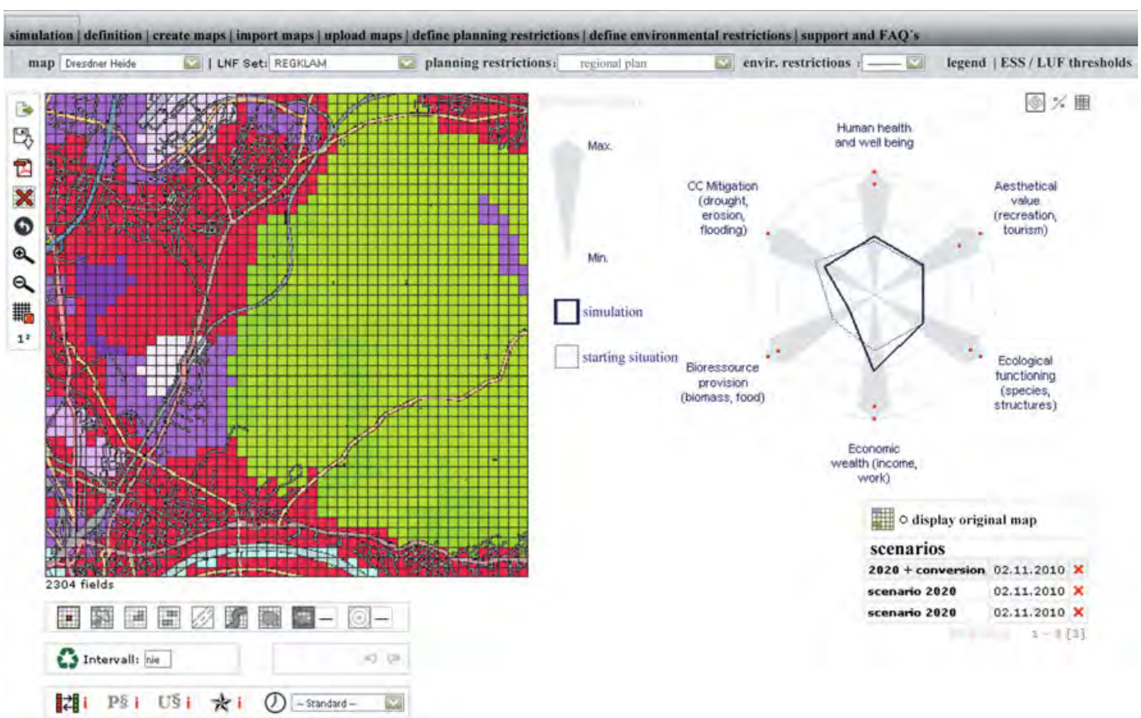

Fig. 5 Exemplary simulation run—effects of the countermeasure "forest conversion to deciduous stands"

can respond to climate change. As a consensus, it was agreed in the REGKLAM project that an adaptation is only possible for moderately changing conditions. The "numbers" 30% less precipitation and temperature increase of 2°C were agreed as "translation" of a moderate climate change scenario for regional environmental management strategies (see also Eisenhauer and Sonnemann 2009; Fischer and others 2009; Goldberg and Bernhofer 2008).

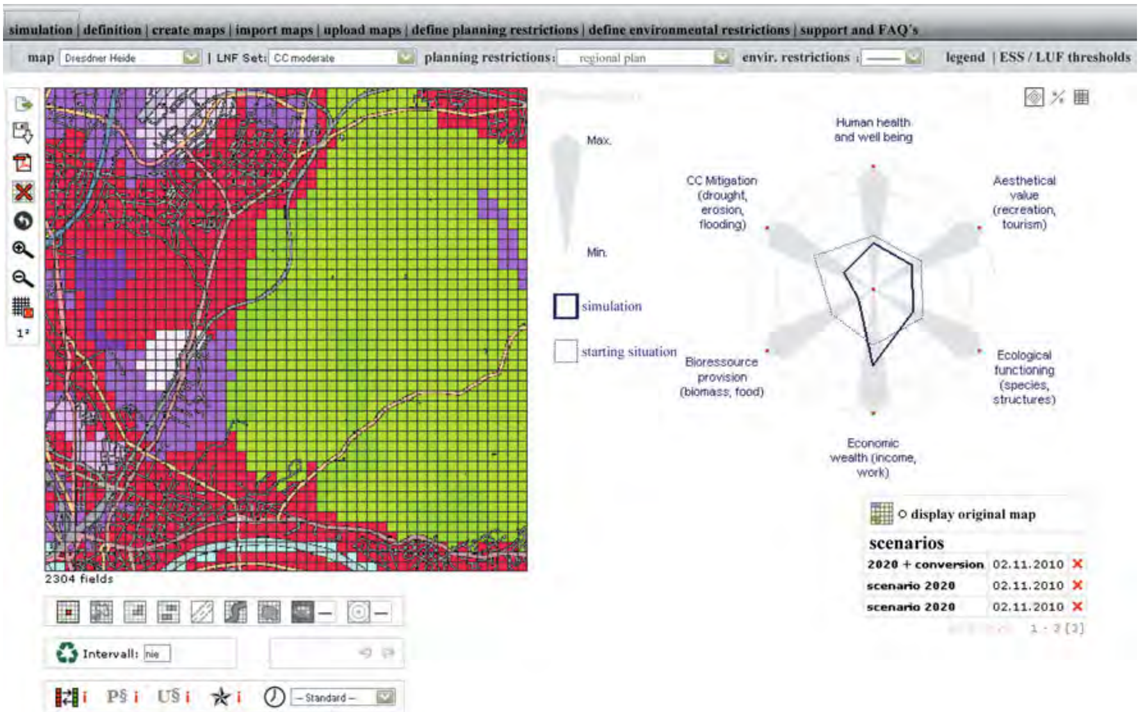

Fig. 6 Exemplary simulation run—impact of a climate change scenario on the evaluation results after forest conversion

Table 3 Evaluation of CC impact on the three forest types (basis: expert opinion and regional research results)

CORINE 2000 land-cover classes	CC mitigation	Bio-resource provision	Ecological functioning	Economic wealth	Aesthetical value	Human health and well being
Deciduous forest	50	25	75	25	75	75
Coniferous forest	100	75	75	25	75	75
Mixed forest	100	50	100	25	100	100

For this scenario, a high impact is expected on the land-use type "deciduous forest" by the forest managers due to the planned dominance of European beech and oak. European beech responds sensitively to a reduction in precipitation, while the risk for oak stands to be damaged by pests is increasing. The respective reduction in the value of the land-use type deciduous forest is based on chrono-sequential field tests along a climatic gradient in the German State of Saxony (Fürst and others 2004). Table 3 and the diagram in Fig. 6 reflect the expected impact of the climate change scenario on the ecosystem services.

As a potential alternative, a conversion of the Scots pine stands into mixed forests was simulated; such a conversion is assumed by the forest managers to be much less sensitive to climate change effects than pure deciduous forests. The evaluation of this land-use type is based on field tests. Figure 7 shows the result of this simulation. The conversion of the Scots pine stands into mixed stands would result in a similar situation when compared to conversion without climate change (Fig. 5). This corresponds well to findings from most recent regional research projects (Goldberg and Bernhofer 2008; Eisenhauer and Sonnemann 2009; Fischer and others 2009).

Discussion

The presented version of PYL supports a comprehensive assessment of possible benefits and risks of planning decisions for ecosystem services. The indication of land-use type impacts on ecosystem services on a relative scale from 0 to 100 represents a highly aggregated evaluation result. PYL uses a qualitative approach, which is based on mixed information sources, such as statistical data, measured and modelled values and on expert opinion in a multicriteria evaluation approach (Koschke and others, accepted). The highly aggregated information might not contribute to a substantial improvement in basic knowledge of ecosystem processes (see e.g., Janssen and Uran 2003), but can contribute to further the understanding of ecosystems in terms of how ecological processes change with land-use change at regional scales. The benefit of our

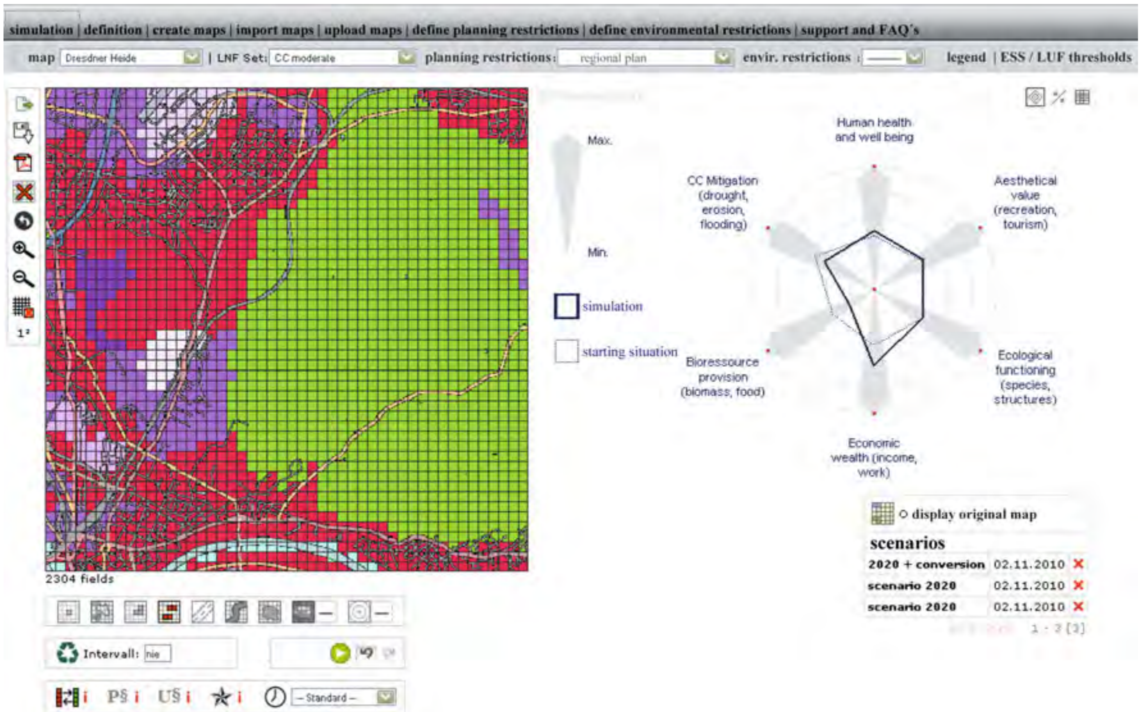

Fig. 7 Exemplary simulation run—effects of the adapted planning measure "forest conversion to mixed stands"

evaluation concept is related to one of the major problems in land-use management support: There is a general lack of cross-sectoral indicator sets that would allow integrated evaluation of the impact of land-use pattern on ecosystem services in environmental and spatial planning. Other problems are related to the fact that either the sectoral evaluation methods are different, or the reference scale levels are different (Yli-Viikari and others 2007; Wijewardana 2008; Volk and others 2008). By the use of mixed information sources and by relating all available information stepwise to a relative evaluation scale, a harmonized evaluation base is provided, which overcomes at least partially the data, indicator and knowledge gaps at a landscape level.

However, the recent version of PYL shows some shortcomings. Services such as the ecological functioning or the aesthetic value at the landscape level cannot be appraised within a cell-based approach, because this would ignore landscape structure characteristics such as patch size, shape and distribution, fragmentation and spatial connectivity and the impact of infrastructural elements such as roads and highways (Uuemaa and others 2005, 2009; Botequilha Leitao and Ahern 2002). Current work includes therefore experiments for the enhancement of PYL with landscape structure indices (landscape metrics), including a validation of the systematic error in the evaluation, which is provoked in PYL by rasterizing the original landscape structures. We plan to consider the additional impact of landscape structures by an increase or decrease of the evaluation results after having finished a simulation. The impact of landscape structures will be integrated and tested first for the services ecological functioning and aesthetical value and later on—if the conceptual phase is finished—also for other services (Frank and others, accepted). Besides using landscape metrics at the landscape level, we plan to consider also structural indices on the level of single land-use classes to reflect better their spatial configuration. An example is the Aggregation Index, which is actually tested to describe the compactness and spatial distribution of the patches of a land-use type. The results will be used as an indicator for the structural richness with relevance for evaluating ecology and aesthetics at the landscape level.

Another constraint in the acceptance and use of PYL is the still-missing interface required for coupling with models. Coupling PYL to models from different sectors and with different degrees of complexity would generate the same problems as described for the indicators, such as different complexity, different reference scales and input data, error propagation in model chains, etc. (e.g., Rossing and others 2007; Lautenbach and others 2009). Taking hydrology and forestry as an example, models might be over-parameterized, which limits their utility for the regions for which they were developed. Systems based on (coupled) models are difficult to administer and to transfer from one region to another (Malczewski 2004; Volk and others 2009). Furthermore, there are few models covering the interactions between land-use types in a landscape context (see e.g., Lambin and others 2000; Roetter and others 2005; Verburg and others 2006). As a consequence, the use of a cellular automaton approach was considered as the most appropriate solution (a) for integrating spatial interactions between different land-use types which mutually influence the transition probabilities in a generalized way, (White and Engelen 1997; White and others 1997) and (b) for standardizing the evaluation of interactions between different land-use types regarding their impact on the provision of ecosystem services.

A missing element in the presented approach is an automatized transition of land-use types, which would reflect the (natural) landscape dynamics as highlightened by Silva and others (2008). Until now, two considerations have caused us to omit an automatized transition: it is essential to distinguish between transition drivers that are man-made (management measures), indirectly impacted by human activities (climate change), or driven by natural ecosystem processes (succession). This is due to the fact that in PYL, management impact and climate change impact are still being taken into consideration, and only naturally-driven-transition processes should be included. So far, it has not been possible to identify appropriate test and training regions where an in-depth analysis of land-use changes could provide sufficient information to derive transition probabilities that are purely dependent on natural processes. On the other hand, planners have yet not shown a desire to overlap natural transition and planning-based transition in the actual application cases of PYL, because this would lower the transparency of the simulation results (“black box style”, Malczewski 2004).

Conclusions and Perspectives

PYL is designed to support a comprehensive analysis of the impacts of planning measures on ecosystem services. The feedback of planners involved in different application cases, such as the REGKLAM project, was positive and has proved that the demand to easily visualize and evaluate planning ideas and to identify the most adequate alternative has been met. A most recent application in testing afforestation alternatives in Dresdner Heide has shown that the evaluation procedure is highly accepted and intensively supported by the involved stakeholders and experts. Based on a few examples of how to evaluate the impact of a land-use type on an ecosystem service, only three-one-day workshops were needed to complete the evaluation matrix. Also the use of the ecosystem services concept was highly appreciated and was considered to facilitate especially the mediation of conflicting land-use interests. Further development in other application cases is in progress, and existing shortcomings in the evaluation and up-scaling approach are intended to be eliminated.

Considering the development perspectives of PYL, Verburg and others (2009) highlight that land-cover-based analysis of land-use changes does not really reflect the effects on land-use functions or ecosystem services, because the management within land-cover classes or land-use types has a considerable impact on the services to be provided. As an example, Dale and Polasky (2007) propose an indicator set that reflects management aspects within agriculture. For PYL it is planned to complete the CLC 2000 classes by types of management practices in forestry and agriculture. These will be integrated as sub-classes of the classes non-irrigated arable land, deciduous forests, coniferous forests and mixed forests and will help to test the impact of regional management practices, e.g., in organic farming or sustainable forestry compared to scenarios of “practices as usual”. In forestry, two aspects are intended to be combined within the management types: the forest ecosystem type and the forest development type (Eisenhauer and Sonnemann 2009). Forest ecosystem types are classified by the dominating tree species and the admixed tree species (stand type), most important site properties (water balance, fertility) and geo-topographically driven climate conditions (e.g., continental/subcontinental, alpine, mountainous or lowland climate type). Hence, the ecosystem types could help to localize or assign the management types by the stand type to remote sensing-based land-use type classifications (e.g., CLC 2000 or other land cover maps). The forest development type reflects management strategies focusing on the tree species mixture and stand structure with their impact on water balance, nutrient cycles, habitat quality and bio-resource productivity. In agriculture, the formulation of management types is still in discussion, but is planned to combine cultivation and fertilization techniques with crop rotation schemes to reflect the most representative management practices with a classifiable impact on ecosystem services.

Other future plans for improving PYL include increased internal use of the layers of information to designate, for instance, cell specific risk zones related to climate change. An example is soil erosion risk depending on pedo-geological information, topography and land-use type or even linear landscape elements, such as hedges, fences, ditches.

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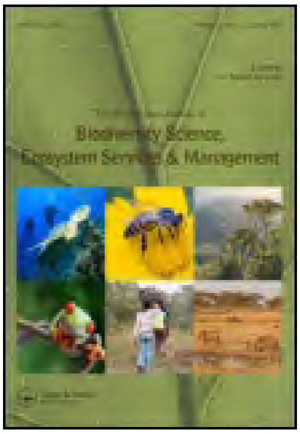

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Integrating land management and land-cover classes to assess impacts of land use change on ecosystem services

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The paper presents a case study in which land use strategies to mitigate Climate Change effects are developed for a model in Saxony, Germany. In this region, the degree of freedom to respond to Climate Change with land-cover changes is very small. Based on a participatory process, an approach was developed to extend land-cover classes (e.g. forest, agriculture) by land management classes. In this paper, the focus is on the forest management classification. In the discussion with regional actors, four recommendations were identified that must be fulfilled to make land management classes regionally applicable and relevant. They should (1) reflect the effectiveness of management practices to mitigate Climate Change impacts, (2) express different management objectives, (3) show the compatibility with future trends (new crops, new public demands) and (4) provide a link to land-cover data. Finally, 22 mixed land-cover and management classes in forestry and around 30 classes in agriculture could be derived. For a test case on afforestation of agricultural sites the paper demonstrates that a more differentiated look at land management practices instead of land-cover classes helps to improve the understanding of (a) regional potentials to adapt to Climate Change and to mitigate its effects and (b) the impact of sectoral management strategies at landscape level on the provision of ecosystem services.

Keywords: land-cover changes; land management classes; Climate Change mitigation strategies; ecosystem services; participatory approach

Introduction

Land-cover changes are the consequence of direct and indirect human impact on nature to produce and secure essential abiotic and biotic resources (see e.g. Rackham 2007; Armesto et al. 2010; Dreibrodt et al. 2010; Ellis and Pontius 2010). In Europe, the actual spatial distribution of forests, agricultural areas and settlements has more or less been achieved since the Late Middle Ages, with only small recent modifications (Antrop 2005). Nowadays, ongoing migration, demographic changes and globalization processes in natural resource production and consumption might amplify heterogeneity in land use intensity and could intensify land-cover changes even in Europe (Lambin et al. 2001; Lambin and Meyfroidt 2010).

Though land cover change is an important factor for the sustainability and extent to which ecosystem services are provided (Metzger et al. 2006; Lautenbach et al. 2010), a problem exists in the evaluation of the impact of such changes: within a land cover class large heterogeneities are evident in the way that land management is practiced. Land management practices in forestry or agriculture, for instance, are difficult to assess through remote sensing techniques. In consequence, valuable information concerning their potential to contribute to a healthy and well-functioning environment might be lost (Dale and Polasky 2007; Verburg et al. 2009; Power 2010). Furthermore, at least in Western Europe, large spatial changes in the land cover rarely occur, as they are restricted for economic reasons and by legal barriers (Faaij and Domac 2006).

Much higher dynamics can be observed in spatial changes of land management. A recent trend is, for instance, the large scale reduction of crop diversity within crop rotations with an increasing preference for, and intra-crop rotation frequency of, bioenergy crops such as maize or rapeseed, as a result of the renewable energy use targets at the EU level (Zegada-Lizarazu and Monti 2011). The impact of such large scale trends in land management can superpose the impact of smaller land cover changes. Programmes for enhancing biodiversity, protecting soils, or reducing Climate Change driven risks such as flooding, which target land-cover changes (e.g. afforestation programs) and which ignore, at the same time, the impact of land management on the landscape scale, must consequently be questioned; even more so as they are at the same time often weak in their practical relevance and applicability (Firbank et al. 2008).

Taking agriculture and forests as the most important spatial examples, the integration of land management practices in an improved evaluation of the natural potential of a landscape to provide ecosystem services is faced with three major challenges (see e.g. Verburg et al. 2009; Fürst, König, et al. 2010, Fürst, Volk, Pietzsch, et al. 2010):

(1) identifying and classifying regionally typical land management practices. 'Regionally typical' might

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include criteria that reflect different practices dependent on ownership type and size classes of owned land. The classification could then be combined with ownership patterns to reflect scenarios of land management patterns instead of the real situation, which for the most part cannot be assessed;

(2) identifying generic classification criteria which focus rather on the impact of land management practices than on a too-detailed consideration of single management items. In addition, criteria must be defined that support the permanent location of the classes on maps; and

(3) developing a land management classification that expresses the extent to which a land management type can contribute to the provision of ecosystem services. This should include also temporal development processes if they are relevant (e.g. in forests).

The paper intends to present and discuss a possible approach for how to improve the consideration of land management practices using the REGKLAM study (www.regklam.de) as example.

REGKLAM is a joint research initiative supported by the German Federal Ministry of Education and Research with the aim to develop Climate Change adaptation strategies in the strategic areas urban development, water and waste water management (including water protection and flood control), industry, land use (including agriculture and forestry), nature conservation and human health for a model region in Saxony, Eastern Germany.

Figure 1 illustrates the research concept of the strategic area 'land use' in REGKLAM and its interfaces with the other strategic areas in this project. Land use strategies to be developed in the strategic area 'land use' comprise (a) strategies for adapting the land management to expected future climatic conditions and (b) strategies for mitigating the impact of Climate Change on ecosystem services. Both types of strategies are closely related. They are distinguished because adaptation strategies focus more on onsite aspects of land use (e.g. sensitivity to extreme weather events, productivity), while mitigation strategies consider on-site effects as well as off-site effects (e.g. flooding, loss of biodiversity, impact on human health, provision of bioresources). Within the strategic area 'land use', (a) sectoral management strategies are developed for forestry and agriculture and (b) an integrative evaluation is carried out concerning how to make the best use of sectoral management strategies at the regional level, and where to identify a need for complementary land-cover changes. The combined land management/land-cover changes strategies will deliver the basis for the Climate Change adaptation strategies to be developed in the areas 'nature conservation' and 'water management'. Considering the strategic areas 'industry' and 'human health', similar

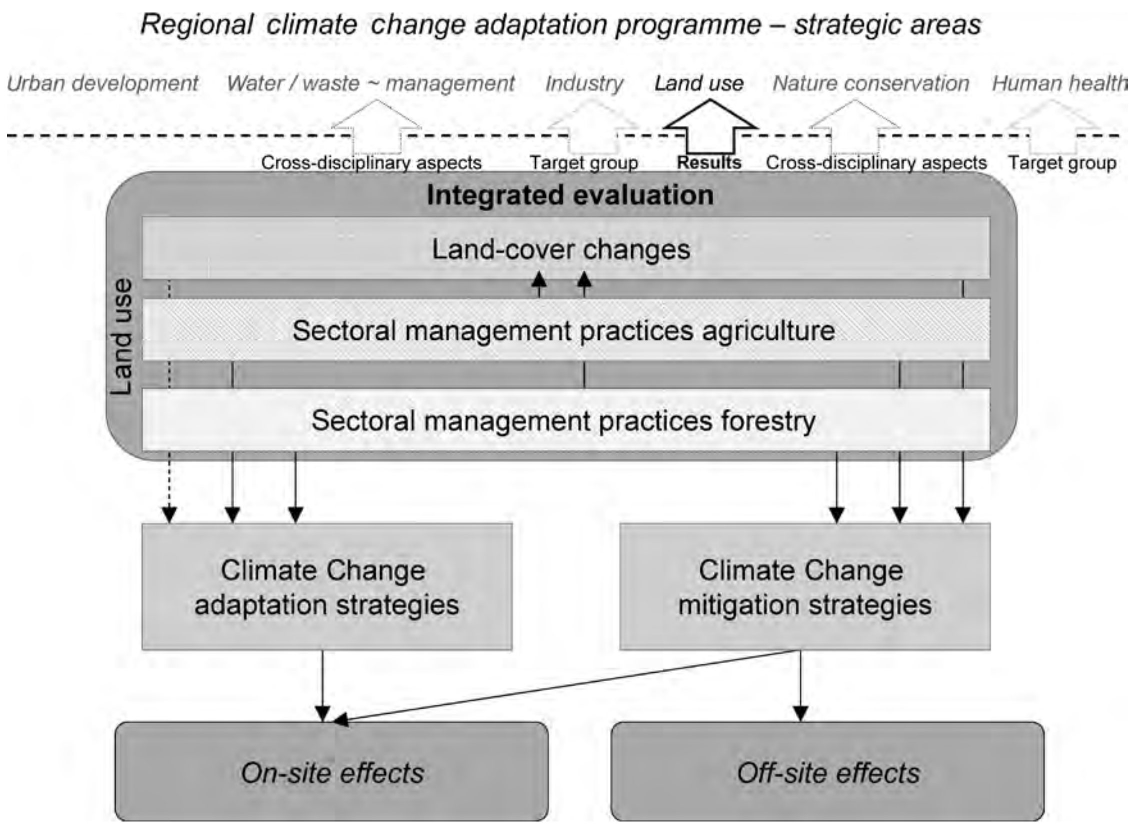

Figure 1. Flowchart of the research concept in the strategic area 'land use' in REGKLAM and of its interfaces with the other strategic areas in the project.

target groups are addressed, such as industrial enterprises, timber industry, regional citizens or water management authorities.

We introduce a theoretical framework for a classification approach in forestry by showing examples from the REGKLAM study. The applicability of this approach is tested using management classes in forestry to derive best practices for afforestation in an exemplary part of the REGKLAM model region. The test is carried out with the ‘Pimp Your Landscape’ (PYL) software (Fürst, König, et al. 2010, Fürst, Volk, Pietzsch, et al. 2010). We discuss the advantages and disadvantages of our approach and then draw conclusions regarding future developmental needs.

Material and methods

Land management/land-cover questions

In REGKLAM, adapted forest management strategies focus mainly on the development of less drought-sensitive forest ecosystem types and related innovations in silvicultural treatment and harvesting techniques. In agriculture, strategies are subdivided into strategies for crop production, orcharding, olericulture and viticulture with specific variations in the consideration of breeding and pest management aspects, technical protection against extreme weather events and soil management techniques. In a subsequent step, the ability of these strategies to mitigate Climate Change impact at a regional level (off-site effects) will be tested.

Within the REGKLAM project period, it is impossible to test each strategy in combination with one another considering each possible impact on ecosystem services. Therefore, consensus had to be reached among the farmers, foresters and regional planning authorities (a) regarding the most important services in the region, which have to be provided with land use (see Section 2.2), and (b) regarding scenarios for which Climate Change impact mitigation ability is tested.

For the formulation of the test scenarios, two subregions of the REGKLAM model region were selected as focus areas. The ILE (integrated rural development) region ‘Silbernes Erzgebirge’ and the ILE region ‘Dresdner Heidebogen’ represent typical socio-ecological systems in the model region. They are supported in the programme European Agricultural Funds for the Development of Rural Areas and have set up a regional coordination bureau and working groups representing the strategic areas of REGKLAM. These working groups consist of regional representatives from practice sectors (e.g. farmers, nongovernmental forest owners), municipalities, district administrations, the regional development planning association and governmental organizations (state forest enterprise, state office for environment, agriculture and geology).

In discussion with the land use working groups in the ILE regions, three most significant threats from Climate Change were identified: (a) biodiversity losses, (b) erosion and flood risks and (c) the divergence of bioresource production and consumption.

Scenarios to be tested to overcome threats (a+b) were afforestation with optimally adapted forest ecosystem types on agricultural sites in combination with improved (less intensive) farming practices, and for threats (a+c) conversion of existing forests with adapted forest ecosystem types in combination with short rotation plantations and increased share of bioenergy crops on agricultural sites. In both scenarios, an optimal implementation of the potential of adapted land management was intended.

Methodological approaches for assessing land management impact

For testing the scenarios and evaluating changes in the provision of ecosystem services, the software PYL was used (Fürst, König, et al. 2010, Fürst, Vacik, et al. 2010, Fürst, Volk, Pietzsch, et al. 2010). PYL combines the technology of a cellular automaton with geographic information system (GIS) features and a multi-criteria evaluation approach (Koschke et al. 2010). The cellular automaton approach supports the testing of variable land cover and of land management change scenarios. The GIS features help to handle and aggregate planning relevant information, which is necessary for the formulation of the scenarios (e.g. layers describing planned priority or reserved areas, protection areas, ownership type information) and for their evaluation (e.g. regionalized climate scenarios, site quality information, orographic conditions). The multi-criteria evaluation approach integrates step-wise information on the value of land-cover classes/land management classes for the provision of ecosystem services, starting with the selection of appropriate criteria and indicators and taking into account the impact of environmental attributes, proximity effects at the level of land-cover classes/land management classes and of landscape metrics at the regional level (Fürst, König, et al. 2010). Figure 2 illustrates the hierarchical evaluation approach.

Since the applied criteria and the underlying indicators are highly variable in their reference units, temporal and spatial resolution, mathematical operations are used to categorize the evaluation results on a relative scale from 0 (worst) to 100 (best).

Using the service ‘provision of bioresources’ and here the forest management class ‘Oak-Scots pine mixed forests’, Figure 3 gives an example of how the data aggregation and evaluation process was done in our study (cf. Koschke et al. 2010; see results: Table 2). For this application case, biomass productivity characteristics based on statistical agricultural data (online information of the Statistical Office, Saxony, www.statistik.sachsen.de) and growth and yield tables (Hilfstafeln 1990) were taken and were normalized in a first step to the scale 0–100. Considering forest data sets, an average stand age of 100 years and an average yield class of 2 were assumed based on the proposition of the forest experts (state forest enterprise) in our study.

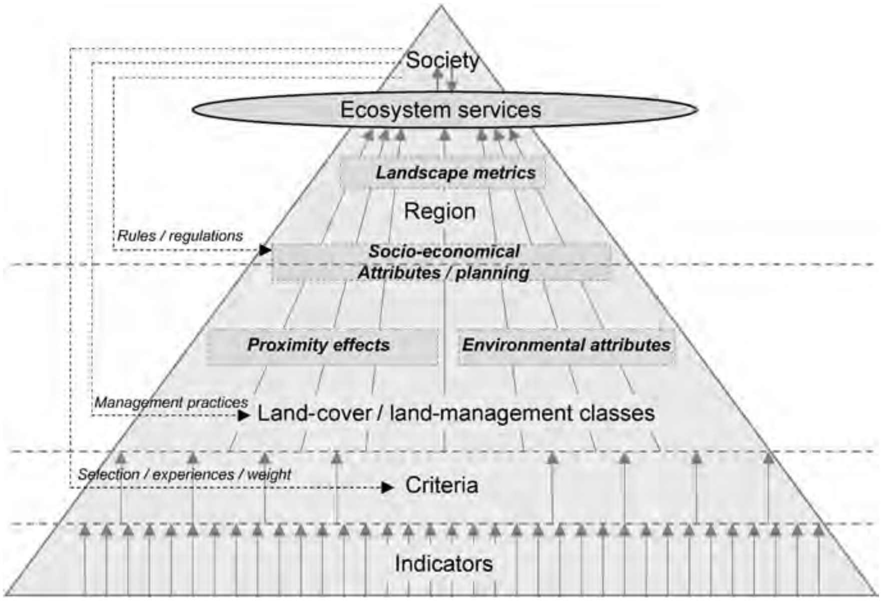

Figure 2. The hierarchical evaluation approach in PYL aggregates stepwise indicator and criteria-based information and integrates proximity effects, environmental and socio-economic attributes, and finally structural aspects at the landscape level.

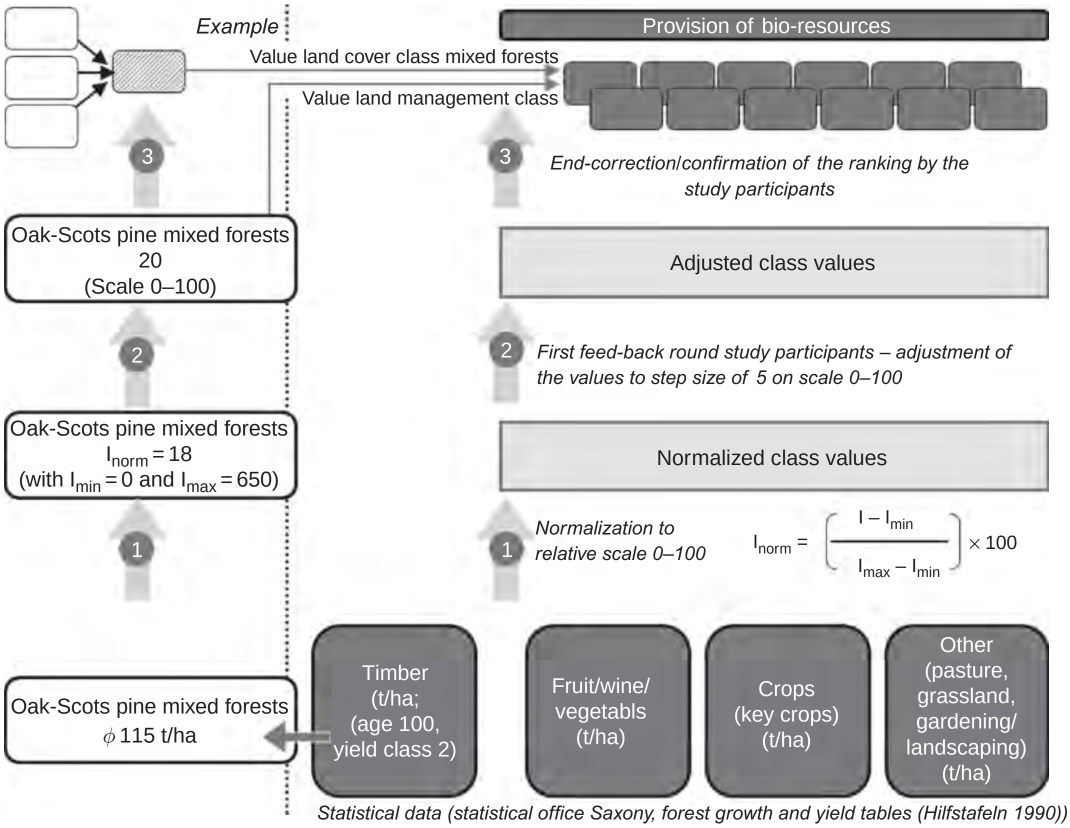

Figure 3. Application example for the data aggregation and evaluation process.

Based on the study participants feedback (see Figure 4), the values resulting from the normalization were adjusted to a step size of five on the scale 0–100. In a third step, the participants in the study did an end-correction and confirmed the final ranking of the forest management classes in relation to the land-cover classes.

Note here that the ‘old’ land-cover classes ‘coniferous forests’, ‘deciduous forests’ and ‘mixed forests’ are still included in the set of available classes. The values of these three land-cover classes for the different ecosystem services were calculated as a weighted average for the management classes that can be assigned to them.

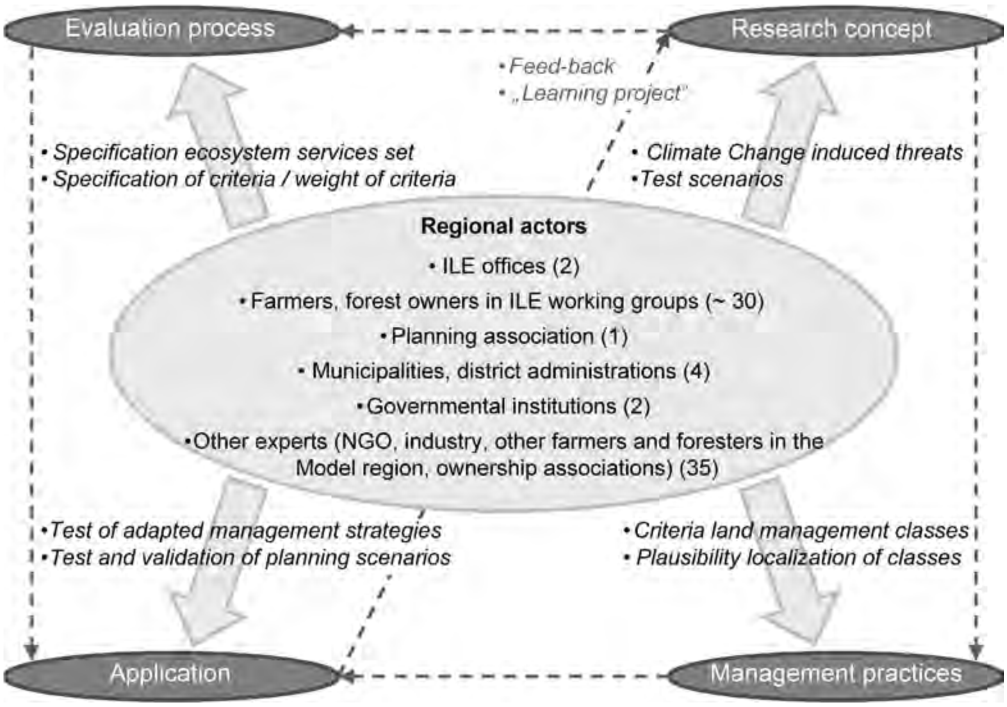

Figure 4. Participation of regional actors takes place in manifold parts of our work. Regional actors participate in improvement and concretization of the research concept; they are the core element in the evaluation process, and formulation of the management classes is based on their experience and knowledge. Finally, they give feedback from testing the approach.

The impact of proximity effects and environmental and socio-economical attributes shown in Figure 2 is quantified as a percentage correction of the achieved results per cell. Considering landscape metrics, the result which is achieved for an ecosystem service on a regional scale is corrected again by a percentage reduction or increase to express disadvantages or benefits of landscape structural aspects such as compactness or fragmentation of the area belonging to a land-cover or land management class (Frank et al. 2010). In consequence, the results of our evaluation approach only allow a qualitative appraisal of the impact of land-cover or land management changes on the provision of ecosystem services.

The most important point in our evaluation approach is that the set of analyzed ecosystem services is modified and partially extended compared to the standard set within the MEA (2005). This modification results from an intensive participation process by the working groups in the ILE regions (see Section 2.2) and by further experts at the level of the complete REGLAM model region, who are consulted for development of the adapted land management strategies (Fürst, Volk, Pietzsch, et al. 2010; Koschke et al. 2010). Taking the classification of the MEA (2005) into account, the set applied in our study considers provisioning services (bioresource provision including in our case timber, food and fibers; fresh water and air, defined in our case as a contribution to human health and well-being), regulating services (in our case formulated as 'mitigation of Climate Change impact'), cultural services (aesthetic value) and supporting services (contribution to the ecological integrity). Additionally, 'regional economy' was introduced, because this aspect was most important for the regional actors (Fürst, Volk, Pietzsch, et al. 2010; see also Menzel and Teng (2009)). Participation was also extended to the evaluation process itself (see Figures 2 and 3). First, the regional actors gave input regarding the selection of evaluation criteria and their regional importance in the course of a Delphi approach, which is actually completed by a public survey in the ILE regions (cf. Koschke et al. 2010). Second, knowledge basis and criteria for identifying land management practices and deriving land management classes were contributed, and third, information on planning regulations and planned priority and reserved areas came directly from the planning authorities (Fürst, Volk, Pietzsch et al. 2010). Figure 4 summarizes all activities within the development of the adapted land use management strategies where participation takes place.

Classification approach – concept and criteria

Together with the participants of our study, we developed a theoretical framework for classifying land management in forestry and agriculture in a way that (a) ensures its compatibility with the CORINE Landcover 2000 and Euromaps Land Cover data as reference standards in REGKLAM and (b) makes assessable the impact of land management practices on ecosystem services. Therefore, the classification criteria had to reflect cause–effect relationships.

The study participants identified some further requests for classification under the specific conditions of REGKLAM. These requests were (a) the classification

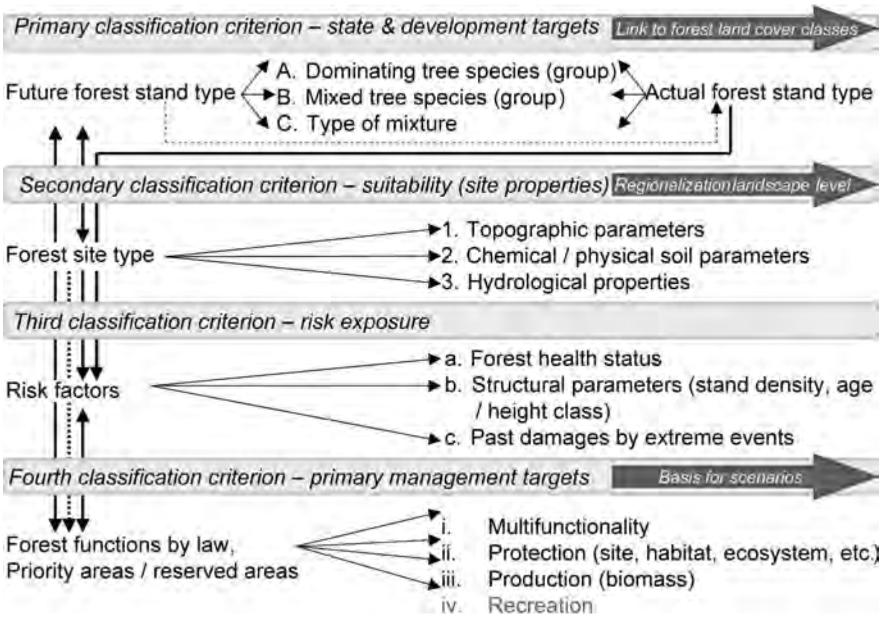

Figure 5. Hierarchical concept for classifying the management practices in forestry.

should consider the ability of land management to mitigate Climate Change effects, (b) prior or multiple management objectives (concept of multifunctionality in forestry) should be expressed by the classes and (c) compatibility with future land management practices such as new crops or crop rotations and soil management techniques should be ensured.

In forestry, the focus in REGKLAM was to express through appropriate classification criteria the sensitivity of the forest management classes against drought as a manageable Climate Change-related risk. By the participants of our study, the risk of windthrow was considered as too accidental and stochastic to be managed by silvicultural practices. Finally, the classification framework for forestry could be based on four criteria, (1) stand development type, (2) suitability (site properties), (3) (drought) risk exposure and (4) prior management targets.

The first criterion ‘stand development type’ expresses the silvicultural management concept in Saxony (Eisenhauer and Sonnemann 2009) in which eligible future forest stand types are determined by the actual stand types. The stand development types are characterized (a) by the vegetation type, that is, the dominating tree species, the mixed tree species and the type of mixture and (b) by the silvicultural management strategy, including tending and harvesting concepts, which determines the conversion of the actual stand types into the future forest stand types. Note that ‘tree species’ in our case frequently subsumes groups of tree species (e.g. the group ‘Scots pine’ includes different pine and larch species), which are similar in their demands on growth conditions (Richtlinie 2005). The actual stand types at the level of silvicultural management planning units (called ‘stands’) are documented in forest inventory (at least for state-owned forests) and they can easily be linked by the dominating tree species to the forest land-cover classes. Taking the interdependence between actual and future (planned) stand types into account, this classification provides a basis for simulating possible future development of the regional forests in REKGLAM.

The stand types as a core management instrument in forestry are closely related to forest site types, which express the second classification criterion ‘suitability’. The forest site types are characterized by topographical, soil-chemical and physical, and hydrological site properties. Information on these site properties is aggregated in so-called silvicultural growth regions, for which only a specific set of stand types is eligible (Richtlinie 2005; Eisenhauer and Sonnemann 2009). The site properties can be used for the spatial transfer of the silvicultural growth regions to areas that are not (yet) covered by forests, and their regionalization makes accessible forest management planning information for scenarios such as afforestation at agricultural sites.

Both, forest stand types and forest site types are decisive for the third criterion ‘risk exposure’. This criterion stands (a) for the urgency of management measures to accelerate the development of the actual stand types into the future stand types and (b) restricts the eligibility of otherwise possible future stand types under particularly risky conditions. The risk exposure is expressed by the actual forest health status from forest health monitoring, structural stand parameters, which are recorded in forest inventory, and from stand-related records of past hazards from operational forest management. The risk exposure is only applicable to existing forests, but the potential risk exposure at possible afforestation areas as an example where this information might be needed, can be estimated by considering the situation at neighboring forests.

A similar problem in the spatial transfer applies to the fourth classification criterion ‘primary management targets'. The management targets are basically regulated in the Saxonian Forestry Act (Sächsisches Waldgesetz 1992). Which forest areas are dedicated to which primary or multiple services is specified by forest function mapping (function ∼ service, Waldfunktionenkartierung (2004)) and is available only for already-established forest areas. Forest function mapping uses information on the forest site types, the actual stand types and the risk exposure, and respects also the specific spatial context of a forest area (off-site effects: possible impact on, or proximity to sensitive sites; special public demands on a forest area). Most forests have to provide multiple services, but there are some areas dedicated primarily to soil, habitat or ecosystem protection or for the protection of rare sites (so-called 'azonal' sites including peat bogs, creek valleys and floodplain sites). Also a prioritization of biomass production on less sensitive sites with eligibility of future stand types with fast growing tree species, such as Douglas fir or Red oak is possible. The spatial transfer of the classification criterion 'primary management targets' to nonforest areas is again possible by considering information from forest function mapping in neighboring forests, or by taking into account information on priority areas or reserved areas for nature and habitat protection from regional development planning.

Results

Classification approach – resulting theoretical framework

In our results, we came up with a classification framework that allowed us to define a quantity of 22 classes in forestry and 30 (preliminary) management classes in agriculture, here with a focus on crop production. In agriculture, the final classification framework is in discussion with our regional actors.

Figure 5 illustrates schematically the classification hierarchy and the applied classification criteria (see Chapter 2.3) in forestry. Table 1 gives an overview of the 22 management classes identified in forest management, including information on their fulfillment of primary management targets, the dominating tree species and mixed tree species and the suitability of the types depending on the regionally important biogeographical zones (Eisenhauer and Sonnemann 2009). Eligibility of the dominant tree species for the forest site classes and risk maps for drought are based on projections from the Intergovernmental Panel on Climate Change (IPCC) scenario A1B (Werrex IV, Küchler and Sommer 2003), as were the drought risk maps. Additionally, a vast number of mixed tree species was introduced in the management classes, which are foreseen to vary within a broad range on level of the forest stands to correspond best to the local site conditions and forest management experiences (Richtlinie 2005; Eisenhauer and Sonnemann 2009). Table 2 provides information regarding the evaluation of forest management classes in relation to the other land-cover classes – here for the CORINE Landcover Class 2000 standard.

Application example – test case afforestation

In the following, afforestation at agricultural sites is presented as an application case in which both aspects, land-cover change and impact of (adapted) land management classes, can be demonstrated. For the application case, a part of the model region was selected that is actually dominated by agricultural land (Figure 6).

In regional development planning, a number of priority areas for afforestation are delineated in this region. They represent a regionally specific minimum consensus between governmental targets to increase the forest land-cover and economic objectives in the privately owned farms. In contrast, much larger priority and/or reserved areas are delineated for enhancing the natural and environmental development. Note here that 'priority areas' are given a higher weight compared to 'reserved areas' in regional development planning procedures, where permits are granted for eligible land-cover changes (e.g. new settlement or industrial areas) and for the establishment of infrastructural facilities (e.g. new highways). The delineation of priority and reserved areas for natural and environmental development considered in our application case, in particular, nature-conservation factors that would provide niches, step-stones and moving corridors for enhancing the floral and faunal diversity at the landscape level.

A set of different scenarios with increasing sizes for the afforestation area and variable combinations of the locally eligible forest land management classes from the pool of our 22 classes was formulated, including and combining iteratively priority areas for afforestation, and priority and reserved areas for enhancing natural and environmental development. Figure 6 shows as an example the results of simulating the afforestation of the foreseen priority areas with the best site adapted forest management classes (large map). The diagram to the right of the map displays two different lines: the dashed line expresses to what extent (on the scale from 0–100) the ecosystem services are provided before afforestation; the solid line shows the impact of the simulated afforestation scenario. The small difference between these two lines gives evidence that the minimum consensus afforestation on the respective priority areas has no (or almost no) impact as far as improving (or worsening) any of the ecosystem services. In this case, even the implementation of the best suitable management classes could not contribute much to enhance the provision of ecosystem services, because the area for afforestation was just too small.

In contrast, Figure 7 shows an extreme afforestation scenario (map left side of the figure) including all priority areas for afforestation and all priority and reserved areas for natural and environmental development. Here, the impact of different forest management classes becomes visible: Figure 7 displays the results of simulating the afforestation with two different forest management classes: the class 'Scots pine – Oak mixed forests' (large map) is one of the 'multifunctional' forest management

Table 1. Overview of the forest management classes and their suitability for the three regionally relevant biogeographical zones. The dominant and mixed tree species and their possible range in the tree species distribution are specified. (abbr.: abbreviation; Eisenhauer and Sonnemann 2008, 2009).

			Suitable for			Tree species		
No.	Abbr.	Management class	Lowlands	Downs	Mountains	Dominating 50–80%	Mixed > 10%	Mixed < 10%
Group 'multifunctionality' management classes designed to provide multiple services								
1	SP-B	Scots pine – Birch mixed forests	X			Scots pine	Silver birch	Red oak
2	SP-O	Scots pine – Oak mixed forests	X			Scots pine	English/Sessile oak, European hornbeam, European basswood	Silver birch, Red oak
3	SP	Scots pine mixed forests		X	X	Scots pine	European beech, Silver fir, European larch, Sessile oak	Silver birch, Norway spruce, Douglas fir
4	O-SP	Oak – Scots pine mixed forests	X			Sessile/English oak	Scots pine, European hornbeam, Red oak	Silver birch, Norway maple
5	O-B	Oak – European beech mixed forests	X	X		Sessile/English oak	European beech, European basswood, Norway maple, Red oak, European beech, Scots pine,	Silver birch, Wild cherry
6	O-DT	Hydromorphic Oak – Deciduous tree mixed forests	X	X		English oak	European hornbeam, European basswood, Red oak, Scots pine, Silver fir, European ash, Sycamore maple, Black alder	Silver/Downy birch, Wild cherry
7	O-NH	Oak – Noble hardwoods mixed forests	X	X	X	Sessile/English oak	Sessile/English oak, European basswood, Douglas fir, European hornbeam, Sycamore maple, Red oak	Silver birch, Wild cherry, Chequer tree
8	B-O	European beech – Oak mixed forests	X	X	X	European beech	Sessile/English oak, European basswood, Douglas fir, European hornbeam, Sycamore maple, Red oak	Silver birch, Wild cherry, European larch, (Norway spruce)
9	B-SF	European beech – Silver fir mixed forests			X	European beech	Silver fir, Douglas fir, Sycamore maple, Wych elm, European ash, Norway spruce, Scots pine	European larch, Silver birch
10	B-NS	European beech – Norway spruce mixed forests			X	European beech	Norway spruce Douglas fir, Silver fir, Sycamore maple, Wych elm, European ash, Scots pine	Silver birch, European rowan, European larch
11	B-NH	European beech – Noble hardwoods mixed forests		X	X	European beech	Sycamore maple, Wych elm, European ash, Sessile/English oak, Norway maple, lime, hornbeam	Chequer tree, Silver birch

(*Continued*)

Table 1. (Continued).

No.	Abbr.	Management class	Suitable for: Lowlands	Downs	Mountains	Tree species: Dominating 50–80%	Mixed > 10%	Mixed < 10%
12	NS	Norway spruce – Mountain forests			X	Norway spruce	European rowan, European beech, Silver fir	Silver birch, Sycamore maple, European ash
13	NS-SF	Norway spruce – Silver fir mixed forests			X	Norway spruce	Silver fir, Silver birch, European ash, Sycamore maple	European rowan
14	NS-B	Norway spruce – European beech mixed forests			X	Norway spruce	European beech, Silver fir, European ash, Sycamore maple, Scots pine	Silver birch, European rowan
15	CT	(extensive) Coniferous trees mixed forests			X	None	Scots pine, Norway spruce, European beech, Silver fir, European larch	Silver birch
Group 'azonal' sites: management classes for highly sensitive sites with high priority of nature and soil protection aspects								
16	PBF	Peat-bog forests	X			None	Norway spruce, Downy birch, European rowan, Scots/Mountain pine, Black alder	
17	CVF	Creek valley forests	X			Alder/ash	Sycamore maple, Wych elm, English oak, Norway spruce	
18	FPF	Floodplain forests	X			English oak	Black alder, European ash, Wych/European White elm, Sycamore/Norway maple, European basswood, European hornbeam	Wild cherry
Group 'biomass production': management classes on less sensitive sites designed to optimize biomass productivity								
19	RO	Red oak mixed forests	X	X		Red oak	Not further specified	Not further specified
20	DF-O	Douglas fir – Oak mixed forests	X	X		Douglas fir	Sessile/English oak	Not further specified
21	DF-B	Douglas fir – European beech mixed forests		X	X	Douglas fir	European beech	Not further specified
22	Bm	European beech mixed forests	X			European beech	Sessile/English oak, Norway maple, European ash, European hornbeam, European basswood	Scots pine, birch, Chequer tree, Wild cherry

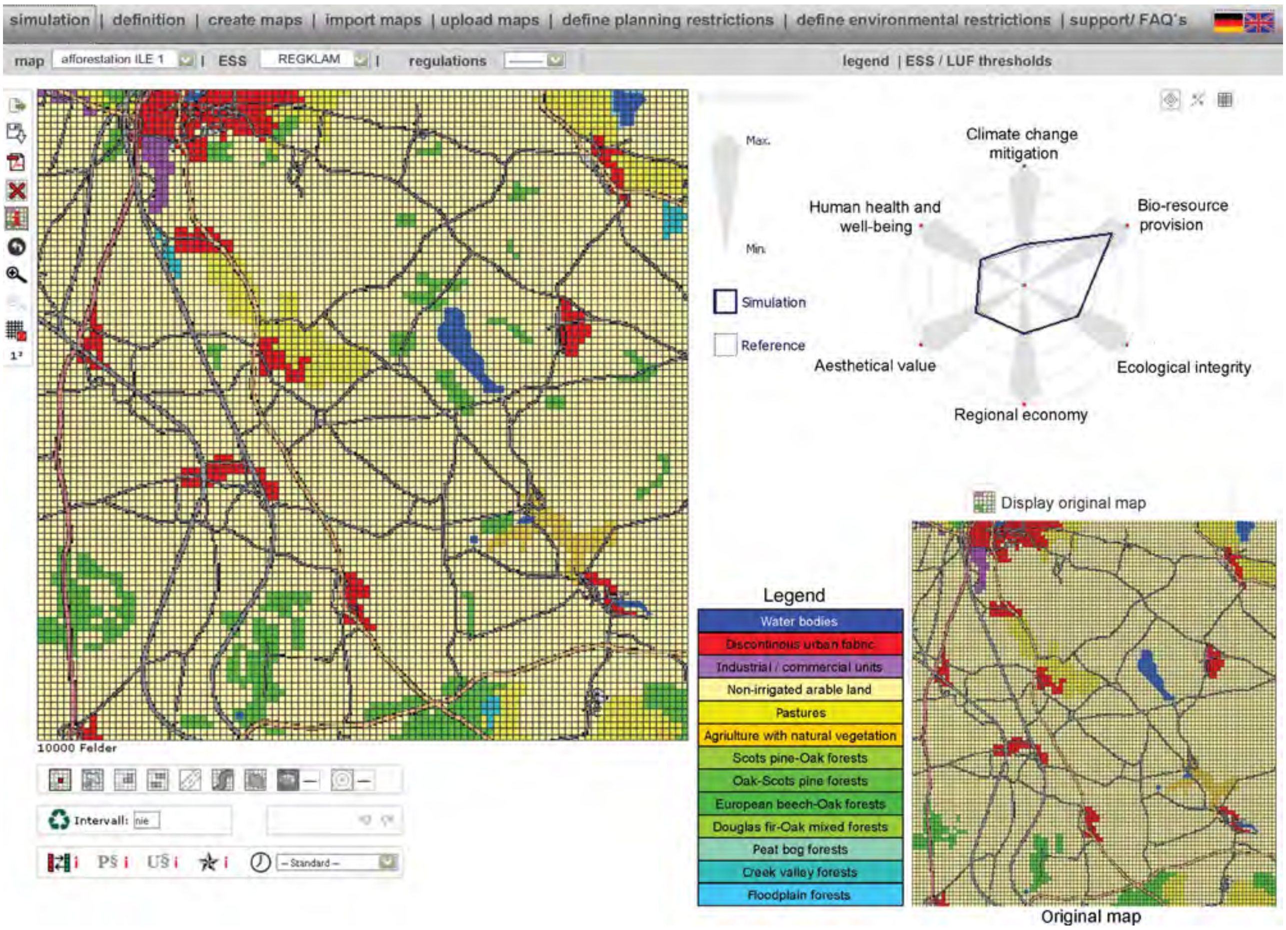

Figure 6. The impact of afforestation at the priority areas foreseen by the regional development plan in the ILE Region 'Dresdner Heidebogen' on improving the provision of ecosystem services is minor compared to the situation without afforestation.

classes (Table 1) with slight prioritization of ecological aspects (close to the so-called 'potential natural vegetation' (Schmidt et al. 2002). This class is of high regional relevance, because it can be easily cultivated on nonforest sites and its implementation (planting of oak) is in particular encouraged in the framework of (EU supported) funding programmes for afforestation. The forest management class 'Douglas fir – Oak mixed forests' (small map at the right bottom of the figure) is one of the economy-oriented forest management classes that are thought to enhance biomass productivity as the primary management target (Richtlinie 2005; Eisenhauer and Sonnemann 2009).

The solid black line in the diagram to the right of the large map shows that afforestation with the multifunctional class 'Scots pine – Oak mixed forests' enhances – as intended – provision of the ecosystem services 'mitigation of Climate Change impact', 'human health and well-being', 'esthetic value' and 'ecological integrity'. On the other hand, compared to the situation without afforestation (dashed black line in the diagram), provision of services 'regional economy' and 'provision of bioresources' decreases.

In contrast, afforestation with the class 'Douglas fir – Oak mixed forests' (dashed red line in the diagram) could contribute to compensate partially for the loss in the service 'provision of bioresources' from the former scenario. Due to the high value which was assigned to Douglas fir stands in the participatory evaluation process, with respect to the high timber prices, the high biomass productivity, the short rotation period and the comparably lower harvesting costs, also the service 'regional economy' could be improved slightly compared to the scenario with the class 'Scots pine – Oak mixed forests'. On the other hand, the enhancement of services such as 'esthetic value' or 'ecological integrity' would be inferior. The contribution to improve the service 'Mitigation of Climate Change impact' would be comparable in both scenarios as both forest management classes consider highly drought-adapted tree species. Also, the enhancement of 'human health and well-being' (provision of drinking water and clean air) is estimated to be similar for both scenarios on the basis of our stakeholder driven evaluation.

Discussion

In the case study REGKLAM, the degree of freedom to mitigate Climate Change effects by land-cover changes is very small. Conflicts of interest in using one and the same

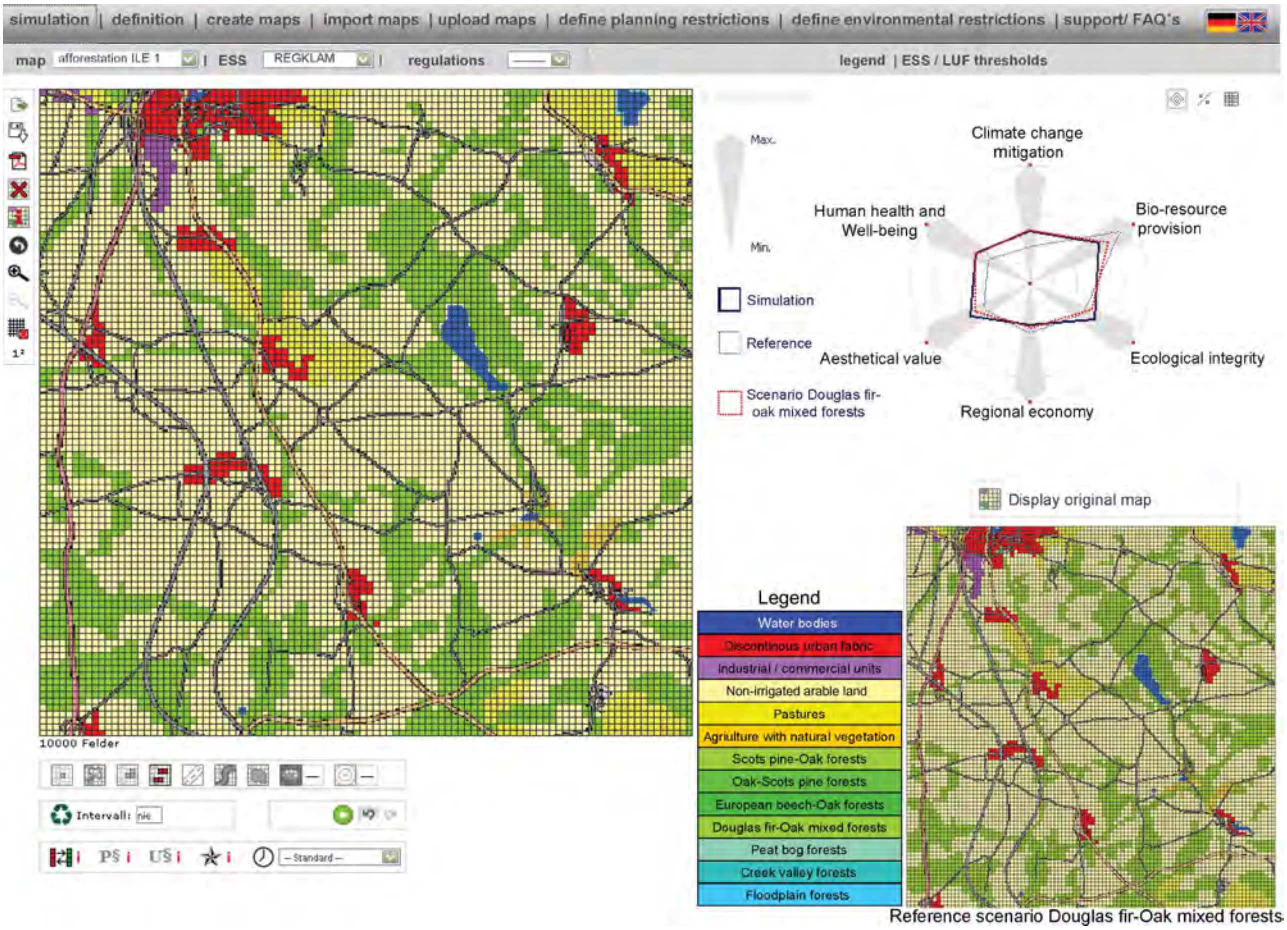

Figure 7. In the event that all priority areas for afforestation and priority and preference areas for enhancing the natural and environmental development are afforested, differences in the impact of the forest management classes on ecosystem service provision become visible. The management class 'Scots pine – Oak mixed forests' improves the services 'mitigation of Climate Change impact', 'human health and well-being', 'esthetic value' and 'ecological integrity', while afforestation with the class 'Douglas fir – Oak mixed forests' would be more beneficial for the services 'provision of bioresources' and 'regional economy'.

piece of land between 'big land users' such as forestry and agriculture are marginal and if land-cover changes take place, they are mostly restricted to small areas in the vicinity of larger settlements (urban sprawl). Furthermore, the high standing of private (land) property in Germany and manifold (often contradictory) legal regulations and missing motivation instruments (e.g. adequate funding) restrict the implementation of 'trendy ideas' such as converting larger agricultural areas into forests or short rotation plantations. Therefore, the highest potential to achieve success in mitigating Climate Change effects is expected from adapted land management in existing forest and agricultural areas.

Taking the case-study-related classification criteria for the forest management classes into consideration, direct transferability of our approach to other regions and other application cases might be restricted. First, our classification was based on a regionally specific (Saxony) silvicultural management concept. Second, all information needed for description of the classes and for their spatial transfer to nongovernmental forest areas or to areas without forests was available from forest inventory, forest site classification/soil mapping and topographical survey. Third, our classification approach was driven by the aim to make the impact of the classes on the provision of ecosystem services more appraisable: therefore, we tried to combine regionally known cause–effect relationships between tree species composition and site factors and climatic conditions with regionally specific socio-economic considerations, the latter based on expert knowledge and stakeholder perception.

Using the example of forestry, our approach can be considered as a suggestion for how to consider the large potential of land management opportunities within a land-cover class to impact the provision of ecosystem services (de Groot et al. 2010). A specific challenge in classifying forest management opportunities consists in considering the ecosystem dynamics of forests over their whole rotation period. Ecosystem dynamics can hardly be assessed through remote sensing techniques without combining them with a terrestrial survey (Verburg et al. 2009; Wiens et al. 2009). Terrestrial surveys, however, primarily provide information on the actual status of the forest ecosystem and its management and can thus not really reflect

Table 2. Overview of the evaluation of the forest management classes in relation to the CORINE Landcover (2000) classes 'Broad-leaved forest', 'Coniferous forest', 'Mixed forest'. The values express on a relative scale from 0 (worst) to 100 (best) the contribution of each class to the provision of the set of ecosystem services in the REGKLAM model region.

	Regional set of ecosystem services					
Land-cover/land management classes	Climate Change mitigation	Bioresource provision	Ecological integrity	Regional economy	Aesthetic value	Human health and well-being
CORINE Landcover (2000) forest classes						
Broad-leaved forest	100	25	100	25	90	100
Coniferous forest	80	40	90	65	80	80
Mixed forest	95	25	100	35	100	100
Forest management classes						
Scots pine – Birch mixed forests	70	10	90	5	80	85
Scots pine – Oak mixed forests	80	20	100	15	90	90
Scots pine mixed forests	80	20	100	20	100	90
Oak – Scots pine mixed forests	70	20	100	10	100	95
Oak – European beech mixed forests	95	25	100	20	100	100
Hydromorphic oak – Deciduous tree mixed forests	90	25	100	20	100	100
Oak – Noble hardwoods mixed forests	100	20	100	15	100	100
European beech – Oak mixed forests	100	35	100	35	100	100
European beech – Silver fir mixed forests	85	40	100	55	100	95
European beech – Norway spruce mixed forests	95	30	100	40	100	100
European beech – Noble hardwoods mixed forests	100	35	100	45	100	100
Norway spruce – mountain forests	70	40	90	65	80	80
Norway spruce – Silver fir mixed forests	95	40	100	75	100	100
Norway spruce – European beech mixed forests	85	40	100	60	100	80
(extensive) Coniferous trees mixed forests	80	10	100	10	90	85
Peat-bog forests	100	10	100	5	100	100
Creek valley forests	100	30	100	20	100	100
Floodplain forests	100	20	100	15	100	100
Red oak mixed forests	95	25	80	30	60	95
Douglas fir – Oak mixed forests	95	35	80	55	70	90
Douglas fir – European beech mixed forests	95	40	80	65	70	90
European beech mixed forests	85	20	100	30	100	100

long-term processes (Fürst, Lorz, et al. 2007, Fürst, Vacik, et al. 2007). Our forest management classes include tending and harvesting strategies over the whole forest stand rotation period and are intended to reflect thereby the accumulated impact from the regeneration period up to the old forest stand on the provision of ecosystem services. This might be problematic in the case that the actual status of ecosystem services provision should be assessed on a local scale (e.g. growth dynamics and biomass productivity in younger and elder stands) but it is beneficial for the regional planner if the impact of long-term planning strategies such as forest conversion or afforestation is assessed on landscape scale (Chertov et al. 2002, 2005). Especially for the research objective in REGKLAM, to develop 'Climate Change mitigation and adaptation strategies', such long-term processes and aggregated information on cause–effect relationships are relevant. On the other hand, for impact assessment at the interface between regional development planning and sectoral land management planning also temporal aspects should be considered. Regarding the forest management classes, a solution we have already tested is the introduction of time slots of 10, 30, 50 and 100 years (Fürst, König, et al. 2010, Fürst, Volk, Pietzsch, et al. 2010). These time slots reflect important phases in vegetation development (from young to mature trees or stands) and in forest management planning (operational, tactical, strategic planning, see Baskent and Keles (2005) and Fürst, Volk, et al. (2010)). However, the same approach and comparable time slots cannot be applied for other land use sectors, such as in agricultural management. Here, the intra-annual impact of single crops on ecosystem services might be evaluated totally differently as compared to the impact of a complete crop rotation. Most likely, the introduction of additional time slots <10 years, but >1 year could help to overcome this problem, but so far we have not identified a satisfactory solution.

Also the implemented ecosystem service set was specifically adapted to the questions and needs raised by the participants in our case study. The MEA (2005) and its concept, approaches and aims were not well known by our regional protagonists. Services to be provided at the landscape level are discussed at the sectoral level (forestry, agriculture) with different philosophies and definitions regarding what should be understood as ‘service’ (Waldfunktionenkartierung 2004; Klimawandel 2009; de Groot et al. 2010). At the regional level and in regional development planning, the term ‘services’ is not really in use. Planning measures at this scale level tend to consider political claims such as sustaining ‘protected goods’ (soil, water, natural areas) and ensuring adequate areas for the production of food, other (bio)resources, energy, and for regional economic development (Raumordnung 2004). Therefore, the actual set of services and the underlying evaluation criteria and indicators are still preliminary. An example might be the high value which was given to the forest management class ‘Douglas fir – Oak mixed forests’ for the service ‘regional economy’. The impact of afforestation with Douglas fir dominated forests on regional economy might in fact be much lower, and the right choice of evaluation criteria and indicators and their weight are topics of current investigations. We intend to complement and improve our approach in the ongoing participatory evaluation process with the aim of optimally reflecting regional demands on current, but also possible future ecosystem services (Koschke et al. 2010).

Conclusion

We conclude from our case study that a more differentiated look at land management practices instead of land-cover classes helps to improve the understanding (a) of regional potentials to adapt to Climate Change and to mitigate its effects and (b) of the impact of sectoral management strategies at the landscape level on the provision of ecosystem services. The applied participatory approach in developing a classification based on forest management practices and in evaluating the impact of forest management contributed also to an improved awareness of the ecosystem services concept, which – after the process – was much better understood and even applied by the regional actors in their daily work. The next step will be to finalize a conceptual framework for classifying agricultural management practices and to combine both forest and agricultural management opportunities at the landscape level as a discussion basis for land users and regional planners in the course of updating the regional development plan. Currently in final validation (Frank et al. 2010) is the consideration of landscape structural aspects in our model region, which are assumed to have an equally high significance for an evaluation of the opportunities of land use to mitigate Climate Change effects.

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How to better consider sectoral planning information in regional planning: example afforestation and forest conversion

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How to better consider sectoral planning information in regional planning: example afforestation and forest conversion

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This paper presents, by means of a case study, an approach for how to make use of sectoral planning information on forestry in regional planning. Exemplary issues addressed in this study were, first, how to evaluate the conversion of existing forests and, second, afforestation on agricultural sites, regarding the impact of these strategies on the provision of ecosystem services at a regional scale. We demonstrate that the conversion scenarios planned by the state forest administration have only a minor impact at the regional scale because the proportion of forests is too small. As a consequence, recommendations for regional planning were to: (a) considerably increase the planned afforestation areas under consideration of the locally suitable future forest ecosystem types; and (b) concentrate preference areas for afforestation along corridors, which augment, at most, the additional benefits provided by connecting the biotopes at the landscape level.

Keywords: regional planning; afforestation and conversion scenarios; ecosystem services; impact assessment; 2-D cellular automaton

1. Introduction

At the landscape level, forests are considered to be the most important terrestrial ecosystems for providing manifold benefits to society, for supporting local and global climate regulation and for making essential contributions to the mitigation of climate change impacts (Rounsevell and Reay 2009, de Groot *et al*. 2010). Spatial strategies that are discussed in relation to these benefits of forests are afforestation – mostly of agricultural sites – and conversion of coniferous to deciduous forests (e.g. Trabucco *et al*., 2008, Padilla *et al*. 2010).

Forest growth and yield models can be applied at the forest stand level to assess the impact of conversion on economic and ecological parameters and, supported by regionalisation algorithms, also at the level of larger forest areas or forest regions (Peng 2000, Fürst *et al*. 2007, Landsberg and Sands 2011). More difficult is the regionalisation of such modelling results at the landscape level if the interactions with other land use types and the spatial context in which the forest(s) is(are) situated

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are considered (Weimin *et al*., 2009). The few existing 'Forest landscape models' focus on interactions between forest stands or forest areas or spatial processes, such as seed dispersal, and disturbances such as wildfire or windthrow (see e.g. Mladenoff 2004, Lischke *et al*. 2006, Weimin *et al*. 2009).

Even more challenging is the evaluation of afforestation scenarios. First, forest site classification systems are often different from 'non-forest' soil classification systems, as the forest site classification focuses on expressing production-relevant site potentials and risks for forest management planning. Conversely, soil classification focuses more purely on a description of chemical and physical soil properties without translating these properties into risks or potentials (e.g. Thwaites and Slater 2000). Regionalisation of this relevant forest management planning information to a landscape scale is difficult or even impossible, and decisions such as choice of tree species for afforestation are based on incomplete information. Second, it is not easy to define and assess the optimal spatial location for afforestation areas, as this requires taking into consideration not only information on site potentials and risks, but also landscape structural aspects and interactions with other land use types (Dilek *et al*. 2008). This question is partially addressed in multi-criteria optimisations of landscapes, which target an optimal land cover pattern in order to minimise risks such as water erosion, and to maximise the gains from land use, such as biomass production or an in increase biodiversity (see e.g. Grabaum and Meyer 1998, Kurttila, 2001, Vendema *et al*. 2005).

An additional challenge is a complementary evaluation of the potential from, and need for, combined conversion and afforestation scenarios. Practical application cases where this might be interesting are, for example, development of regional strategies for the mitigation of climate change effects, or identification of reaction opportunities to avoid a worsening of the regional provision of ecosystem services due to either urban sprawl or the establishment of infrastructural elements such as highways. The question of afforestation and conversion strategies at the landscape scale was, for example, also addressed in the development of strategies for reducing the output of Greenhouse Gases (see e.g. Zomer *et al*. 2008, Rounsevell and Reay 2009).

In the context of better answering how to integrate sectoral strategies in regional planning, the software tool, 'Pimp Your Landscape (PYL)' was developed. PYL supports the assessment of the impact of land cover and land management changes in the provision of ecosystem services (Fürst *et al*. 2010a, 2010b).

PYL is a modified 2-D cellular automaton with GIS features and an integrated multi-criteria evaluation module. The software has been developed to support regional planning and, particularly here, the visualisation and evaluation of alternative planning scenarios (Fürst *et al*. 2010b).

In this paper we first address the issue of how sectoral knowledge from forestry should be processed to be usable for regional planning. Of particular importance here is the decision where to establish new forests and what type of forests we need to have for maximum impact in the provision of ecosystem services on the regional scale. Regional planning is understood as the placement of land use activities, infrastructure and settlement growth across a larger area of land for which (in Germany) a public regional planning authority is responsible (Fürst and Ritter 1993). Sectoral planning is understood as planning at the level of the land use sectors of forestry and agriculture (ARL 2005). Second, we ask how to integrate landscape structure aspects, assuming that the area for afforestation on the regional scale is limited and that we should maximise the benefit gained from afforestation through optimal spatial positioning.

The manner in which these two issues should be approached is presented by means of a case study in which conversion and afforestation strategies for mitigating climate change effects are tested with PYL. We introduce the case study specific evaluation base to assess concrete planning scenarios from forest management planning and regional planning. We tested the potential for combining the conversion of an existing forest area with afforestation on agricultural sites and we conclude with recommendations for regional planning. Finally, we discuss the lessons learnt from this case study.

2. Materials and methods

2.1. Developing a climate change mitigation strategy: case study REGKLAM

In the case study REGKLAM (www.regklam.de), PYL is used to support the development of a regional climate change mitigation strategy in a model region in Saxony, North-Eastern Germany (Figure 1).

In this model region, changes in the land cover and land-management intensity in forestry and agriculture are considered as highly relevant strategies to reduce climate change risks such as water erosion, flooding and drought. The actual regional plan (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge, 2009) therefore defines a number of preference areas for afforestation, while forest management planning foresees a conversion of the actual stand types into types with better adaptation to

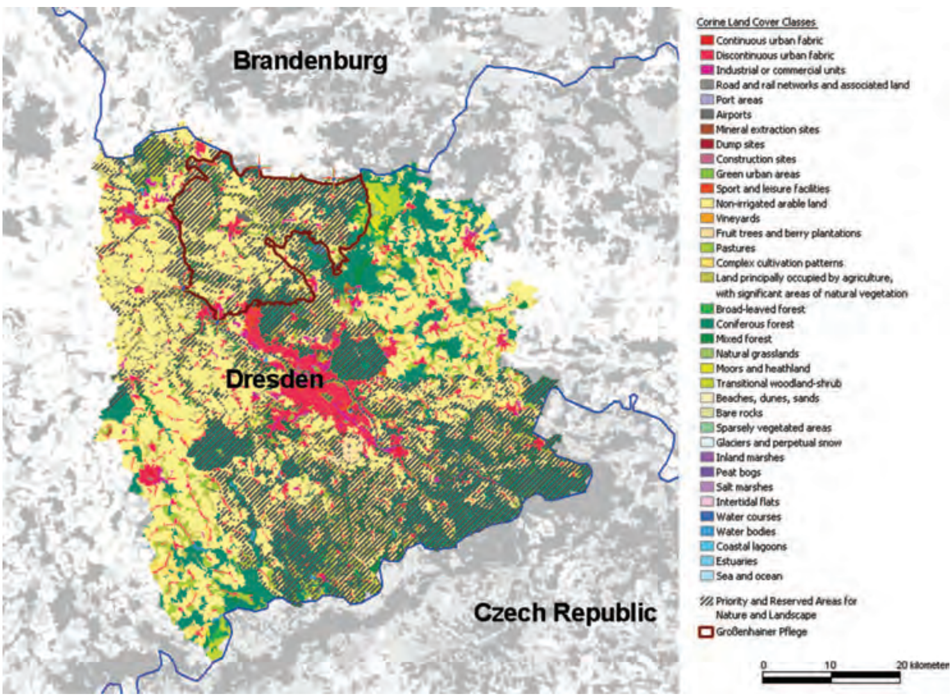

Figure 1. Localisation of the REGKLAM model region in Germany, land cover classes according to CORINE Land Cover 2006 and localisation of the priority and reserved areas for nature and landscape and of the macrochore 'Großenhainer Pflege'. (Colour version online.)

the expected future water scarcity under climate change (Anonymous, 2004b). Both the regional plan and forest management plan are the basis for the scenario formulation.

A focus area within the model region is the so-called 'Großenhainer Pflege'. The 'Großenhainer Pflege' is a macrochore within the REGKLAM model region with predominance of loess sites and, consequently, a high share of agricultural land (Hanspach and Porada 2009). The area was impacted on Whitsun Monday 2010 by both a tornado and, shortly thereafter, a big flooding event. Its agricultural sites have been heavily affected by water erosion for many years. Furthermore, the 'Großenhainer Pflege' is considered to become in the future one of the model region areas that will be under extreme threats from climate change. The reasons for this are the high vulnerability of the loess sites against drought and water erosion and the poor structure of the landscape, with large agricultural management planning units and a very small proportion of forest areas. As an example, one of the largest forests in this area, the so-called 'Kupferberg', amounts to only 30 ha and was completely destroyed by the tornado.

Research issues in this area are: first, how to evaluate the conversion, which was recommended by the State Forest Enterprise 'Sachsenforst' for the 'Kupferberg' with regard to the ability of this forest area to contribute to the provision of regionally important ecosystem services; second, how to identify strategies for appropriate afforestation corridors, which ensure, by optimising the landscape structure, an additional benefit beyond the pure increase of the forested area.

So far, conversion as foreseen by the State Forest Enterprise and afforestation as planned by the regional plan have hardly been realised because a consensus between the private interests of the affected landowners and the public demands in planning could not be achieved. As a consequence, the outcomes of this study will also be included in regional agricultural funding programmes for enhancing the feasibility of afforestation and conversion.

2.2. Structure of the simulation process and software tool PYL

The process to answer the questions/issues raised in the previous section was structured into four steps: (1) scenario selection; (2) selection of suitable forest ecosystem types; (3) multi-criteria assessment of the scenarios that go along with the simulation of the scenarios; and (4) simulation of the scenarios with the software PYL. The four steps and the questions, which guided us through this process, are illustrated in Figure 2.

For testing and spatial optimisation of the conversion and, in particular, the afforestation scenarios, the software tool PYL ('Pimp Your Landscape', Fürst *et al.* 2010a, 2010b) was applied. In the context of this paper, PYL can only be briefly described in order to demonstrate its structure and functioning. PYL consists of a combination of three different components. The first component is a Geographical Information System (GIS), which supports handling available digital information on the regional scale, such as land cover or land use (land use: more detailed information on management in forest and agricultural or other classes) maps, soil maps, regionalised climate data, topographical information, landownership type maps, etc. These data serve as an information base (attributes) for the second component, a cellular automaton.

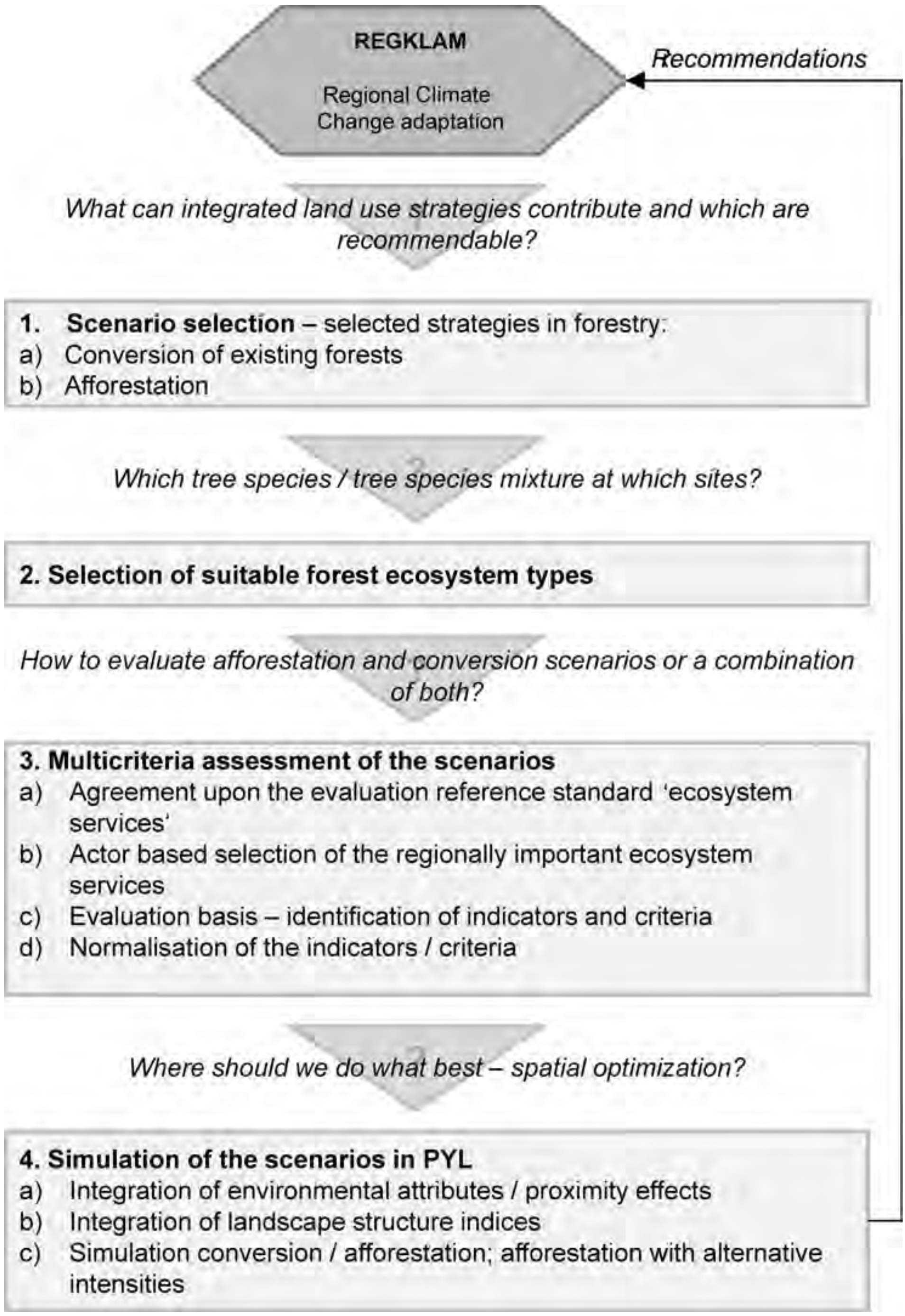

Figure 2. Process steps and structure in testing alternative planning scenarios.

A cellular automaton is a discrete dynamic system, where cells form the basic unit in a regular spatial lattice. These cells can have any one of a finite number of states and – in the original cellular automaton model – they are updated according to a local rule, whereby the cell, at any given time, depends only on its own state one time step previously and the states of its neighbours at the previous time step. All cells are updated synchronously and in discrete time steps (Cochinos 2000). The cells in our automaton can have GIS attributes (for example also see White and Engelen 1997, Soares-Filho *et al*. 2002, Holzkämper and Seppelt 2007, Silva *et al*. 2008, Yang *et al*. 2008, Moreno *et al*. 2009, Wickramasuriya *et al*. 2009) which (a) can impact the probability of a cell to adopt a state or (b) can be relevant for the third component, the multi-criteria evaluation.

This component is organised as a hierarchical evaluation approach, where, first, the contribution of land cover classes (for example, CORINE Land Cover 2006)/ land use types for providing ecosystem services is evaluated on a relative scale from 0 (lowest value) to 100 (highest value). As each cell can adopt, at a distinct point in time, only one land cover class or land use type as the primary attribute, the value, which is assigned to a land cover or land use type, is identical to the basic value of each cell. This value can be modified depending on the above-mentioned attributes. For example, the value of a cell with a forest or agricultural type can be higher for provisioning services if the soil fertility, as one additional attribute, is above average. A cell can also be modified depending on the land cover class/land use type of the neighbouring cells. To calculate the value of a region for each ecosystem service to be provided, we take the mean value of all cells in this region. This interim result is finally corrected by landscape structure indices, such as biotope connectivity, effective mesh size, core area of near-to-nature land cover classes/land use types, hemeroby index, Shannon's diversity index (Frank *et al*. forthcoming). These indices can increase or reduce the value of the region for a specific ecosystem service.

2.3. *Planning basis: defining and up-scaling future forest ecosystem types and scenario formulation*

As a basis for conversion and afforestation, 22 regionally suitable forest ecosystem types were selected (Table 1). These ecosystem types are considered to be well adapted to a moderate climate change scenario A1B, Werrex IV (Eisenhauer and Sonnemann 2009). 'Moderate' means that scenario A1B expresses a possible negative impact from climate change, which however can still be buffered by silvicultural management decisions. In the model region, scenario A1B will lead to an increase in the mean annual temperature by 0.9 K by the year 2050 compared to the reference period 1981–2000. Furthermore, a decrease in the mean annual precipitation by 6–14% is expected, which mainly concerns the precipitation during the growing season. In comparison, the 'more pessimistic' emission scenario A2 would lead to an increase in the mean annual temperature by 1.9 K and a decrease in the mean annual precipitation by up to 18% with an even stronger trend in the reduction of the precipitation during the growing season (LfULG 2010). The forest ecosystem types are characterised by one or several dominating tree species, a set of suitable mixed tree species and the type of tree species mixture. Note that 'tree species' in our case often subsumes groups of tree species (e.g. the group 'Scots pine' includes different pine and larch species), which are similar in their demands on nutrients and water (Anonymous 2005, Eisenhauer and Sonnemann 2009).

The local eligibility of the forest ecosystem types is based on four different criteria, (I) actual stand type, (II) forest site type, (III) drought risk exposure and (IV) local management targets (Figure 3).

Table 1. Overview of the 22 forest ecosystems types for silvicultural management planning in the REGKLAM model region.

		Tree species		
No.	Name	Dominating 50–80%	Mixed > 10%	Mixed < 10%
'Multifunctional' types				
1	Scots pine – Silver birch mixed forests	Scots pine	Silver birch	Red oak
2	Scots pine – oak mixed forests		English/Sessile oak, European hornbeam, European basswood	Silver birch, Red oak
3	Scots pine mixed forests		European beech, Silver fir, European larch, Sessile oak	Silver birch, Norway spruce, Douglas fir
4	Oak – Scots pine mixed forests	Sessile oak/ English oak	Scots pine, European hornbeam, Red oak	Silver birch, Norway maple
5	Oak – European beech mixed forests		European beech, European basswood, Norway maple, Red oak, European beech, Scots pine	Silver birch, Wild cherry
6	Oak – Noble hardwoods mixed forests		European hornbeam, European basswood, Norway/ Sycamore maple, European beech, European ash, Wych elm, Small-leaved lime	Silver birch, Wild cherry, Chequer tree
7	Hydromorphic Oak - Deciduous tree mixed forests	English oak	European hornbeam, European basswood, Red oak, Scots pine, Silver fir, European ash, Sycamore maple, Black alder	Silver/Downy birch, Wild cherry
8	European beech – Oak mixed forests	European beech	Sessile/English oak, European basswood, Douglas fir, European hornbeam, Sycamore maple, Red oak	Silver birch, Wild cherry, European larch, (Norway spruce)

(*continued*)

Table 1. (*Continued*).

		Tree species		
No.	Name	Dominating 50–80%	Mixed > 10%	Mixed < 10%
9	European beech – Silver fir mixed forests		Silver fir, Douglas fir, Sycamore maple, European ash, Wych elm, Norway spruce, Scots pine	European larch, Silver birch
10	European beech – Norway spruce mixed forests		Norway spruce Douglas fir, Silver fir, Sycamore maple, Wych elm, European ash, Scots pine	Silver birch, European rowan, European larch
11	European beech – Noble hardwoods mixed forests		Sycamore maple, European ash, Wych elm, Sessile/English oak, Norway maple, Small-leaved lime, European hornbeam	Chequer tree, Silver birch
12	Norway spruce – Mountain forests	Norway spruce	European rowan, European beech, Silver fir	Silver birch, Sycamore maple, European ash
13	Norway spruce – Silver fir mixed forests		Silver fir, Silver birch, European ash, Sycamore maple	European rowan
14	Norway spruce – European beech mixed forests		European beech, Silver fir, European ash, Sycamore maple, Scots pine	Silver birch, European rowan
15	(extensive) Coniferous trees mixed forests	None	Scots pine, Norway spruce, European beech, Silver fir, European larch	Silver birch
'Azonal' types				
16	Peat-bog forests	None	Norway spruce, Downy birch, European rowan, Scots/Mountain pine, Black alder	

(*continued*)

Table 1. (*Continued*).

		Tree species		
No.	Name	Dominating 50–80%	Mixed > 10%	Mixed < 10%
17	Creek valley forests	Black alder/ European ash	Sycamore maple, Wych elm, English oak, Norway spruce	
18	Floodplain forests	English oak	Black alder, European ash, Wych/European White elm, Sycamore/Norway maple, European basswood, European hornbeam	Wild cherry
'Highly productive' types				
19	Red oak mixed forests	Red oak	not further specified	not further specified
20	Douglas fir – oak mixed forests	Douglas fir	Sessile/English oak	not further specified
21	Douglas fir – European beech mixed forests		European beech	not further specified
22	European beech mixed forests	European beech	Sessile/English oak, Norway maple, European ash, European hornbeam, European basswood	Scots pine, Silver birch, Chequer tree, Wild cherry

Sources: Eisenhauer and Sonnemann (2009); Anonymous (2005).

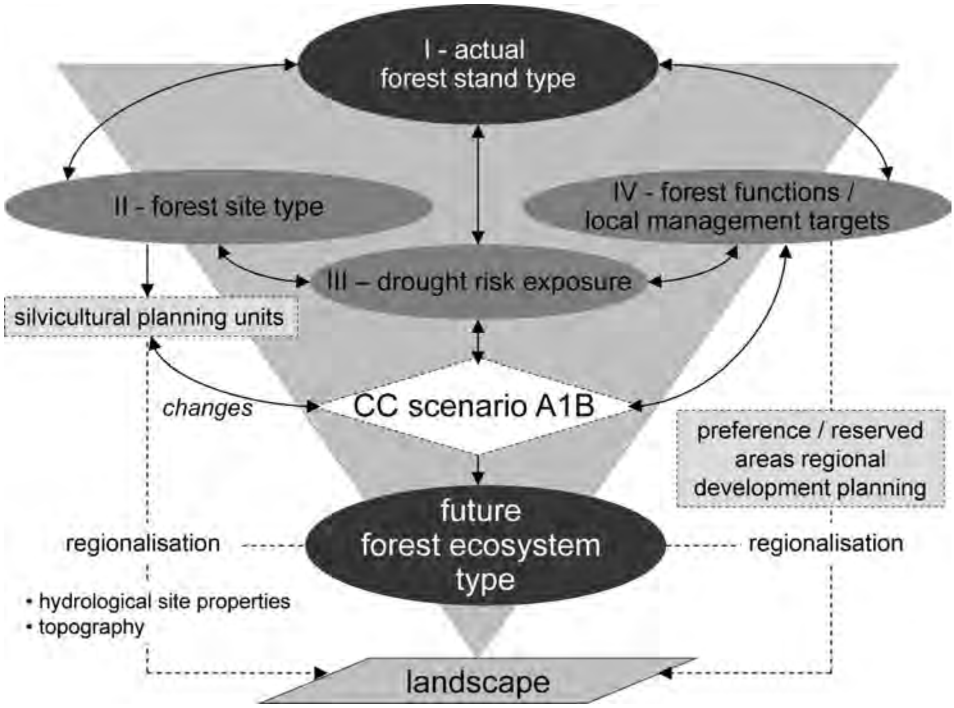

Figure 3. Flow chart formulation of future forest ecosystem types and information applied for up-scaling at the landscape level.

The first criterion 'actual stand type' can be taken from the forest management plan. This applies to governmental and municipal forests, while this information is often missing in privately-owned forests and outside existing forest areas. In this case, information from neighbouring governmental forests and national forest inventories can be used.

The stand types as the core management instrument in forestry are closely related to the second criterion 'forest site types'. The forest site types include information on topographical, soil chemical and physical, and hydrological site properties. The site types are documented in the forest site classification and they are used for planning in an aggregated form as so-called 'silvicultural planning units', for which only a specific set of forest ecosystem types is eligible (Anonymous 2005, Eisenhauer and Sonnemann 2009). A problem exists in the regionalisation of these silvicultural planning units, in that they are only delineated in existing forest areas. For regionalisation at the landscape level, hydrological and physical site properties and topographical parameters were used (Figure 3). Chemical site properties (nutrition potential) could not be used for the regionalisation as this information is not available at agricultural sites or other non-forest areas in a form which can be linked to the forest site classification (Kopp and Schwanecke 2003).

The criterion 'drought risk exposure' indicates the urgency for management measures to develop the actual stand types into forest ecosystem types and can restrict the eligibility of other possible ecosystem types under particularly risky conditions. The drought risk exposure is contingent upon the localisation of a stand

and upon the stand type. For instance, Norway spruce stands, which are located in the lower layers of the Ore Mts., the Lowlands or the Loess Uplands, already have a high drought, and in consequence bark beetle infestation, risk exposure. The drought risk exposure is consequently expressed by the forest health status from forest health monitoring, structural stand parameters (which are recorded in the forest inventory) and from stand-wise records of past hazards. The drought risk exposure is only applicable to existing forests, but the potential risk exposure in possible afforestation areas can be estimated by considering the situation in neighbouring forests. The risk of windthrow/windbreak was considered to be too unpredictable, and too difficult to avert, to be taken into consideration in this scheme. Wildfire risk was assumed to go along with drought risk (see also Eisenhauer and Sonnemann 2009).

The fourth criterion 'forest functions/local management targets' is taken from the mapping of forest functions, which are legally binding, and must be primarily fulfilled by the forests, contingent upon specific local vulnerabilities (e.g. drinking water protection, soil protection), or the specific local role of the forest (e.g. protection against noise emissions, recreation) (Anonymous 2004a). The forest function map is also part of the forest management plans at the stand level and impacts not only the eligibility of distinct future stand types, but also the intensity of other forest management operations, such as harvesting or tending. The forest function concept is not identical with the ecosystem services concept (see Costanza 2008, Fisher and Turner 2008), but it represents the only applicable concept in which digital information on the potential fulfillment of the functions is available at the sectoral planning level. The criterion 'forest functions/local management targets' is also only available for previously established forest areas. In the majority of cases, forests in Germany have to fulfill multiple services. However, there are some areas that are exclusively or primarily dedicated to soil, habitat or ecosystem protection (excluded from active forest management, or application of extensive management practices; such so-called 'protective forests' were not present in our test area), or for the protection of highly vulnerable sites (so-called 'azonal' sites, including peat bogs, creek valleys and floodplain sites). In addition, prioritisation of biomass production for less sensitive sites with eligibility of forest ecosystem types with fast growing tree species, such as Douglas fir or Red oak (so-called 'production forests') is possible. The spatial transfer of the classification criterion 'local management targets' to non-forest areas is again possible by considering information from forest function mapping in neighbouring forests, or by taking into account information on preferential areas or reserved areas for nature and habitat protection from regional planning (Figure 3).

The locally eligible forest ecosystem types formed the basis for designing the scenarios to be tested in our case study. The conversion scenario was based on the valid silvicultural planning at the forest district level, which consists of a map with the actual stand types and a verbal description of the management measure (tending, thinning, harvesting, natural or artificial regeneration) to be implemented in each forest stand as a basic planning unit to convert the actual stand type into one of the forest ecosystem types (see also Anonymous 2005). In the macrochore 'Großenhainer Pflege', we focused the test of the regional contribution of conversion to the provision of ecosystem services in the largest regional forest area, the Kupferberg (see also section 2.1 and Figures 4 and 5). All other forest areas were too small and fragmented, and some pretests have shown that their contribution to impact any ecosystem service through conversion is negligibly small.

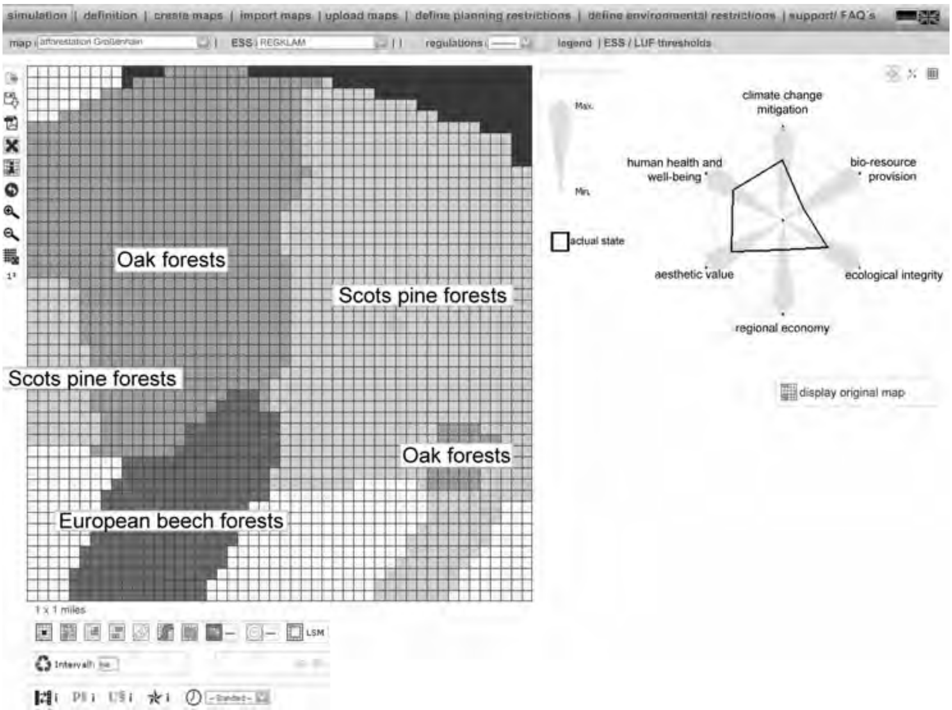

Figure 4. Actual spatial distribution of the stand types. The diagram to the right of the map shows (continuous line) the extent to which the ecosystem services are provided on the basis of our evaluation results (Table 3).

With regard to afforestation, we tested a number of different alternatives, starting with a test of the (very small and few) afforestation areas which are recommended in the actual regional plan (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge 2009) ('minimum scenario') over several alternatives of afforestation with increasing forest area towards a complete afforestation of all agricultural sites. An afforestation of all agricultural sites is rather unrealistic and, in an iterative optimisation process with the actors of our case study (see section 2.4), we came up in with a more probable alternative to afforest preference areas for nature and habitat protection ('maximum scenario'). These preference areas are delineated in the regional plan (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge 2009) to form optimal biotope networks and the intention is to further the development of near-to-nature land cover or land use types on these areas. From the pool of different possible scenarios, we focused the demonstration of the results in section 3.2 on the afforestation according to the recommendations in the regional plan ('minimum scenario') and on the afforestation of the preference areas for nature and habitat protection ('maximum scenario') to avoid an information overflow.

2.4. *Regional ecosystem services: assessment and evaluation*

To assess the impact of the conversion and afforestation strategies, a common evaluation reference standard had to be identified with the actors participating in our

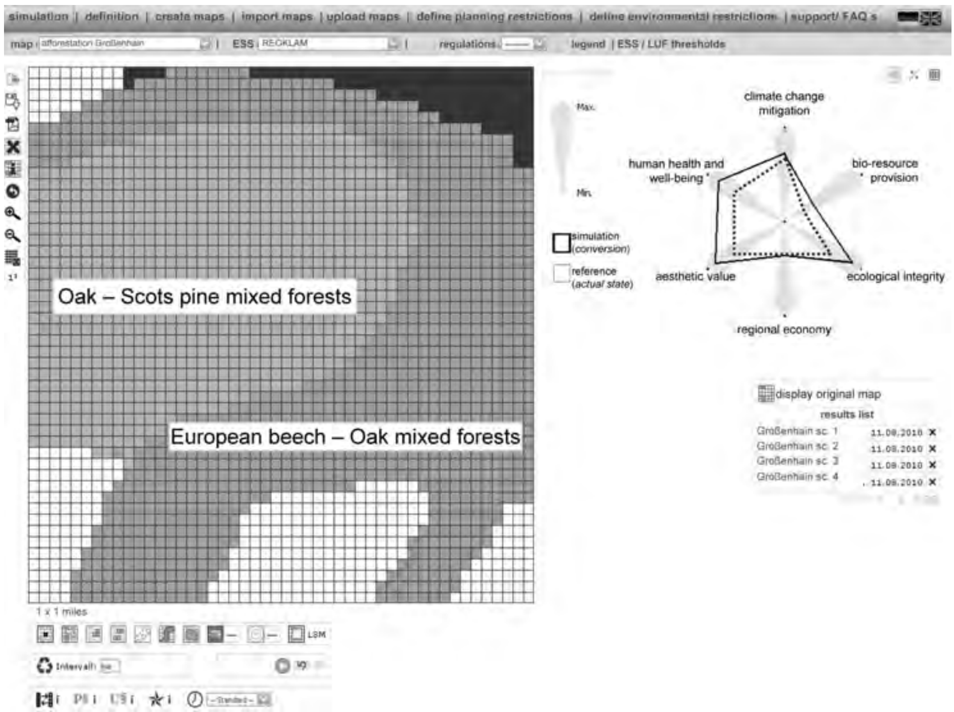

Figure 5. Simulation of the conversion proposed by the governmental forest administration. The continuous line in the diagram to the right of the map shows to what extent the conversion would (or would not) improve provision of the ecosystem services compared to the starting situation (dashed line).

case study (see also de Groot *et al.* 2010). These actors came from forestry (State Forest Enterprise ‘Sachsenforst’ and non-governmental forest owners), agriculture (farmers and State Agency for Environment, Agriculture and Geology), nature conservation (NGO’s) and regional planning and management (regional planning authority ‘Oberes Elbtal, Osterzgebirge’, ILE (Integrated Rural Development) regions ‘Dresdner Heidebogen’ and ‘Silbernes Erzgebirge’, Fürst *et al.* forthcoming). They participate in the working group ‘land use’ in the REGKLAM project and take part permanently in surveys and evaluations of expert opinion.

In Germany, the evaluation philosophies that are applied in the forestry and agriculture sectors are different. While in forestry the concept of ‘forest functions’ is still applied (Anonymous 2004a), the concept of ‘welfare services for society’ is used in agriculture (see e.g. Weingarten 2010). Regional planning itself intends to optimise the share of land dedicated to food production, settlement, biodiversity corridors, energy production, etc. under consideration of so-called ‘protective goods’, such as soil and water (Anonymous 2004b). To bring these different points of view together in evaluating the impact of land use, the actors in our study agreed to refer to the concept of ecosystem service (Millennium Ecosystem Assessment, 2005).

To evaluate the conversion and afforestation strategies, together with our actors we selected a set of six ecosystem services in an iterative process (Fürst *et al.* forthcoming). The iterative selection of the ecosystem service set was based on a modified Delphi process (EVALSED 2003) in a number of workshops, where first the original ecosystem services of the Millennium Ecosystem Assessment (2005) were presented. In a second step, the participants could select and propose services which they considered to be most important for the model region. This also included 'services', which were not originally included in the Millennium Ecosystem Assessment (2005). Our modified set was presented again to the regional actors and an ultimate set was defined and described with the actors, which was then confirmed to be applicable in our study. Taking the classification of the Millennium Ecosystem Assessment (2005) into account, the set applied in our study considers provisioning services (bio-resource provision including in our case timber, food and fibre provision of fresh water and air, defined in our case as a contribution to human health and well-being); regulating services (in our case formulated as 'mitigation of climate change impact'); cultural services (aesthetic value); and supporting services (contribution to the ecological integrity). In addition, 'regional economy' was introduced, because this service was considered to be most important by our regional actors (Fürst *et al.* forthcoming; see also Menzel and Teng 2009). 'Regional economy' was understood to be 'contribution of the region to private and public income', for the evaluation criteria and indicators, see Table 2.

To evaluate the extent to which a forest ecosystem type (or other land use) contributes to the provisioning of these ecosystem services and to assess the planning strategies, a hierarchical multi-criteria evaluation approach was applied (Fürst *et al.* 2010a, 2010b). In a first step, we selected a set of appropriate criteria and indicators for the assessment with our regional actors (Table 2).

Next, the indicators and criteria values were normalised by mathematical transformation (see also section 2.2) to a relative scale from 0 (lowest value) to 100 (highest value) to avoid the problem of comparing heterogeneous information (units, temporal/spatial scale) and to make comparable, in a qualitative manner, the relative changes in the provisioning of the ecosystem services (for a detailed description of the methodology, see Fürst *et al.* 2010b, Koschke *et al.* 2010).

In a subsequent step, the impact of local (cell-related) environmental attributes (site information, climatic and topographic parameters) and the impact of proximity effects, e.g. the mutual impact of neighbouring forest and agricultural sites, was assessed and was used to formulate rules (percentage reduction/increase of the value of the forest and other land use types contingent upon local environmental parameters, see section 2.2 and Fürst *et al.* 2010a).

Finally, landscape structure indicators, in this case biotope connectivity and average size of core areas with near-to-nature land use types, were used and test-referenced to correct the value achieved at the regional level for the ecosystem service 'ecological integrity' (Frank *et al.* forthcoming). This is due to the fact that, for this service, landscape structure is known to be of high significance (Frank *et al.* 2010, Reza and Abdullah 2011). Both landscape structure indices were integrated in PYL in a two-step procedure: (1) landscape-structure-indices values were calculated in PYL and the absolute values were assigned to five classes from low (-10 points) to high ($+10$ points) to express the extent to which the service 'ecological integrity' at the regional level has to be decreased or increased when taking into account the landscape structure (see also section 2.2 and Frank *et al.* forthcoming). The assignment to classes from low to high was done because the qualitative evaluation approach applied in PYL does not allow for direct integration of the indicator values. (2) As in our case – two indicators were used to correct the service 'ecological

Table 2. Ecosystem service set and criteria and indicators used in the case study REGKLAM.

Ecosystem services	Description	Criteria	Indicators
Climate change mitigation	Contribution of the land use type to the reduction/mitigation of climate change driven risks such as water erosion, drought and flooding	• Water balance regulation • Contribution to local climate regulation • Contribution to global climate regulation • Soil erosion protection	• Water retention capacity [$m^3 * ha^{-1}$] Run-off coefficient [Ψ], soil sealing [%] • Albedo [%] • C-Sequestration: Storage of C in soil and biomass [kg C ha^{-1}] • C-factor (USLE)
Ecological integrity	Contribution of the land use type to the ecological functioning	• Biological diversity • Functioning of matter and water cycles • Capacity for biological regulation	• Composition of flora and fauna communities in relation to the potential natural communities • N- and P export with seepage water [kg N/P * ha^{-1}] • Ground water recharge [$m^3 * ha^{-1}$], evapotranspiration • Number of habitats for pest control species
Bio-resource provision	Contribution of the land use type to the production of bio-resources (biomass and food)	• Production of plant biomass • Production of bio-resources from livestock	• Food and fodder from plants [$t * ha^{-1} * a^{-1}$] • Food from livestock [$t * ha^{-1} * a^{-1}$] • Biomass for industrial use/processing [$t * ha^{-1} * a^{-1}$] • Biomass for energy production [$t * ha^{-1} * a^{-1}$]
Human health and well-being	Contribution of the land use type to the provision of essential resources (water, fresh air)	• Regulation of air quality • Regulation of water quality	• Cool air production [$m^3 * ha^{-1} * h^{-1}$] • Leaf area index (LAI => combing out of dust emissions) • N-export with seepage water [kg N $ha^{-1} * a^{-1}$]

(*continued*)

Table 2. (*Continued*).

Ecosystem services	Description	Criteria	Indicators
Aesthetic value	Contribution of the land use type to the attractiveness of the landscape	• Natural-aesthetic value • Recreation potential	• Number of visitors • Expert opinion/regional preferences (here, an integrative evaluation at the landscape level by landscape metrics is in preparation, because the aesthetic value cannot really be assessed for single land use types)
Regional economy	Contribution of the land use to private and public income	• Return from land-based production • Contribution to private income and economic wealth • Contribution to regional tax revenue • Contribution to job provision	• Return from selling products from primary production [$€ * ha^{-1} * a^{-1}$] or [$€ * t^{-1} * ha^{-1} * a^{-1}$] • Average per capita income [$€ * a^{-1}$] • Average tax revenue per capita [$€ * a^{-1}$] • Number of inhabitants per hectare • Average tax revenue from industry/commerce [$€ * a^{-1}$]

Sources: Criteria and indicators adapted from Koschke *et al*. (2010), Burkhard *et al*. (2009), Costanza *et al*. (1997), Daily (1997), de Groot *et al*. (2010), MEA (2005), Pérez-Soba *et al*. (2008).

integrity' – they had to be combined by a so-called 'ecological connection matrix' (Frank *et al.* forthcoming), which describes the interactions between both indicators and allows calculation of the ultimate value (lowest -20 points, highest $+20$ points) to which the service 'ecological integrity' has to be increased or decreased at the regional level.

To date, the evaluation of landscape aesthetics has not yet been completed since not all structural indicators have been programmed into PYL.

3. Results

3.1. Contribution of actual stand types and future forest ecosystem types to the provision of ecosystem services at the landscape level

Table 3 shows the evaluated contribution of the actual stand types and the future forest ecosystem types in relation to other land use types (i.e. 'land cover classes') taken from the CORINE Land Cover 2000 classification. This evaluation result was approved by our regional actors in a set of workshops, and thus could be used as a basis for simulating the conversion and afforestation scenarios.

Note that classification of the actual stand types is based on the dominating tree species and that these stand types, according to their description in forest inventory, can be pure or mixed stands (Anonymous 2005). For these stand types, more differentiated information on the mixed tree species or the type of mixture is not documented in digital form, and thus evaluation of the contribution of these stand types to the provisioning of ecosystem services is less precise than for the more detailed characterised forest ecosystem types.

3.2. Scenario simulation: conversion

In a first step, in PYL we tested the impact of the conversion planned by the state forest administration for the 'Kupferberg'. Figure 4 shows the actual spatial distribution of the stand types 'Oak stands', 'Scots pine stands' and 'European beech stands' taken from the forest inventory, and in Figure 5 the results from simulating the conversion of the forest area with the site-specific forest ecosystem types are displayed.

Comparing the starting situation and the conversion scenario, we could show that within the forest area 'Kupferberg', and based on the regionally valid evaluation (Table 3), the planned conversion would enhance the ecosystem services 'biomass provision', 'ecological integrity', 'aesthetic value' and 'human health and well-being'. In contrast, an increase in the services 'regional economy' and 'mitigation of climate change impact' is less evident. The reasons for this are that the actual stand types are estimated to be as well adapted to recent drought risks as the future forest ecosystem types are expected to be adapted to increasing drought risks in the future. Evaluation of the stability of the future forest ecosystem types against windthrow was therefore meant to express the uncertainty as to how these ecosystem types would react to such random events. With regard to the regional economy, the forest ecosystem types 'Oak – Scots pine mixed forest' and 'European beech – Oak mixed forests' were estimated in the evaluation not to contribute much more to private and public income than the actual stand types in the forest area; they are dominated by deciduous tree species, for which the value is estimated by the regional experts to be lower compared to coniferous tree species, even under climate change (see Table 3).

Table 3. Overview of the evaluation results for the actual stand types and forest ecosystem types in relation to the other land use types (land cover classes) taken from CORINE Land Cover 2000.

Land cover classes/actual stand types/ future forest ecosystem types	Ecosystem services					
	Climate change mitigation	Bio-resource provision	Ecological integrity	Regional economy	Aesthetic value	Human health and well-being
Regionally applicable land cover classes, CORINE Land Cover 2000						
Water bodies	100	0	100	5	100	100
Continuous urban fabric	0	0	0	70	40	0
Discontinuous urban fabric	0	0	0	35	50	0
Industrial or commercial units	0	0	0	100	0	0
Road and rail networks and associated land	0	0	0	0	0	0
Port areas	0	0	0	70	20	0
Airports	0	0	0	85	0	0
Mineral extraction sites	0	0	0	45	0	0
Dump sites	0	0	0	70	0	0
Construction sites	0	0	0	0	0	10
Green urban areas	20	0	10	0	40	10
Sport and leisure facilities	20	0	30	0	20	30
Non-irrigated arable land	30	100	50	45	40	40
Vineyards	50	15	70	45	50	40
Fruit trees and berry plantations	60	5	80	20	60	40
Pastures	50	5	80	10	70	30
Complex cultivation patterns	60	5	90	5	70	45
Land principally occupied by agriculture, with significant areas of natural vegetation	50	60	50	60	40	100
Broad-leaved forest	100	25	100	25	90	100
Coniferous forest	80	40	90	65	80	80
Mixed forest	95	25	100	35	100	100

(*continued*)

Table 3. (*Continued*).

Land cover classes/actual stand types/ future forest ecosystem types	Ecosystem services: Climate change mitigation	Bio-resource provision	Ecological integrity	Regional economy	Aesthetic value	Human health and well-being
Natural grasslands	50	5	80	0	50	70
Moors and heathland	50	0	100	0	70	70
Transitional woodland-shrub	80	0	90	0	70	0
Actual stand types						
European beech stands	70	30	100	30	100	90
Oak stands	60	15	100	20	80	80
Norway spruce stands	25	40	10	35	50	60
Scots pine stands	85	10	25	20	60	60
Larch stands	65	15	0	10	70	60
Other stand types	70	10	30	5	90	70
Future forest ecosystem types						
Scots pine – Birch mixed forests	70	10	90	5	80	85
Scots pine – Oak mixed forests	80	20	100	15	90	90
Scots pine mixed forests	80	20	100	20	100	90
Oak – Scots pine mixed forests	70	20	100	10	100	95
Oak – European beech mixed forests	95	25	100	20	100	100
Hydromorphic Oak – Deciduous tree mixed forests	90	25	100	20	100	100
Oak - Noble hardwoods mixed forests	100	20	100	15	100	100
European beech – Oak mixed forests	100	35	100	35	100	100
European beech – Silver fir mixed forests	85	40	100	55	100	95
European beech – Norway spruce mixed forests	95	30	100	40	100	100
European beech – Noble hardwoods mixed forests	100	35	100	45	100	100
Norway spruce – mountain forests	70	40	90	65	80	80
Norway spruce – Silver fir mixed forests	95	40	100	75	100	100
Norway spruce – European beech mixed forests	85	40	100	60	100	80
(extensive) Coniferous trees mixed forests	80	10	100	10	90	85
Peat-bog forests	100	10	100	5	100	100

(*continued*)

Table 3. (*Continued*).

Land cover classes/actual stand types/ future forest ecosystem types	Ecosystem services					
	Climate change mitigation	Bio-resource provision	Ecological integrity	Regional economy	Aesthetic value	Human health and well-being
Creek valley forests	100	30	100	20	100	100
Floodplain forests	100	20	100	15	100	100
Red oak mixed forests	95	25	80	30	60	95
Douglas fir – oak mixed forests	95	35	80	55	70	90
Douglas fir – European beech mixed forests	95	40	80	65	70	90
European beech mixed forests	85	20	100	30	100	100

In a next step, we tested the impact of the conversion of the 'Kupferberg' on the provision of ecosystem services at the scale of the 'Großenhainer Pflege'. This was done with the 'area focus tool' in PYL. This tool allows a comparison of the evaluation result in a 'zoom area' (local scale) of flexible size with the evaluation at regional scale. The diagram in Figure 6 therefore displays four different lines. The dashed and the solid black lines again show the impact of the conversion at the 'Kupferberg' on the provision of the ecosystem services. These results are due to differences in the size of the zoom area compared to the area in Figures 4 and 5 and due to a simplification of the conversion scenario (CORINE Land Cover Class 'mixed forests' into the forest ecosystem type 'Oak – Scots pine mixed forests') not totally identical with the lines displayed in Figure 5. The solid and the grey dashed lines in Figure 6 show the provision of our six ecosystem services on the regional scale with (solid grey line) and without (dashed grey line) conversion. Both grey lines overlap as the area of the 'Kupferberg' is simply too small to have an impact on the provision of our six services on the regional scale.

3.3. Scenario simulation: afforestation

The simulation of afforestation at the sites which regional planning forecasts will be covered by forests in the future ('minimum afforestation scenario') did not result in noteworthy improvements in the provision of ecosystem services (Figure 7), irrespective of the tested forest ecosystem type.

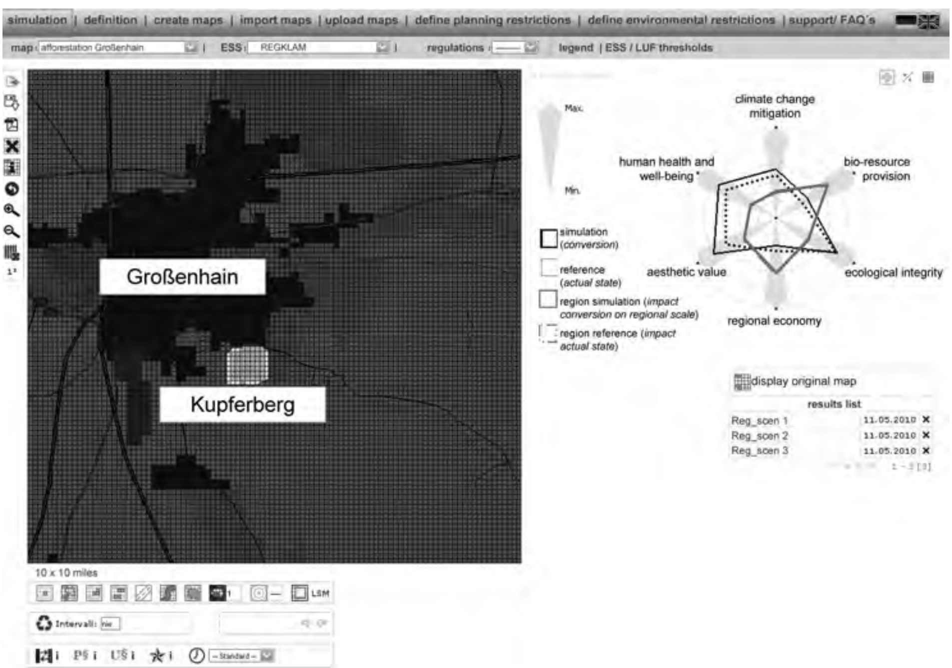

Figure 6. Results from comparing the provision of ecosystem services within the 'Kupferberg' in its current state (black dashed line in the star diagram right to the map) and after conversion (black continuous line) and the changes on the scale of the 'Großenhainer Pflege' (grey dashed line for the starting situation and grey continuous line for the situation after conversion; both are overlapping).

In this afforestation scenario, and comparable to what was written previously in section 3.2 considering the impact of the 'Kupferberg' conversion on the regional scale provision of ecosystem services, the proportion of the forest areas on the regional scale remains too small to have a measurable impact. Furthermore, aspects such as biotope connectivity (Table 4), which could provide additional

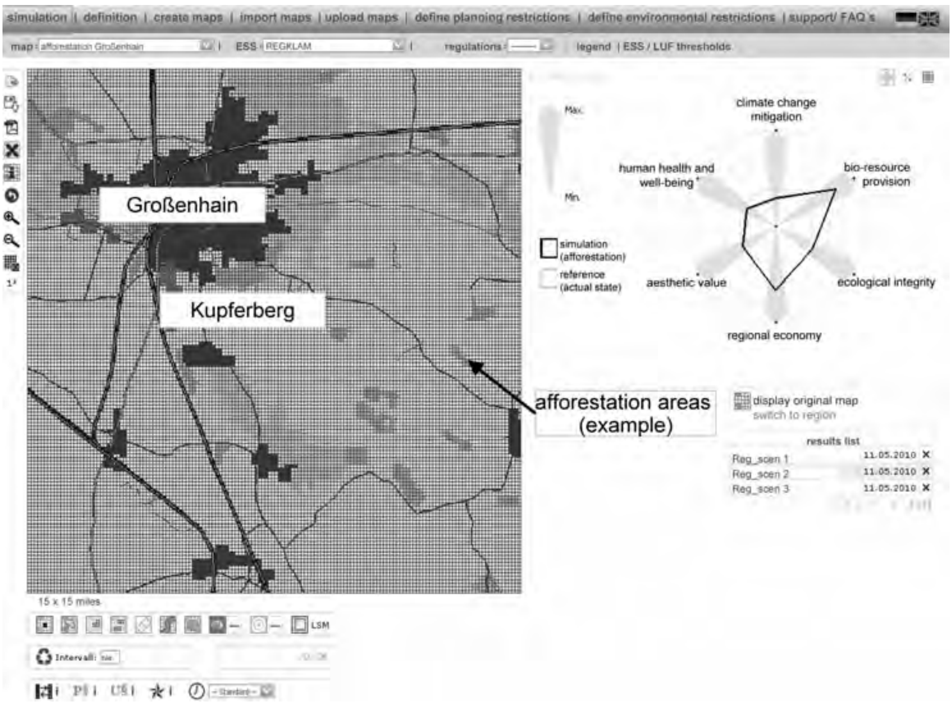

Figure 7. Afforestation at the sites foreseen in regional planning, here demonstrated for the forest ecosystem type "oak - Scots pine mixed forests". The diagram to the right of the map shows that the difference in the provision of ecosystem services without afforestation (dashed line) and with afforestation (continuous line) is negligibly small.

Table 4. Testing the impact of landscape structure on the evaluation results for the service 'ecological integrity' for the starting situation, the afforestation of the preference areas for afforestation and an additional afforestation of preference areas for nature and habitat protection (see also Frank *et al.*, 2010).

Ecosystem service 'ecological integrity'	1. Starting situation (no afforestation)	2. Minimum afforestation (1. + preference areas for afforestation)	3. Maximum afforestation (1. + 2. + preference areas for nature and habitat protection)
Without landscape metrics	46	47	55
With landscape metrics	26	27	65
% connected biotopes	1.34	1.48	21.42
% near-to-nature core areas	0.8	0.84	12.12

benefits for the service 'ecological integrity', were not thoroughly considered in this scenario.

In contrast, using so-called preference areas for nature and habitat protection as an afforestation scenario ('maximum afforestation scenario') results in a visible impact on the ecosystem services provision (star diagram, Figure 8). In this afforestation scenario, the impact of choosing different forest ecosystem types is relevant. For example, afforestation with the ecologically well-adapted but less productive forest ecosystem type 'Oak – Scots pine mixed forests' would enhance, on the regional scale, provision of the ecosystem services 'ecological integrity', 'aesthetic value', 'mitigation of climate change effects' and 'human health and well-being' compared to the situation without afforestation. In contrast, a reduction in provision of the services 'biomass provision' and 'regional economy' would be the trade-offs for this strategy (Figure 8 star diagram, simulation, black line). Realising the afforestation with the alternatively eligible ecosystem type 'European beech – Oak mixed forests' would reduce to a lesser degree the provision of the two ecosystem services 'biomass provision' and 'regional economy' and would even enhance the provision of the ecosystem services 'human health and well-being' and 'aesthetic value' (Figure 8 star diagram, alternative 1, dark grey dashed line). Afforestation with the ecosystem type 'Douglas fir – Oak mixed forests' would result in an almost

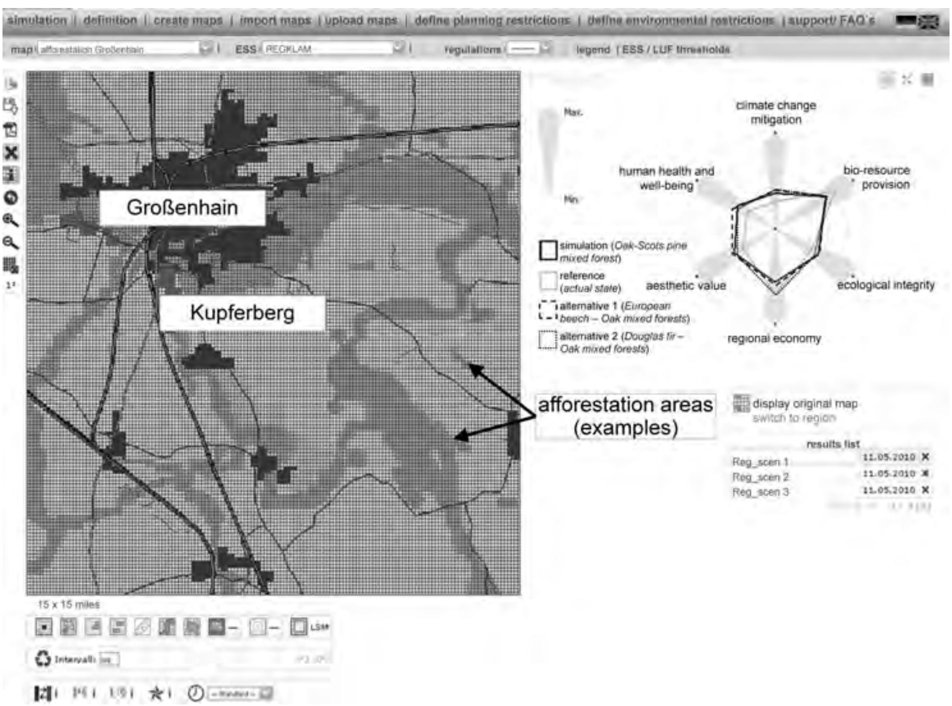

Figure 8. Afforestation of preference areas for nature and habitat protection along biotope connection corridors with different forest ecosystem types. The black dashed line shows the extent to which ecosystem services are provided without afforestation (reference), the black continuous line gives the results for afforestation with the ecosystem type Oak - Scots pine mixed forests''. The dark grey dashed line stands for afforestation with ''European beech - mixed forests'', the light grey dashed line for ''Douglas fir - Oak mixed forests''.

complete compensation of possible trade-offs for 'regional economy', because biomass productivity and the expected market prices of this stand type (returned from primary production) were expected to be rather high (cf. Table 3). On the other hand, the trade-off of this strategy would be lower enhancement of 'ecological integrity', 'human health and well-being' and of the 'aesthetic value' (Figure 8 star diagram, alternative 2 light grey dashed line).

Accounting for the landscape structure (see Table 4) would lead to a considerable reduction in the results achieved for 'ecological integrity' for the starting situation from 46 to 26. In addition, in the case of afforestation of the preference areas for afforestation ('minimum afforestation scenario') a reduction in the achieved value from 47 to 27 is calculated. In contrast, an increase in the value from 55 to 65 could be achieved in the event that the preference areas for nature and habitat protection are also afforested ('maximum afforestation scenario').

To summarise, the results of testing the different strategies lead to the following recommendations for regional planning: (a) to increase considerably the planned afforestation areas under consideration of locally suitable future forest ecosystem types; and (b) to concentrate preference areas for afforestation along corridors, which augment at most – as a result of simulating manifold afforestation scenarios in PYL – the additional benefits provided by connecting the biotopes at the landscape level.

4. Discussion: lessons learnt from the case study

The results from our case study have shown that the conversion as planned on the level of the forest district 'Kupferberg' has a positive impact on the provision of a set of six selected ecosystem services, but that this impact is negligible on the regional scale. To enhance and better balance the provision of ecosystem services on the regional scale, afforestation as a measure beyond pure sectoral planning proved to be indispensable.

However, we were also able to show that the actual regional plan does not really make use of the full potential of sectoral planning information. This applies especially for forest and agricultural land cover classes for two reasons. First, taking the forest land cover classes as an example, within a land cover class such as 'coniferous, deciduous or mixed forest', as it is defined by the standard reference CORINE Land Cover (2002/2006), large heterogeneities are evident regarding the actual composition of a forest (see e.g. Dale and Polasky 2007, Verburg *et al.* 2009). More detailed information on the forest types and their management is difficult to assess through remote sensing techniques and to classify in a way that leaves room for generalisation, as shown in our approach based on sectoral planning information. The same applies for the agricultural land cover classes, even more so as their vegetation cover also underlies much higher temporal dynamics. Second, missing regionalisation of the eligible forest ecosystem types or crops in the case of agricultural land use can provoke incorrect decisions. In Forestry as an example, this concerns which tree species to choose in the case of afforestation. In addition, the decision where to best allocate which ecosystem type is affected in order to ensure that new forests are well adapted to climate change and that negative trade-offs in regional water balance are minimised (see e.g. Wattenbach *et al.* 2007).

As a consequence, recent results regarding the most suitable and well-adapted forest ecosystem types (Eisenhauer and Sonnemann 2009) were simply ignored in regional planning. One reason – additional to what was described above and specific for the forest sectors – is that detailed information on the types of forest, the occurring tree species and their mixture is only available for the governmental forests on the basis of forest inventory and almost unavailable for non-governmental forests in digital form. The latter account for more than 70% of the forest area in our case study region. Information on the eligible forest ecosystem types outside existing forests was completely missing because the responsibility for sectoral (forest) planning is restricted to forests, and regionalised planning information, as an interface to regional planning, is not provided by the respective sectoral planning authority 'Sachsenforst'.

If only the restricted information that is available on the regional scale is applied, uncertainties concerning how to evaluate conversion and afforestation scenarios occur. Better consideration of spatially explicit information from sectoral planning on the actual land use (instead of land cover) and on alternatives to the actual land use, for example, by conversion of a forest or by afforestation of an agricultural site could contribute, first, to a more precise assessment of how, and to what extent, the provision of ecosystem services can be impacted in the regional context. Second, it could also contribute to improvements in decision making on a regional scale regarding where to focus specific sectoral planning alternatives as an interface to regional development and public funding (see, for example, Wiek and Walter 2009). Here, we should add that, in Germany, public funding is managed partially at county level, where the county is an administrative district within a federal state, and at the level of regional co-ordination bureaus, which are established in the context of the programme European Agricultural Funds for the Development of Rural Areas. Both counties and regional co-ordination bureaus base their decisions where to fund, for example, afforestation on the delineated preference areas from regional planning. As a consequence, if we deliver an improved spatially explicit planning basis for regional planning, funding decisions could be also be optimised by referring to this planning basis. As a result, types of indirect payments for enhancing the regional scale provision of ecosystem services could be initiated.

A reason why this interface to public funding is so important is that the conversion of the actual stand types into future ecosystem types is carried out as being the responsibility of the respective owner of the forest. Thus, it is only binding in the governmentally owned forest, while in private or municipal forests public funding is the most essential legal instrument for realising political targets. These targets involve conversion of the actual forests into forests that are better adapted to climate change, and enhancement of the provision of ecosystem services. So far, however, efforts have been very weak regarding exploitation of existing funding opportunities to achieve a higher conversion success rate from non-governmental forest owners under consideration of optimisation of the ecosystem services provision on the landscape scale. The same applies for afforestation. Here, the delineation of preference areas for afforestation in the regional plan is based on a proposition by the State Forest Administration (which is not identical with the governmental forest enterprise 'Sachsenforst') as actor in the writing and up-dating process of the regional plan. However, this original proposition only took into consideration which areas were most likely to be afforested in the future due to disadvantages in the site quality for agricultural use, and did not take into consideration where afforestation should best take place in order to support an improvement in the provision of ecosystem services.

A reason why the effort has so far failed to better integrate sectoral forest planning into regional planning (not only in our case study), might be that no real consensus could be achieved concerning which criteria or evaluation system should be used to assess the value of forests in relation to other land uses. The approaches for how to assess the value of forests, however, are broadly variable and consist of terms such as 'functions', 'marketable or non-marketable goods' and 'services', and they are mostly incompatible with evaluation approaches in other land use sectors, such as agriculture, and with such large scale evaluation frameworks as Millennium Ecosystem Assessment (MEA 2005) or The Economics of Ecosystems and Biodiversity (TEEB, Ring *et al.* 2010; see, for example, Buttoud 2000). Standards such as the MEA or TEEB provide generalised frameworks for how the value of nature and different ecosystems can be assessed and we refer therefore, in our application and adaptation of the multi-criteria assessment approach in PYL so far, to MEA as a standard.

Furthermore, research on the interactions between forests and other land use types is quite rare and often restricted to non-spatially transferable questions such as whether N-emissions from a specific agricultural site might have an impact on the productivity, habitat quality or water quality provided by a neighbouring forest stand. Interactions on a larger scale that allow conclusions regarding the role of forests as contingent upon their spatial localisation are mostly discussed with regard to water catchment management (e.g. Lorz *et al.* 2007), but not so much with regard to looking at the optimal use of forests for solving other landscape pattern related issues. As an example, an application of landscape metrics to form conclusions regarding optimised corridors for afforestation as an interface to regional (and rural) development planning and an improved allocation of funding opportunities has thus far been missing and is therefore integrated into the further development of PYL (Frank *et al.* forthcoming).

If we do not come to a common consensus in the evaluation system to be applied and if we ignore interactions between different land use types and the impact of the land use pattern, valuable information will be lost regarding the potential of forests to contribute not only to a healthy and well-functioning environment – an aspect that is broadly acknowledged – but to regional economic and social targets as well (Dale and Polasky 2007, Verburg *et al.* 2009, Power 2010). This might explain the often-observed low motivation level to increase the proportion of forest areas on the landscape scale (e.g. Ní Dhubháin *et al.* 2009).

To conclude from the above-discussed aspects and our experience in adapting the PYL software to test regional planning scenarios, three recommendations can be derived to promote a better integration and consideration of (forest) sectoral planning aspects into regional planning: (1) Land cover classes for forests (and agriculture) as they are used in regional planning should be replaced by classes which express management aspects, thus enhancing assessment of the impact of concrete and regionally typical land use practices. Therefore, as an example, sectoral information from forest inventory and forest management planning must be aggregated in a form ('classification'), which is applicable on the landscape scale and compatible with the land cover information; (2) Criteria for deciding on the eligibility of a forest or agricultural class for a certain site should be translated and prepared in a way that allows regionalisation of this information as well as the application of sectoral management planning information in regional planning; (3) A compatible evaluation standard such as the ecosystem services concept must be applied. This would not only help to assess the specific contribution of forests or agriculture, for example, in relation to all other land cover classes, but would also help to better communicate the real opportunities and benefits from sectoral planning measures in the regional planning context.

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Assessment of the effects of forest land use strategies on the provision of ecosystem services at regional scale

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ABSTRACT

This paper presents results of a case study in Middle Saxony, Germany, where the impact of conversion, afforestation and alternatively introduction of short rotation coppice areas on the provision of ecosystem services was tested in a spatially inexplicit and a spatially explicit way to formulate recommendations for regional planning. While the spatially inexplicit testing did not lead to clear results regarding to what degree forests or short rotation coppice areas are desirable and applicable, the spatially explicit testing revealed that an increase in the forest area or area with short rotation coppice by 29.7% in unstructured agriculturally dominated Loess regions, 14.4% in more topographically structured parts in the North-East of the model region and 23.6% in its mountainous parts would be beneficial. Potentially resulting losses in the provision of bioresources and regional economy can be considerably reduced by replacing afforestation areas with short rotation coppice.

In summary, we found that the spatially explicit analysis of land use scenarios in combination with a more detailed land use classification and including an assessment of changes in land use pattern gave us an improved basis for assessing different possible planning strategies and to enhance the communication between forest management planners and regional planners.

1. Introduction

A most important issue in sustainable land use is how to maintain the functioning of ecosystem processes and to ensure thereby the provision of natural resources, goods and benefits to human beings, nowadays called ecosystem services (de Groot et al., 2010; O'Farrell and Anderson, 2010). Though knowledge and approaches how to assess the monetary or non-monetary value of such services are widely developed and acknowledged, the use and acceptance of ecosystem services as a goal or criterion for success in land use or regional planning is still in discussion (Viglizzo et al., 2011; Fürst et al., 2010a). Reasons therefore might be that (a) monetary terms into which most recent research activities such as TEEB (Jones-Walters and Mulder, 2009; Ring et al., 2010) translate ecosystem services intend to address the scale of thinking in land use (microeconomic) and regional planning (societal needs), but they focus however much more on conclusions from a macroeconomic (political) point of view. (b) Furthermore, for planning items, the provision of ecosystem services must be translated into demands for land (land requirements), which must be allocated in a spatially explicit way. Such land requirements have to be checked carefully considering interferences between different services to be provided by the same piece of land and planning relevant restrictions such as nature conservation areas, which might impact the prior provision of one or several services by a piece of land (Egoh et al., 2011; Ulgiati et al., 2011; Smith et al., 2010). Land requirements in land use planning (forestry, agriculture) and regional planning are calculated based on criteria such as the expected future demand for wind and bioenergy, drinking water or food, or the expected need for settlement areas and infrastructural facilities (for state regional planning in Saxony see e.g. SMI, 2004). This means that already some of the criteria and underlying indicators in regional planning can be directly linked with the ecosystem services approach, while others are related to socio-economic considerations, which are more indirectly addressed by the ecosystem services approach (Fürst et al., 2012). Furthermore, difficulties arise in assessing the impact of land use (use = management) strategies on the provision of ecosystem

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services on a regional (meso-) scale because data on the concrete management of a piece of land on a micro-scale are often not available in a way that they could be involved in meso-scale assessment approaches (Verburg et al., 2009; Dale and Polasky, 2007). Examples therefore are crop rotation, soil management techniques and fertilization strategies in agriculture, or tending, harvesting and regeneration measures in forestry. They are recorded on a micro-scale, but mostly not mapped, with the result that immense knowledge on possible land-management related impact factors on the provision of ecosystem services is lost (Salmon-Monviola et al., 2012; Fürst et al., 2011). In consequence, also information on the real land use mosaic is missing, and, even worse, available information on how to account for the pattern of land uses or land-cover classes on the provision of ecosystem services is rarely available (Frank et al., 2011; Lautenbach et al., 2011).

Assuming that the ecosystem services concept offers a valuable method for assessing land use and regional planning alternatives and their impact on the constituents of human well-being in a generic, easily communicable and transferable way, we intended to adopt this concept for regional planning questions. In this paper, we present results from a case study in Middle Saxony, Germany, and focus on testing integrated land use strategies in forestry (conversion, afforestation) and at the interface to agriculture (short rotation coppice as a special case; Fürst et al., 2011, 2012). The case study was done in the context of the updating process of the regional plan (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge, 2009).

We tested our forest land use strategies (a) in a spatially inexplicit way to identify possible general recommendations for our model region and (b) by using the software platform GISCAME (Fürst et al., 2010a,b) in a spatially explicit way for some representative sections of our model region. The spatially inexplicit testing represents thereby the scale of thinking in state regional planning, where policy aims are translated into very generally formulated land requirements; (b) represents the scale of thinking in regional planning, where such land requirements must be concretely located. This can be complemented by additional information such as locally specific priorities for land management strategies, e.g. no-till areas to reduce water erosion.

The paper introduces first the software platform GISCAME and the embedded multicriteria evaluation framework which was implemented for the spatially inexplicit and the spatially explicit testing of the land use strategies including some underlying assumptions related to our land use classification and the selected ecosystem services. Then we provide an overview on the land use scenario matrix which was used for testing in both cases. We compare spatially inexplicit and spatially explicit conclusions and discuss their implications for planning. Lessons learnt from spatially inexplicit and explicit testing, from the use of the GISCAME software platform and from the discussion with our actors are part of the discussion and conclusions.

2. Material and methods

2.1. Model region and basic data

Our aim within the case study was to assess the impact of forest and agricultural land use scenarios on the provision of a set of ecosystem services (see 3.2). The land use scenarios were defined in the course of updating the regional plan (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge, 2009) together with the planning authority and the working groups for (i) agriculture, (ii) forestry and (iii) land management of three ILE (Integrated Rural Development) regions within the district of the planning authority, namely “Dresdener Heidebogen”, “Silbernes Erzgebirge” and “Sächsische Schweiz”. These three ILE regions represent well typical environmental and socio-cultural conditions in the model region and were therefore considered as appropriate reference for the scenario development. In result, recommendations for regional planning should be given, where and how land use should explicitly be addressed by priority or preference areas for specific agricultural or forest land uses to increase the provision of some so far underrepresented services and to achieve an optimal balance in the regional ecosystem services portfolio. Fig. 1 shows the land cover mosaic of our $\sim$10,000 km^2 large model region in the middle of Saxony, eastern Germany, in the way that it is displayed in the software GISCAME (see 2.3); Table 1 provides an overview on some land cover and land ownership statistics, which are later on relevant for the scenario formulation (see sections 2.4 and 2.5).

2.2. Selected ecosystem services

In our case study, we identified a set of six services to be assessed when testing land use and land cover change strategies (Fürst et al., 2011, 2012). We used a participatory process with actors in our planning district including the three ILE regions, which came from forestry, agriculture and regional planning including private land owners, land owner associations and representatives from the public sector (governmental and sub-governmental organizations). We started our assessment in using the ecosystem services concept in the understanding of the Millennium Ecosystem Assessment (MEA, 2005). The indicator and criteria selection process itself was based on extensive literature studies, expert recommendations and stakeholder knowledge on available and applicable information in the regional context as described and critically discussed by Koschke et al. (2012) and Fürst et al. (2012). In the assessment process and following the arguments and planning questions of our actors, our understanding of ecosystem services had to be modified and adapted compared to the original understanding in MEA (2005; see Fürst et al., 2011; Fürst et al., 2012). Our set for this case study comprises provisioning services (“*bio-resource provision*” including timber, food and fibers; “*human health and well-being*” related to the provision of fresh water and air), regulating services (in our case named “*mitigation of climate change impact*”), cultural services (“*aesthetic value*”) and supporting services (contribution to “*ecological integrity*”). Additionally, a service called “*regional economy*” (private and public income from direct and indirect land use) had to be integrated to meet the needs of our regional actors (Fürst et al., 2011, Fürst et al., 2012, Fürst et al., 2010a; see also Menzel and Teng, 2009). Noteworthy is that the naming and definition of what these services imply in the regional context came directly from our actors, who selected also the criteria and indicators for the evaluation (see Table 2) and that it was exclusively developed for the planning questions to be answered. Therefore, these services should not and cannot be compared to and understood in the sense of more complex scientific concepts which are normally addressed, for instance, by “ecological integrity” or “climate change mitigation”.

2.3. GISCAME and the multicriteria assessment framework

GISCAME is a software platform which combines a GIS module with a cellular automaton module and a multicriteria evaluation framework (Figs. 2 and 3). Application area of GISCAME is to assess the impact of land cover and land use change scenarios on planning goals, which can be expressed by ecosystem services or other, to a higher or lower degree, aggregated target figures (Fürst et al., 2010a,b).

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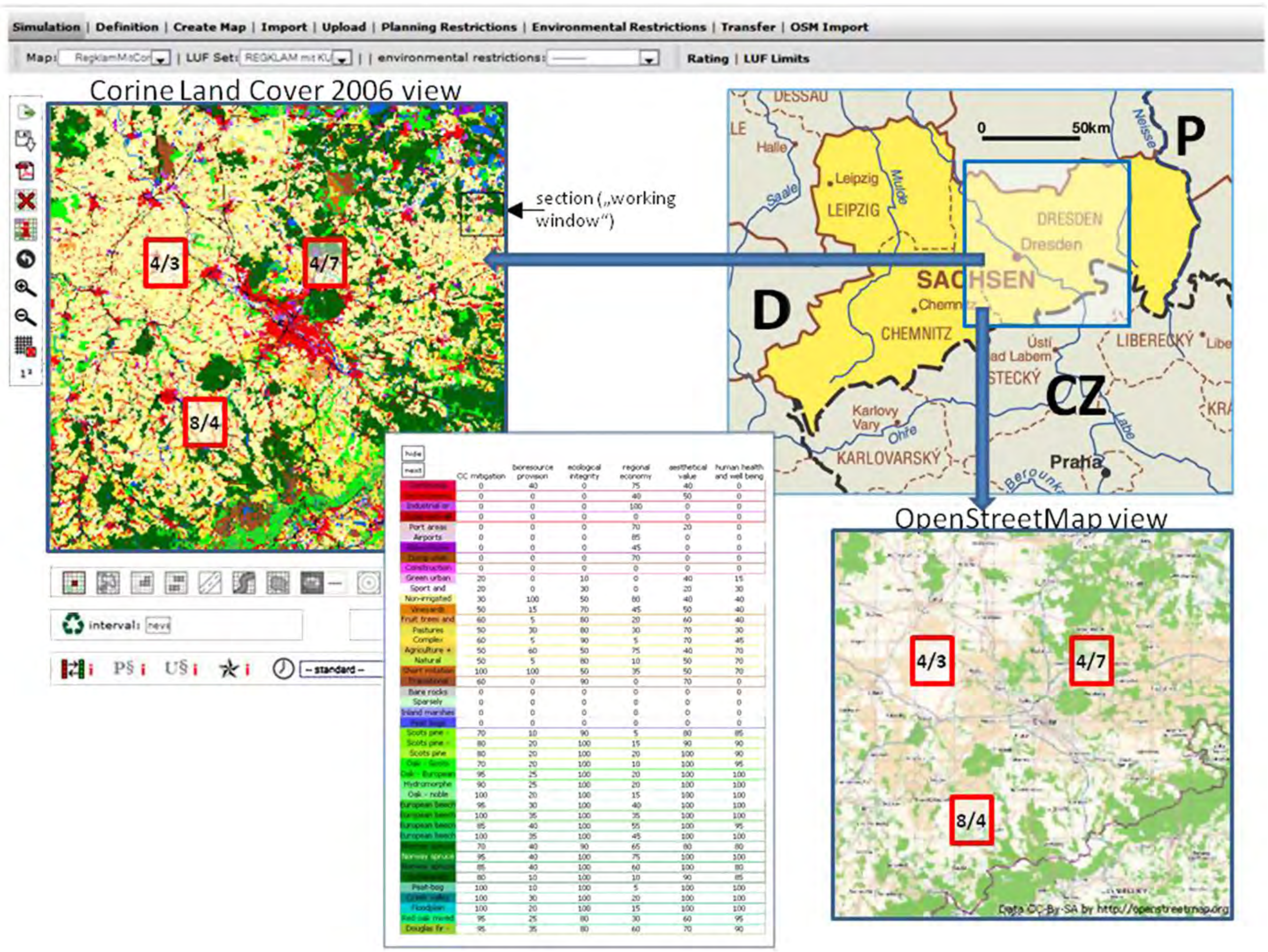

Fig. 1. Model region in the GISCAME display. The map right side at the top shows the location of the model region. Below shown is the OpenStreetMap view of the model region which is used in GISCAME for navigation. Left side shown is the land cover mosaic as imported from Corine Land Cover 2006 and the legend. In the OpenStreetMap and the Corine Land Cover view, the sections in which the spatially explicit testing was done are marked (see section 2.5).

In the following, we focus on our set of six modified ecosystem services as criteria for the fulfillment of planning targets at regional scale. Furthermore, we use subsequently the term land use (-class), which comprises in our case standard land cover classes as they are defined in Corine Land Cover (CLC) 2006 and additional land use classes which give more detailed information on current and future use (=management) alternatives in the land cover classes coniferous, deciduous and mixed forest based on the current state silvicultural planning (Eisenhauer and Sonnemann, 2009) in Saxony, and – adding short rotation coppice – in the land cover class non-irrigated arable land (see Table 2).

The GIS module supports integrating, combining and merging available digital information on land use, environmental features such as soil types, topography or climate characteristics, existing planning layers framing possible restrictions such as nature conservation areas and other possibly relevant information such as land ownership types.

Table 1
Statistical data of the model region and the derived weighing factors for the spatially inexplicit scenario testing. The scenarios F1-10, F1-11, Ecomax and Lignomax – are explained in Table 4.

Statistical data model region (data source: www.statistik.sachsen.de, accessed online November, 14, 2011.)	%	Weighting factors for spatially inexplicit testing				
		Starting situation	F1-10	F1-11	Ecomax	Lignomax
Forest area	25.94	0.26	0.28	0.38	0.50	0.26
Governmental forests	37.00	0.10	0.10	0.10	0.10	0.10
Non-governmental forests sum	63.00	0.16	0.18	0.28	0.41	0.16
Private forests	53.00	0.14	0.16	0.26	0.38	0.14
Municipal forests	10.00	0.03	0.03	0.03	0.03	0.03
Agricultural area	60.64	0.61	0.59	0.49	0.36	0.48
Other land use classes (besides agriculture and forestry)	13.42	0.13	0.13	0.13	0.13	0.13
Short rotation coppice	–		–	–	–	0.12

Table 2
Indicators and criteria applied for assessing the impact of the land use classes on the ecosystem services (adapted from Koschke et al., 2012; Fürst et al., 2012) in the model region.

Ecosystem services	Criteria and indicators
Climate change mitigation	• Water balance regulation: water retention capacity [m^3*ha^{-1}], run-off coefficient [Ψ], soil sealing [%] • Contribution to local climate regulation: albedo [%] • Contribution to global climate regulation: C-Sequestration – storage of C in soil and biomass [kg C ha^{-1}] • Soil erosion protection: C-factor (USLE)
Ecological integrity	• Biological diversity: composition of flora and fauna communities in relation to the potential natural communities • Functioning of matter and water cycles: N- and P export with seepage water [kg N/P*ha^{-1}], ground water recharge [m^3*ha^{-1}], evapotranspiration • Capacity for biological regulation: number of habitats for pest control species
Bio-resource provision	• Production of plant biomass: Food and fodder from plants [t*ha^{-1}*a^{-1}], biomass for industrial use/processing [t*ha^{-1}*a^{-1}], biomass for energy production [t*ha^{-1}*a^{-1}] • Production of bio-resources from livestock: food from livestock [t*ha^{-1}*a^{-1}]
Human health and well-being	• Regulation of air quality: cool air production [m^3*ha^{-1}*h^{-1}], leaf area index • Regulation of water quality: N-export with seepage water [kg N ha^{-1}*a^{-1}]
Aesthetical value	• Recreation potential: number of visitors • Natural-aesthetical value: expert opinion/ regional preferences
Regional economy	• Return from land-based production: return from selling products from primary production [€*ha^{-1}*a^{-1}] or [€*t^{-1}*ha^{-1}*a^{-1}] • Contribution to private income and economic wealth: average per capita income [€*a^{-1}] • Contribution to regional tax revenue: average tax revenue per capita [€*a^{-1}], number of inhabitants per hectare, average tax revenue from industry/commerce [€*a^{-1}]

The cellular automaton module enables simulation of cell-wise or larger scale land use changes in a regional context. A cellular automaton is a mathematical approach, which in our case is used to divide the complex and continuous problem landscape into smaller units, called cells. Currently, the spatial resolution of our cells is limited to 10,000 m^2 to ensure the compatibility of our simulations with the Corine Land Cover data set. The cells hold information on the land use and any other attributes provided by the GIS module and they hold also knowledge regarding the properties of each other cell. The use of this approach helps us to simulate the interdependences between neighboring land uses and to account for the impact of the land use pattern. The cell attributes are relevant for deciding on possible or impossible land use changes within scenarios. Furthermore, they are used in combination with the multicriteria evaluation framework module for calculating the impact of land use changes on the provision of ecosystem services (Fürst et al., 2010a,b).

The multicriteria assessment framework module is a hierarchical approach (Fig. 3) which bundles available information on the impact of land use classes and land use patterns on the provision of ecosystem services based on case-specific criteria and indicators. To enable a comparison of the impact of planning alternatives on a bundle of services, where different indicators with different measurement units have to be applied for the services and also for the land use classes, we developed a qualitative assessment approach. We transform all indicator values (Table 2) by mathematical normalization to a relative scale from 0 (minimum value) to 100 (maximum value). If several indicators are used for calculating a service, they are accounted with equal weight (Koschke et al., 2012). Table 3 provides an overview of the land use classes applied in our model region and of their qualitative values for the ecosystem services. The value between 0 and 100 which an ecosystem service can adopt on the scale of the model region is calculated as the mean value of all cells.

The impact of the land use pattern on the potential of the model region to provide ecosystem services is assessed in GISCAME by a set of landscape metrics and is also expressed in a qualitative way. The landscape metrics are applied to adjust the results achieved for the services "ecological integrity" and "aesthetic value" (Frank et al., 2011). Currently, we implemented in GISCAME (a) the proportion of functionally connected habitats (Zebisch et al., 2004), (b) the proportion of natural land use types (Augenstein, 2002; Steinhardt et al., 1999; Tasser et al., 2008), (c) the average of unfragmented open areas (Gao and Li, 2011; Girvetz et al., 2008; Jaeger et al., 2008), (d) the shape index (Augenstein, 2002; Baessler and Klotz, 2006; Renetzeder et al., 2010), (e) the Shannon–Wiener diversity index (Yeh and Huang, 2009; Kim and Pauleit, 2007) and (f) the patch density per km^2 (Hein et al., 2004). The single

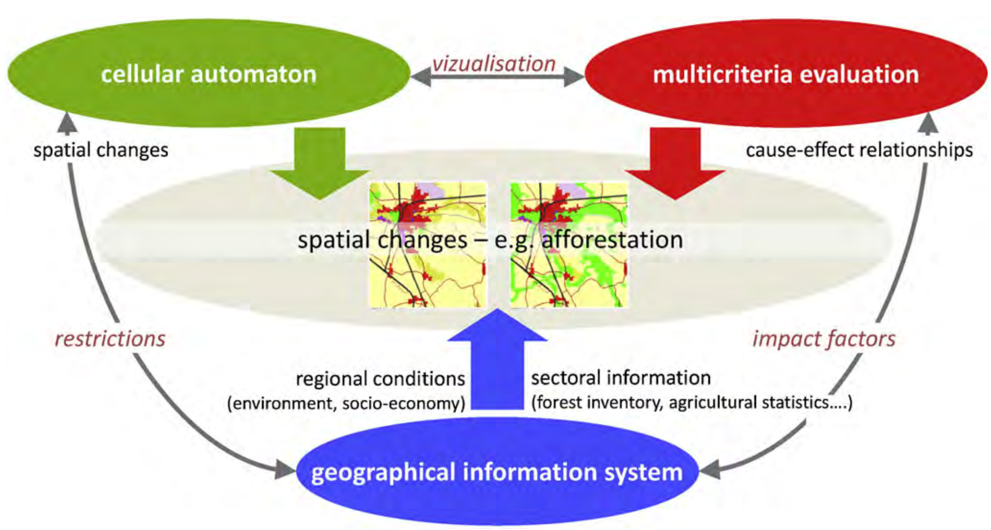

Fig. 2. Modular design of the GISCAME software.

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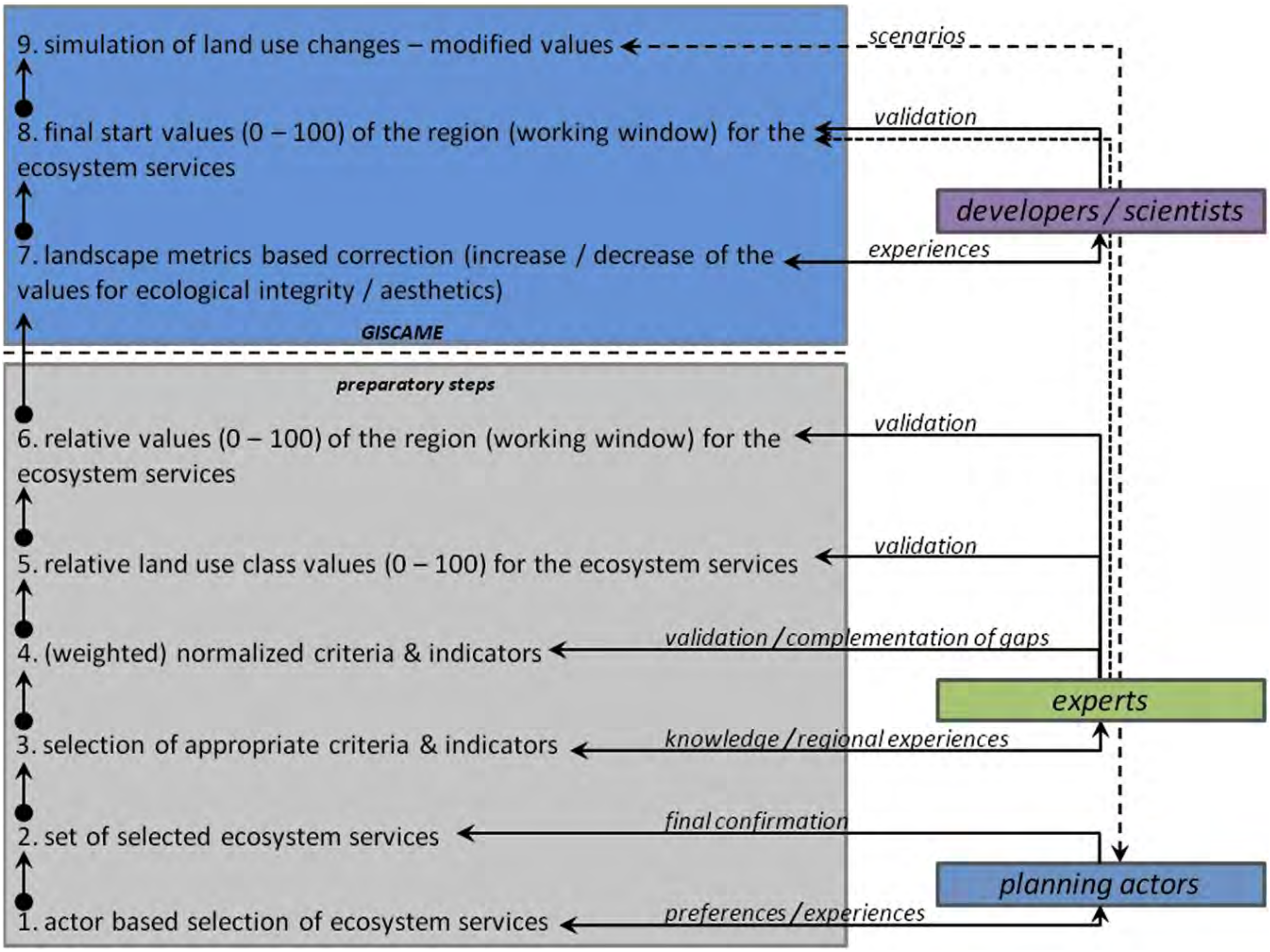

Fig. 3. Hierarchical iterative evaluation approach in GISCAME. Main actors in the evaluation are the planning actors (regional planners/land users, etc.) who decide upon the selected ecosystem services. Expert knowledge is used for the selection of the criteria and indicators and for validating the outcomes of the evaluation. Scientific knowledge is applied in the GISCAME environment for the application of the landscape metrics based correction.

landscape metrics are aggregated, in a second step, in so-called ecological connection matrices (Bastian and Schreiber, 1999) and – as an evaluation convention – the aggregation process results in 0–30 points to which the result for our two services "ecological integrity" and "aesthetical value" can be increased or decreased at the level of the model region, while the lower (0) and upper (100) limit of our relative scale cannot be exceeded. For the aggregation, first the "typical" range of values that can be adopted by each of the landscape metrics for the total region and not specifically for particular sites or locations where management takes place (for consequences see e.g. Zaccarelli et al., 2008), was calculated and then this range was segmented into five "sub-ranges". Subsequently, in the ecological connection matrices, the sub-ranges of the landscape metrics were aggregated pairwise to three assessment criteria for ecological integrity and aesthetics, namely "landscape fragmentation", "habitat connectivity" and "landscape diversity" and these pair combinations were evaluated on a scale from –10 to 10 points. The final aggregation result is then achieved by adding the number of points in each of the criteria. The landscape metrics assessment approach and how it was adapted to the cellular automaton model in GISCAME is described in more detail by Frank et al. (2011).

For our case study, some additional assumptions have been made: first, for calculating and visualizing the landscape metrics in our web-based system in a meaningful amount of time, our 53 land use classes were clustered into classes with higher or lower degrees of naturalness (see e.g. Grabherr et al., 1998; Granke et al., 2004). Currently, the land use classes are regrouped into five classes, "metahemerobe" (lowest degree of naturalness, e.g. continuous urban fabric or industrial and commercial units), "polyhemerobe" (e.g. construction sites or dump sites), "euhemerobe" (e.g. pastures or complex cultivation pattern), "oligohemerobe" (e.g. natural grassland or transitional woodland shrub) and "mesohemerobe" (highest degree of naturalness, e.g. deciduous, coniferous and mixed forests), see Table 3 (Frank et al., 2011). Considering our forest land use classes including these, which express more concrete management opportunities (Table 3), and the class short rotation plantations, the second assumption was to assign them all the class "mesohemerobe". This leads to the result that the calculated landscape metrics do not consider land use changes within forests, such as conversion.

2.4. Spatially inexplicit testing matrix

The spatially inexplicit testing strategy was based on the qualitative values assigned to our land use classes on a scale from 0 to 100 as shown in Table 3 and on the weighting factors for the land use classes shown in Table 1. The weighting factors were used to express the weight to which the relative values of the land use classes (Table 3) were used to calculate the sum values for each of

Table 3
Overview of the land use classes (including Corine Land Cover classes, forest land use classes and short rotation coppice), their clustering into hemeroby classes and their relative values for the selected six ecosystem services and the percentage of the Corine Land Cover 2006 classes for the 10,000 km^2 large model region.

Classes	CLC %	Hemeroby class	CC mitigation	Bioresource provision	Ecological integrity	Regional economy	Aesthetics	Human well-being
Water bodies	0.80	eu~	100	0	100	5	100	100
Continuous urban fabric	0.05	poly~	0	0	0	70	40	0
Discontinuous urban fabric	8.91	meta~	0	0	0	35	50	0
Industrial or commercial units	1.19	meta~	0	0	0	100	0	0
Road and rail networks and associated land	0.05	meta~	0	0	0	0	0	0
Port areas	0.01	meta~	0	0	0	70	20	0
Airports	0.16	meta~	0	0	0	85	0	0
Mineral extraction sites	0.14	poly~	0	0	0	45	0	0
Dump sites	0.02	poly~	0	0	0	70	0	0
Construction sites	0.02	poly~	0	0	0	0	0	10
Green urban areas	0.05	eu~	20	0	10	0	40	10
Sport and leisure facilities	0.22	poly~	20	0	30	0	20	30
Non-irrigated arable land	47.74	eu~	30	100	50	45	40	40
Vineyards	0.00	eu~	50	15	70	45	50	40
Fruit trees and berry plantations	0.47	eu~	60	5	80	20	60	40
Pastures	5.02	eu~	50	5	80	10	70	30
Complex cultivation patterns	3.52	eu~	60	5	90	5	70	45
Land principally occupied by agriculture, with significant areas of natural vegetation	3.81	meso~	50	60	50	60	40	100
Natural grasslands	0.08	oligo~	50	5	80	0	50	70
Moors and heathland	0.22	oligo~	50	0	100	0	70	70
Transitional woodland-shrub	1.58	oligo~	80	0	90	0	70	0
Corine Land Cover Forest Classes								
Broadleaf forest	1.25	meso~	100	25	100	25	90	100
Coniferous forest	20.46	meso~	80	40	90	65	80	80
Mixed forest	4.23	meso~	95	25	100	35	100	100
Multifunctional forest ecosystem types	No data available							
Scots pine – birch mixed forests		meso~	70	15	100	10	100	85
Scots pine – oak mixed forests		meso~	80	20	100	15	100	90
Scots pine mixed forests		meso~	80	20	100	20	100	90
Oak – Scots pine mixed forests		meso~	90	20	100	10	100	95
Oak – European beech mixed forests		meso~	95	25	100	20	100	100
Hydromorphe Oak – deciduous tree mixed forests		meso~	100	25	100	20	100	100
Oak – noble hardwoods mixed forests		meso~	100	20	100	15	100	100
European beech – oak mixed forests		meso~	100	35	100	35	100	100
European beech – Silver fir mixed forests		meso~	90	40	100	55	100	95
European beech – Norway spruce mixed forests		meso~	95	30	100	40	100	100
European beech – noble hardwoods mixed forests		meso~	100	35	100	45	100	100
Norway spruce – mountain forests		meso~	80	40	100	65	100	80
Norway spruce – Silver fir mixed forests		meso~	85	40	100	75	100	90
Norway spruce – European beech mixed forests		meso~	85	40	100	60	100	80
(extensively managed) coniferous mixed forests		meso~	70	20	100	15	100	70
Azonal forest ecosystem types	No data available							
Peat-bog forests		meso~	100	20	100	10	100	100
Creek valley forests		meso~	100	20	100	15	100	100
Floodplain forests		meso~	100	20	100	15	100	100
Production optimizing forest ecosystem types	Non data available							
Red oak mixed forests		meso~	70	25	60	30	60	50
Douglas fir – oak mixed forests		meso~	70	35	80	55	70	50
Douglas fir – European beech mixed forests		meso~	80	40	80	65	70	50
European beech mixed forests		meso~	100	30	100	40	100	100
Stand types from forest inventory (current situation)	No data available							
European beech stands		meso~	70	30	100	30	100	90
Oak stands		meso~	60	15	100	20	80	80
Norway spruce stands		meso~	25	40	10	35	50	60
Scots pine stands		meso~	85	10	25	20	60	60
European larch stands		meso~	65	15	0	10	70	60
Other stand types		meso~	70	10	30	5	90	70
Additional class	No data available							
Short rotation coppice		meso~	100	100	50	35	50	70

the ecosystem services in the scenarios. Here, a differentiation was only made for forestry, agriculture and short rotation coppice, while all other land use classes were included with equal weight in the term "other land use classes".

To test potentially recommendable strategies in modifying the land use, we came up with a set of 83 scenarios. These are built upon three basic scenarios for forest management within forests: (a) business as usual, (b) multifunctional conversion, and (c) economic conversion. Business as usual means that the current forest land use classes are maintained (Table 3). Multifunctional conversion means that the forest is converted into multifunctional forest land use classes as described by Eisenhauer and Sonnemann (2009) for 95% of the forest area and into so called azonal forest land use classes foreseen for highly sensitive sites on 5% of the forest area. The multifunctional forest land use classes are defined as stand types to be developed within the next rotation period, which are expected to provide to maximal extent all classical forest functions, such as timber provision, soil protection, provision of habitats and recreational space (see e.g. Riegert and Bader, 2010). Azonal forests are stands with tree species that provide an optimal potential for hosting rare species and protecting soil functioning at hydromorphic or very dry sites. Economic conversion means that forest is converted into production maximizing forest land use classes for 95% of the forest area and into the azonal forest land use classes again for 5% of the forest area.

In a next step, our basic scenarios were varied projecting the scenarios on the areas related to the two big different forest ownership types in Germany, governmental (Saxony: 37% of the forest area) and non-governmental (Saxony: 63% of the forest area) forests (see Table 1). In a subsequent step, afforestation scenarios were added, which include (a) the type of afforestation and (b) the share to which the forest (including short rotation coppice) area is increased. Considering (a), afforestation with the forest land use classes derived from forest inventory ("default afforestation"), afforestation with the multifunctional or production oriented forest land use classes and short rotation coppice are differentiated. Considering (b), an increase in the forest area by 2% following the current goal of the state regional plan (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge, 2009) and an increase in the forest area by 12% (2% according to state regional planning + 10%: here we took as a reference the German Federal Act for the Protection of Nature, which implies that the minimum area of connected ecologically valuable areas should be 10% for each federal state [§ 20(1)24]) were tested. Finally, some "extreme" scenarios were added, which foresee a multifunctional conversion of all forests and a multifunctional afforestation of all extensively used agricultural areas ("ecomax") or an economic conversion of all forests and an establishment of short rotation coppice for all extensively used agricultural areas ("lignomax"). Fig. 4 illustrates the scenario matrix, and Table 4 gives a detailed description of the scenarios.

2.5. Spatially explicit testing

For spatially explicit testing, the before described scenarios were tested in some selected parts of our model region. Within GISCAME, the model region is segmented into "working windows" of 100 km^2, which helps to test scenarios faster compared to a simulation for the whole 10,000 km^2 large region (Fig. 1). For our scenario test, we selected three of these "working windows" (further called "sections"), which best represent the regional range of site conditions and land use pattern and the specific impact resulting from climate change.

Section 4/3 represents the weakly-structured and agriculturally-dominated Loess areas in our model region, here, the so-called "Lommatzscher Pflege". In the Loess areas, low impact from climate change on agricultural productivity is expected, while on the other hand, high-water erosion risk is already observed and expected to be increased, if no better structuring of the land use pattern can be achieved by afforestation or strategic allocation of short rotation coppice areas. Section 4/7 is representative of a more

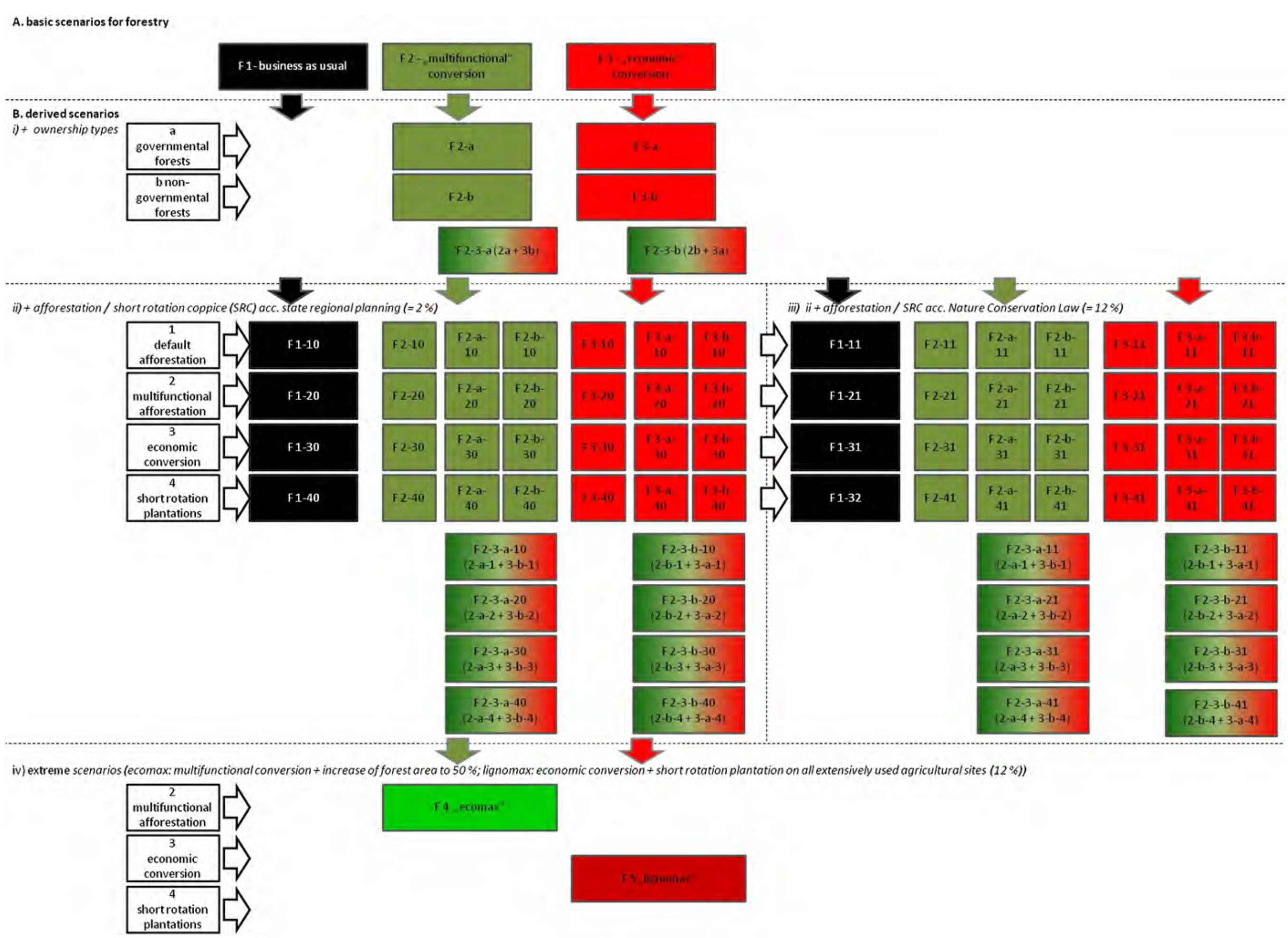

Fig. 4. Scenario matrix for the spatially inexplicit testing. This test matrix was also used as reference for the spatially explicit scenarios.

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Table 4
Description of the scenarios related to Fig. 4

N°	Acronym	Name	Description
A) Basic scenarios for forestry			
1	F-1	Business as usual	Actual forest stand types are continued
2	F-2	Multifunctional conversion governmental/non-governmental forests	Conversion with multifunctional stand types including ecologically-optimized types for azonal sites, excluding production optimized types
3	F-3	Economic conversion governmental/non-governmental forests	Conversion with production optimized types including ecologically-optimized types for azonal sites
B) Derived scenarios			
i) *Ownership types*			
4	F-2-a	Multifunctional conversion governmental forests	Multifunctional conversion governmental forests
5	F-2-b	Multifunctional conversion non-governmental forests	Multifunctional conversion non-governmental forests
6	F-3-a	Economic conversion governmental forests	Economic conversion governmental forests
7	F-3-b	Economic conversion non-governmental forests	Economic conversion non-governmental forests
8	F-2-3-a	Multifunctional conversion governmental forests + economic conversion non-governmental forests	Multifunctional conversion governmental forests + economic conversion non-governmental forests
9	F-2-3-b	Multifunctional conversion non-governmental forests + economic conversion governmental forests	Multifunctional conversion non-governmental forests + economic conversion governmental forests
ii) *Afforestation according to state regional planning (increase of the forest area by 2%) or alternatively short rotation coppice on afforestation areas*			
10	F-1-10	Business as usual + default afforestation	F-1 + increase of forest area by 2% with actual stand types
11	F-1-20	Business as usual + multifunctional afforestation	F-1 + afforestation according to F-2 types
12	F-1-30	Business as usual + economic afforestation	F-1 + afforestation according to F-3 types
13	F-1-40	Business as usual + short rotation coppice	F-1 + short rotation coppice on afforestation areas
14	F-2-10	F-2 + default afforestation	F-2 + increase of the forest area by 2% with the actual stand types
15	F-2-20	F-2 + multifunctional afforestation	F-2 + afforestation according to F-2 types
16	F-2-30	F-2 + economic afforestation	F-2 + afforestation according to F-3 types
17	F-2-40	F-2 + short rotation coppice	F-2 + short rotation coppice on afforestation areas
18	F-2-a-10	F-2-a + default afforestation	F-2-a + increase of the forest area by 2% with the actual stand types
19	F-2-a-20	F-2-a + multifunctional afforestation	F-2-a + afforestation according to F-2 types
20	F-2-a-30	F-2-a + economic afforestation	F-2-a + afforestation according to F-3 types
21	F-2-a-40	F-2-a + short rotation coppice	F-2-a + short rotation coppice on afforestation areas
22	F-2-b-10	F-2-b + default afforestation	F-2-b + increase of the forest area by 2% with the actual stand types
23	F-2-b-20	F-2-b + multifunctional afforestation	F-2-b + afforestation according to F-2 types
24	F-2-b-30	F-2-b + economic afforestation	F-2-b + afforestation according to F-3 types
25	F-2-b-40	F-2-b + short rotation coppice	F-2-b + short rotation coppice on afforestation areas
26	F-3-10	F-3 + default afforestation	F-3 + increase of the forest area by 2% with the actual stand types
27	F-3-20	F-3 + multifunctional afforestation	F-3 + afforestation according to F-2 types
28	F-3-30	F-3 + economic afforestation	F-3 + afforestation according to F-3 types
29	F-3-40	F-3 + short rotation coppice	F-3 + short rotation coppice on afforestation areas
30	F-3-a-10	F-3-a + default afforestation	F-3-a + increase of the forest area by 2% with the actual stand types
31	F-3-a-20	F-3-a + multifunctional afforestation	F-3-a + afforestation according to F-2 types
32	F-3-a-30	F-3-a + economic afforestation	F-3-a + afforestation according to F-3 types
33	F-3-a-40	F-3-a + short rotation coppice	F-3-a + short rotation coppice on afforestation areas
34	F-3-b-10	F-3-b + default afforestation	F-3-b + increase of the forest area by 2% with the actual stand types
35	F-3-b-20	F-3-b + multifunctional afforestation	F-3-b + afforestation according to F-2 types
36	F-3-b-30	F-3-b + economic afforestation	F-3-b + afforestation according to F-3 types
37	F-3-b-40	F-3-b + short rotation coppice	F-3-b + short rotation coppice on afforestation areas
38	F-2-3-a-10	F-2-3-a + default afforestation	F-2-3-a + increase of the forest area by 2% with the actual stand types
39	F-2-3-a-20	F-2-3-a + multifunctional afforestation	F-2-3-a + afforestation according to F-2 types
40	F-2-3-a-30	F-2-3-a + economic afforestation	F-2-3-a + afforestation according to F-3 types
41	F-2-3-a-40	F-2-3-a + short rotation coppice	F-2-3-a + short rotation coppice on afforestation areas
42	F-2-3-b-10	F-2-3-b + default afforestation	F-2-3-b + increase of the forest area by 2% with the actual stand types
43	F-2-3-b-20	F-2-3-b + multifunctional afforestation	F-2-3-b + afforestation according to F-2 types
44	F-2-3-b-30	F-2-3-b + economic afforestation	F-2-3-b + afforestation according to F-3 types
45	F-2-3-b-40	F-2-3-b + short rotation coppice	F-2-3-b + short rotation coppice on afforestation areas
iii) *Afforestation of 12% of the total area – 2% according to state regional planning plus 10% according to nature conservation law (10% of landscape as biotope corridors); alternatively short rotation coppice on afforestation areas*			
46	F-1-11	Business as usual + default afforestation	F-1 + increase of forest area by 12% with actual stand types
47	F-1-21	Business as usual + multifunctional afforestation	F-1 + afforestation according to F-2 types
48	F-1-31	Business as usual + economic afforestation	F-1 + afforestation according to F-3 types
49	F-1-41	Business as usual + short rotation coppice	F-1 + short rotation coppice on afforestation areas
50	F-2-11	F-2 + default afforestation	F-2 + increase of the forest area by 12% with the actual stand types
51	F-2-21	F-2 + multifunctional afforestation	F-2 + afforestation according to F-2 types
52	F-2-31	F-2 + economic afforestation	F-2 + afforestation according to F-3 types
53	F-2-41	F-2 + short rotation coppice	F-2 + short rotation coppice on afforestation areas
54	F-2-a-11	F-2-a + default afforestation	F-2-a + increase of the forest area by 12% with the actual stand types
55	F-2-a-21	F-2-a + multifunctional afforestation	F-2-a + afforestation according to F-2 types
56	F-2-a-31	F-2-a + economic afforestation	F-2-a + afforestation according to F-3 types
57	F-2-a-41	F-2-a + short rotation coppice	F-2-a + short rotation coppice on afforestation areas
58	F-2-b-11	F-2-b + default afforestation	F-2-b + increase of the forest area by 12% with the actual stand types
59	F-2-b-21	F-2-b + multifunctional afforestation	F-2-b + afforestation according to F-2 types
60	F-2-b-31	F-2-b + economic afforestation	F-2-b + afforestation according to F-3 types
61	F-2-b-41	F-2-b + short rotation coppice	F-2-b + short rotation coppice on afforestation areas
62	F-3-11	F-3 + default afforestation	F-3 + increase of the forest area by 12% with the actual stand types
63	F-3-21	F-3 + multifunctional afforestation	F-3 + afforestation according to F-2 types

Table 4 (*continued*)

N°	Acronym	Name	Description
64	F-3-31	F-3 + economic afforestation	F-3 + afforestation according to F-3 types
65	F-3-41	F-3 + short rotation coppice	F-3 + short rotation coppice on afforestation areas
66	F-3-a-11	F-3-a + default afforestation	F-3-a + increase of the forest area by 12% with the actual stand types
67	F-3-a-21	F-3-a + multifunctional afforestation	F-3-a + afforestation according to F-2 types
68	F-3-a-31	F-3-a + economic afforestation	F-3-a + afforestation according to F-3 types
69	F-3-a-41	F-3-a + short rotation coppice	F-3-a + short rotation coppice on afforestation areas
70	F-3-b-11	F-3-b + default afforestation	F-3-b + increase of the forest area by 12% with the actual stand types
71	F-3-b-21	F-3-b + multifunctional afforestation	F-3-b + afforestation according to F-2 types
72	F-3-b-31	F-3-b + economic afforestation	F-3-b + afforestation according to F-3 types
73	F-3-b-41	F-3-b + short rotation coppice	F-3-b + short rotation coppice on afforestation areas
74	F-2-3-a-11	F-2-3-a + default afforestation	F-2-3-a + increase of the forest area by 12% with the actual stand types
75	F-2-3-a-21	F-2-3-a + multifunctional afforestation	F-2-3-a + afforestation according to F-2 types
76	F-2-3-a-31	F-2-3-a + economic afforestation	F-2-3-a + afforestation according to F-3 types
77	F-2-3-a-41	F-2-3-a + short rotation coppice	F-2-3-a + short rotation coppice on afforestation areas
78	F-2-3-b-11	F-2-3-b + default afforestation	F-2-3-b + increase of the forest area by 12% with the actual stand types
79	F-2-3-b-21	F-2-3-b + multifunctional afforestation	F-2-3-b + afforestation according to F-2 types
80	F-2-3-b-31	F-2-3-b + economic afforestation	F-2-3-b + afforestation according to F-3 types
81	F-2-3-b-41	F-2-3-b + short rotation coppice	F-2-3-b + short rotation coppice on afforestation areas
iv) Extreme scenarios			
82	F-4	"ecomax"	Multifunctional conversion in all forest ownership types + multifunctional afforestation at all extensively used agricultural sites
83	F-5	"lignomax"	Economic conversion in all forest ownership types (28% forest land) + short rotation coppice at all extensively used agricultural sites

intensively structured hilly area in the north-east of the model region, which is already highly impacted by increased drought risk. As a consequence, these areas suffer from higher uncertainties in agricultural productivity and they are prioritized for forest conversion. Section 8/4 is representative of the mountainous areas in the model region with a high share of forest land. Here, climate change is expected to prolong the growing season and even to provide a benefit for agricultural productivity. On the other hand, considerable uncertainties in forest productivity and health are expected due to bark beetle gradation (LfULG, 2009; SMUL, 2008).

In our scenarios, we started with forest conversion and added iteratively afforestation or short rotation coppice areas comparable to the spatially inexplicit scenarios. In contradiction to the latter, the decision where and how to convert the forests and where and how to establish new forests or short rotation coppice areas was based on existing planning layers, such as maps regarding the suitability of the forest ecosystem types based on silvicultural planning (Eisenhauer and Sonnemann, 2009; SMUL, 2005). Information was also taken from the current regional plan (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge, 2009), which indicates eligible areas for afforestation or short rotation coppice (priority areas for afforestation, priority and preference areas for nature and environment). Finally, possibly eligible agricultural land use types, where afforestation could be done without provoking economic losses (pastures, complex cultivation pattern, etc.) were integrated.

The priority areas for afforestation correspond to the spatially inexplicit scenario series F1-10–F1-40, the priority and preference areas for nature and environment correspond to the spatially inexplicit scenario series F1-11–F1-41. For testing the scenario "ecomax", afforestation was simulated on extensively used agricultural land cover classes, and all forests were assumed to be converted corresponding to scenario F2 – multifunctional conversion; in the case of "lignomax", short rotation coppice was established on priority areas for forests, priority and preference areas for nature and environment and extensively used agricultural land cover types, and additionally a conversion corresponding to scenario F3 (economic conversion) was done for the already existing forests.

3. Results

3.1. Spatially inexplicit scenarios

When comparing the impact of the three basic scenarios "business as usual (F1)", "multifunctional conversion (F2)" and "economic conversion (F3)", a visible and considerable modification or improvement of the provision of one of our selected ecosystem services was only observed, if the impact assessment refers exclusively to the forest area and not to the total area of the region (Fig. 5a). Referring to the forest area, multifunctional conversion clearly provides the highest positive impact on the provision of almost all services with the exception of regional economy due to the increase in the share of lower productive deciduous tree species. When upscaling the impact of these classic forest management alternatives to landscape scale, where the share of forest amounts only to 26% (Table 1), the differences between multifunctional and economic conversion become much less visible and a clear recommendation of a "best alternative" is not so easily possible (Fig. 5b). Also, the question, if it is sufficient to convert the governmental forests or if incentives that boost conversion of non-governmental forests are beneficial for increasing the provision of the ecosystem services cannot be clearly answered (Fig. 5c).

Analyzing the afforestation scenarios leads to the result that the increase in the share of forest areas by 2% according to state regional planning does not influence the provision of any of our ecosystem services and even the impact of an increase in the forest area by 12% for the ecosystem services provision ranges in the same order of magnitude as multifunctional and economic conversion of all forests (Fig. 5d and e). Also, the impact of different forest stand types for afforestation remains more or less negligible (Fig. 5e). The same applies for the scenarios where the afforestation area is converted into short rotation plantation (Fig. 5f). Only the more extreme scenarios "ecomax" and "lignomax" (Fig. 5g) would provoke a significant increase or decrease in the services. In the case of "ecomax", a significant increase in the services aesthetic value, ecological integrity, human well being and climate change adaptation would result, but at the same time, the services biomass provision and regional

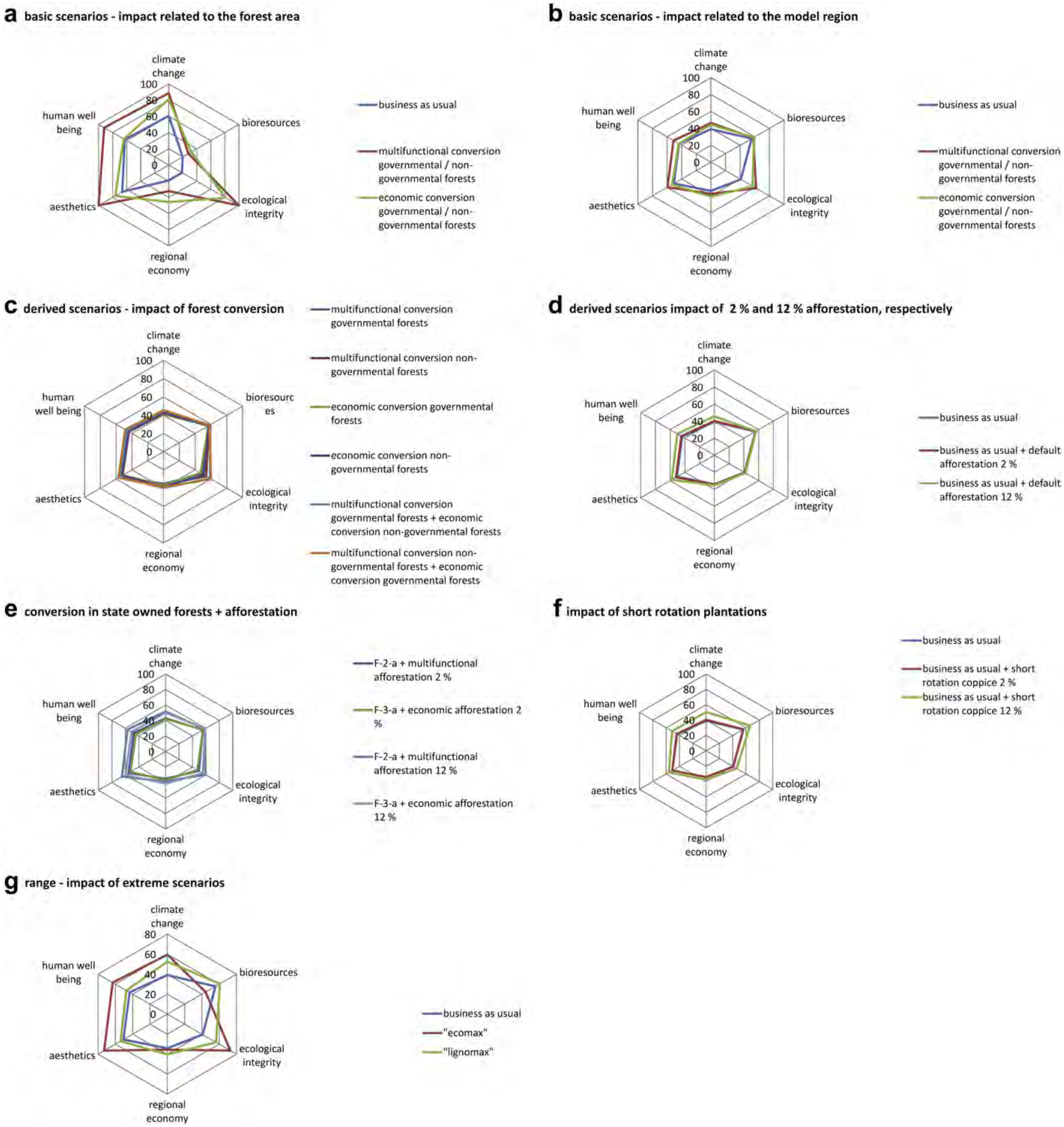

Fig. 5. Results of the spatially inexplicit testing. (a) + (b) show the results of the three basic scenarios F1–F3, (a) related to the forest area and (b) related to the total area of the case study region. (c) Shows the impact of a differentiation according to ownership types, (d) and (e) display the impact of different afforestation scenarios, in the case of (e) in combination with a differentiation according to ownership types for conversion. (f) Shows the impact short rotation plantations can have and (g) provides an overview on the impact range of the extreme scenarios ecomax and lignomax compared to the starting situation.

economy would be considerably decreased. The "lignomax" scenario would provoke a much lower increase in the services aesthetic value, ecological integrity, human well being and climate change adaptation, but at the same time, the provision of bioresources and the benefit for regional economy would be definitively higher.

3.2. Indicator values

In Figs. 6 and 7, we provide an example for the values that some selected indicators take for the scenarios F1-10, F1-11 and F4 compared to the starting situation. Fig. 6 shows the indicators used for measuring the impact of the scenarios on the mitigation of

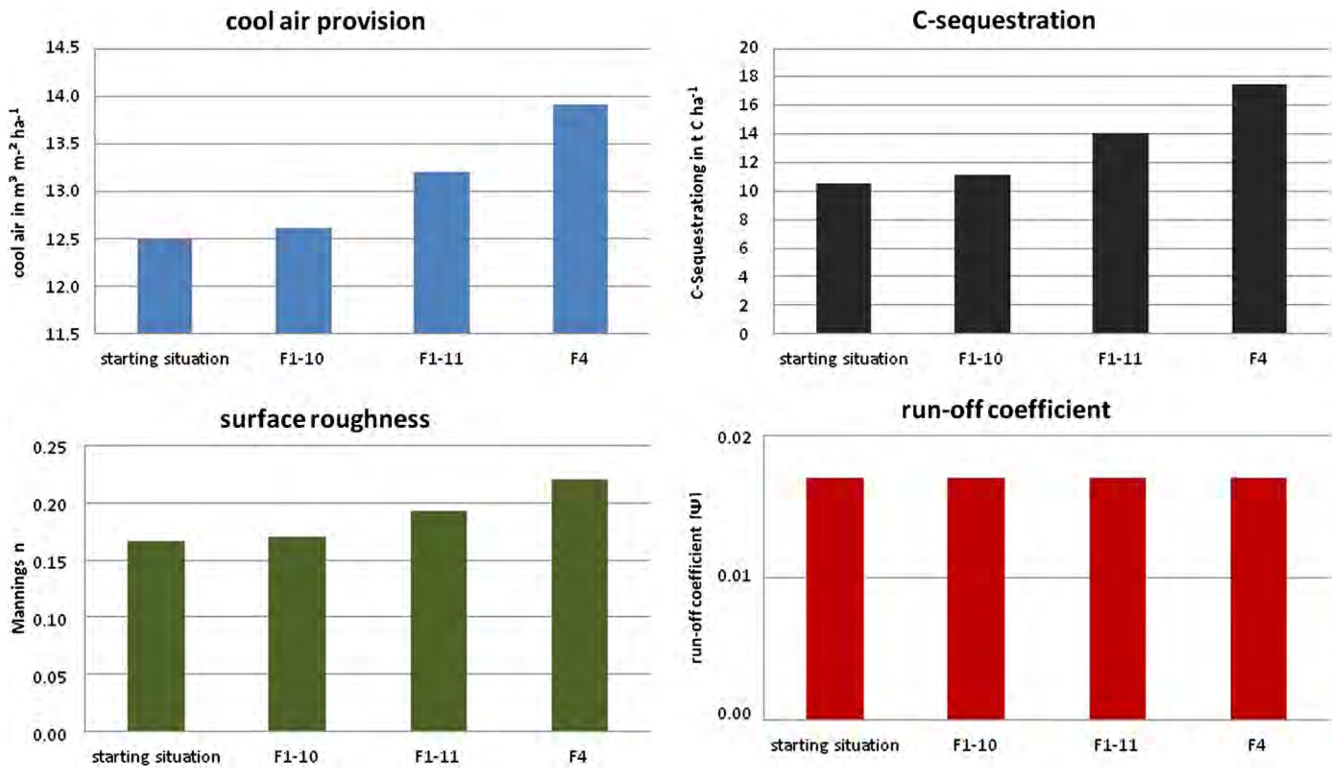

Fig. 6. Effect of the afforestation scenarios F1-10 and F1-11 and of the ecomax scenario compared to the starting situation on indicators applied for assessing the impact of land use strategies on water balance regulation as exemplary criterion used for expressing the mitigation of climate change effects.

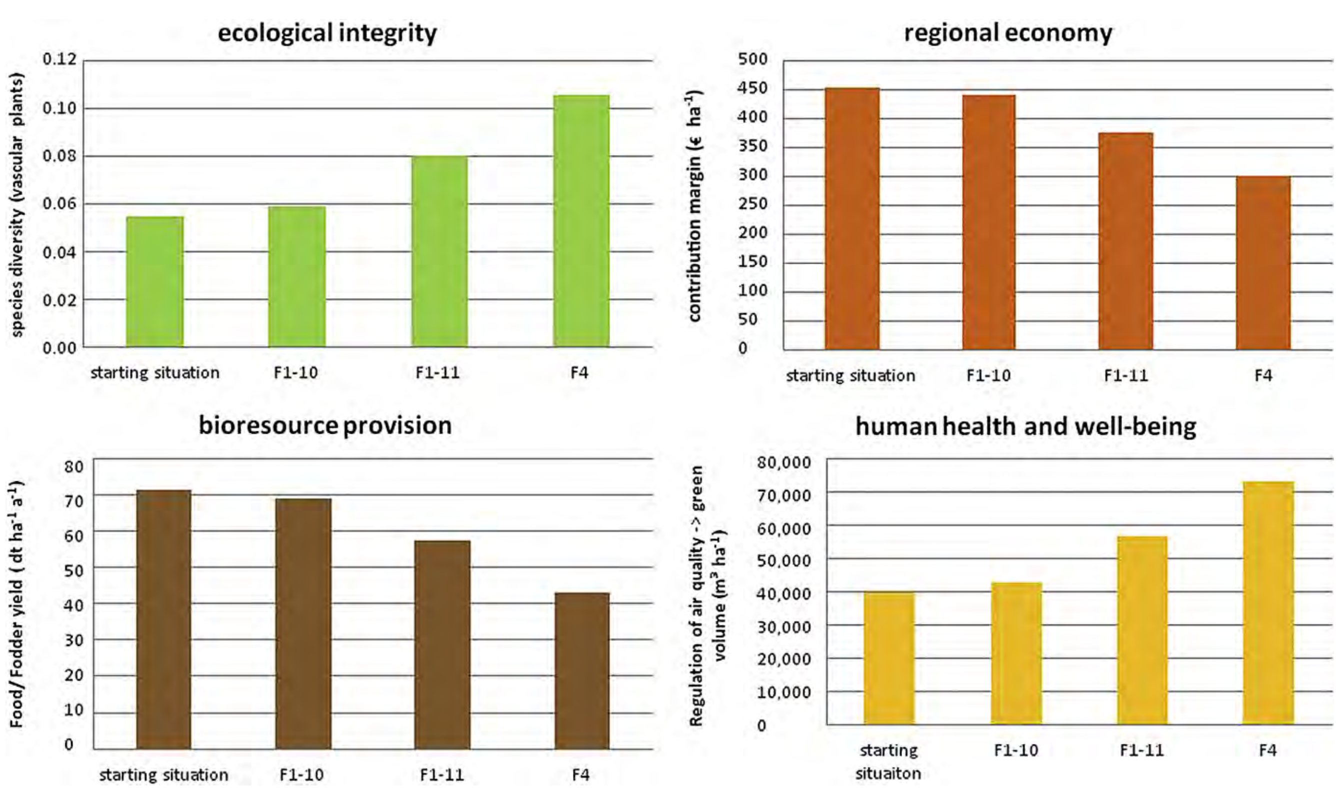

Fig. 7. Effect of the afforestation scenarios F1-10 and F1-11 and of the ecomax scenario compared to the starting situation on indicators applied for assessing the impact of land use strategies on the services ecological integrity, regional economy, bioresource provision and human health and well-being.

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climate change effects for the criterion “water balance regulation” (see also Table 2). While the indicators cool air provision, C-sequestration and surface roughness show clearly a benefit of the scenario ecomax (F4), the indicator run-off coefficient was not impacted by afforestation as it depends mainly on the share of sealed areas. Fig. 7 gives an overview of some of the indicators for ecological integrity, regional economy, bioresource provision and human health and well-being. This comparison shows that the increasing share of forest land from the starting situation towards F4 leads to an improvement in the species diversity (ecological integrity) and the ability to regulate the air quality (human health and well-being). On the other hand, the production of food and fodder (bioresource provision) and consequently, the income from land-based production (regional economy) are decreasing.

3.3. *Spatially explicit scenarios*

Figs. 8–10 and Table 5 provide an overview of the results of the spatially explicit testing in our three sections. In Figs. 8–10, results of the provision of our ecosystem services portfolio are shown: the left column provides information on the impact of the scenarios compared to the starting situation in each of the sections. The scenarios comprise the establishment of new forests (a) in the priority areas for afforestation (corresponds to F1-10) and (b) in priority areas for afforestation as well as priority and preference areas for nature and environment (corresponds to F1-11) and also the two scenarios ecomax (corresponds to F4) and lignomax (corresponds to F5). In the case of the sections 4/7 and 8/4, where forests do already exist, the additional impact of forest conversion was included in the scenarios F4 and F5. For section 4/3 where no forests exist so far, afforestation was simulated with the best adapted forest ecosystem types and an additional conversion was therefore not necessary. The right column in Figs. 8–10 shows how the two services aesthetic value and ecological integrity would be altered if our landscape metrics are additionally included.

Table 5 aggregates the landscape-metric results for those scenarios (F1-10, F1-11, F4), which are related to an increasing share of forests compared to the starting situation. As all forest types and short rotation coppice were grouped into the class “metahemerobe” (see Section 3.3), no differentiation was made in this table for land use changes such as forest conversion and between an increasing share of forests or short rotation coppice areas (F5).

Taking the two indices (a) proportion of functionally connected habitats and (b) core area of natural land use types (Table 5), section 4/3 shows a clear deficit in the landscape structure compared to the two other sections. This is accounted for in our assessment by an additional reduction in the results achieved for aesthetic value and

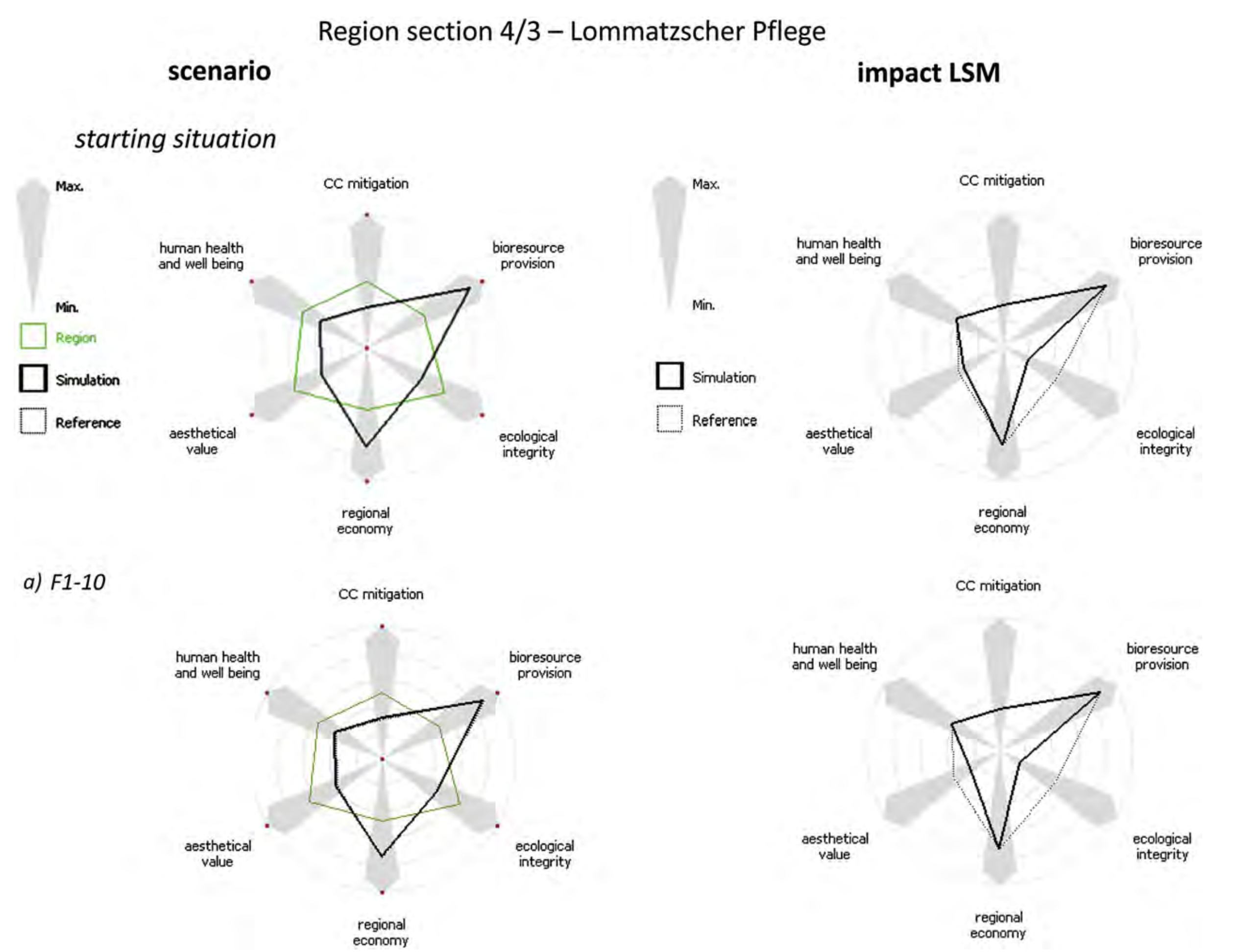

Fig. 8. Results from spatially explicit testing of the afforestation scenarios F1-10 and F1-11 as well as the scenarios ecomax (F4) and lignomax (F5) for the section 4/3 (Lommatzscher Pflege). The starting situation is displayed in the scenarios by the dashed black line, the result for the section are displayed by the solid black line. The green line shows the impact of the changes in the section on the total model region. The left column shows the impact of the scenarios compared to the starting situation on the provision of the ecosystem services. The right column shows the impact of the scenarios on the services aesthetics and ecological integrity of landscape metrics are additionally taken into account. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

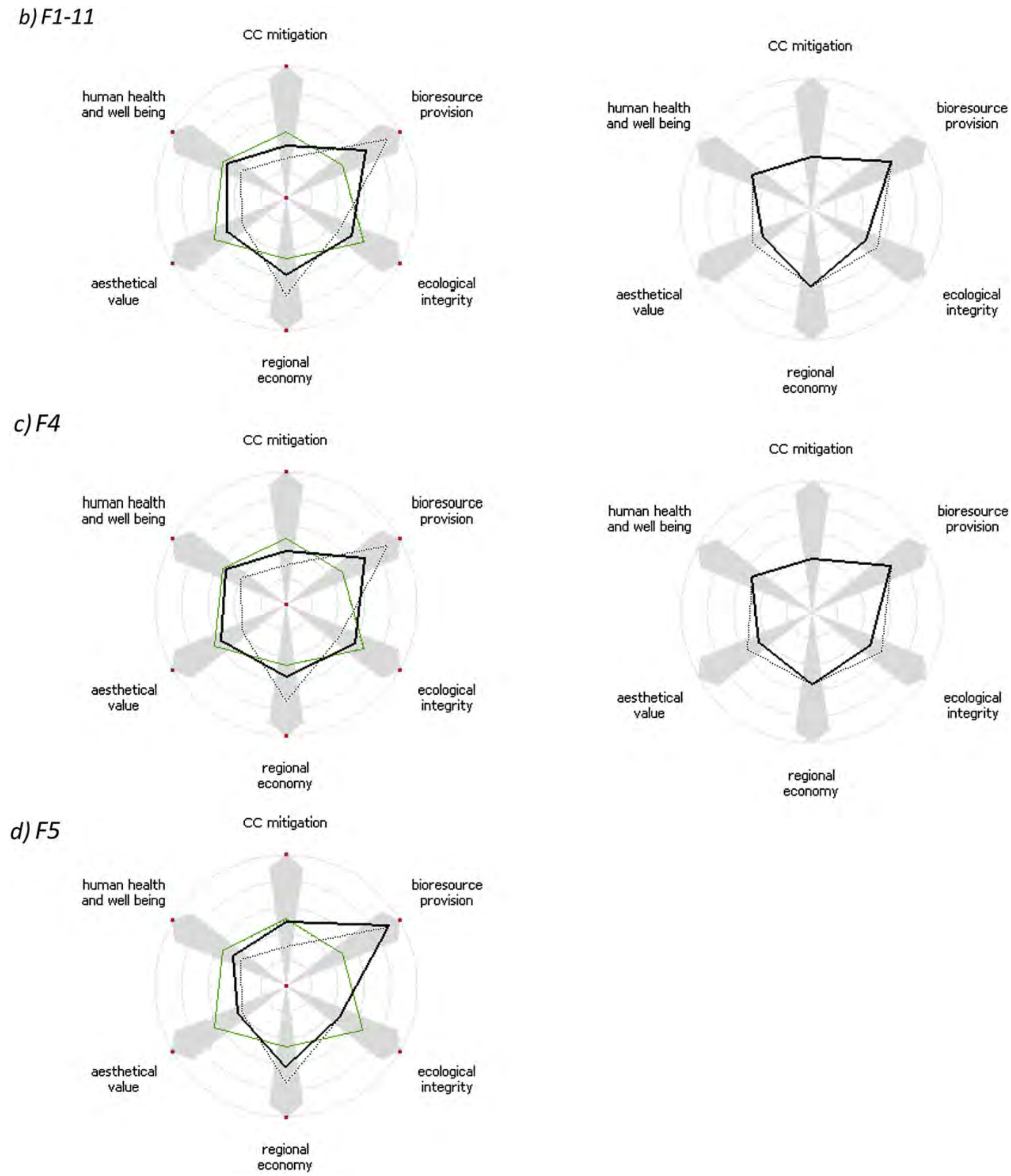

Fig. 8. (*continued*).

ecological integrity (Fig. 8, right column). In section 4/3 an "optimal" balance between our services can be achieved in the scenario "ecomax (F4)", where in our case an afforestation of 29.7% of this 100 km^2 section would be requested (Fig. 11). In spatially inexplicit testing, a comparable result in altering the ecosystem services provision could only be achieved with an increase in the forest area by 34% (ecomax). Our result from spatially explicit testing would reflect well the aims of the state regional plan to achieve an average share of 30% for forest land cover. Comparable to the results from spatially inexplicit testing, a loss in the provision of bioresources and – in consequence – a negative impact on the service regional economy are the trade-offs in this scenario. In contrast, the scenario "lignomax", in which 29.7% of the land in our case was covered with short rotation coppice instead of forests, would almost avoid losses in the provision of bioresources in section 4/3 and would thus have a much less negative impact on the service regional economy (Fig. 12; Table 5).

Looking at the average value of non-fragmented open areas and the shape index (Table 5), no major differences can be identified in our three sections 4/3, 4/7 and 8/4 with or without afforestation. In contrast, the Shannon Wiener diversity index and the patch density (only in section 4/3) varied more and were clearly impacted by our

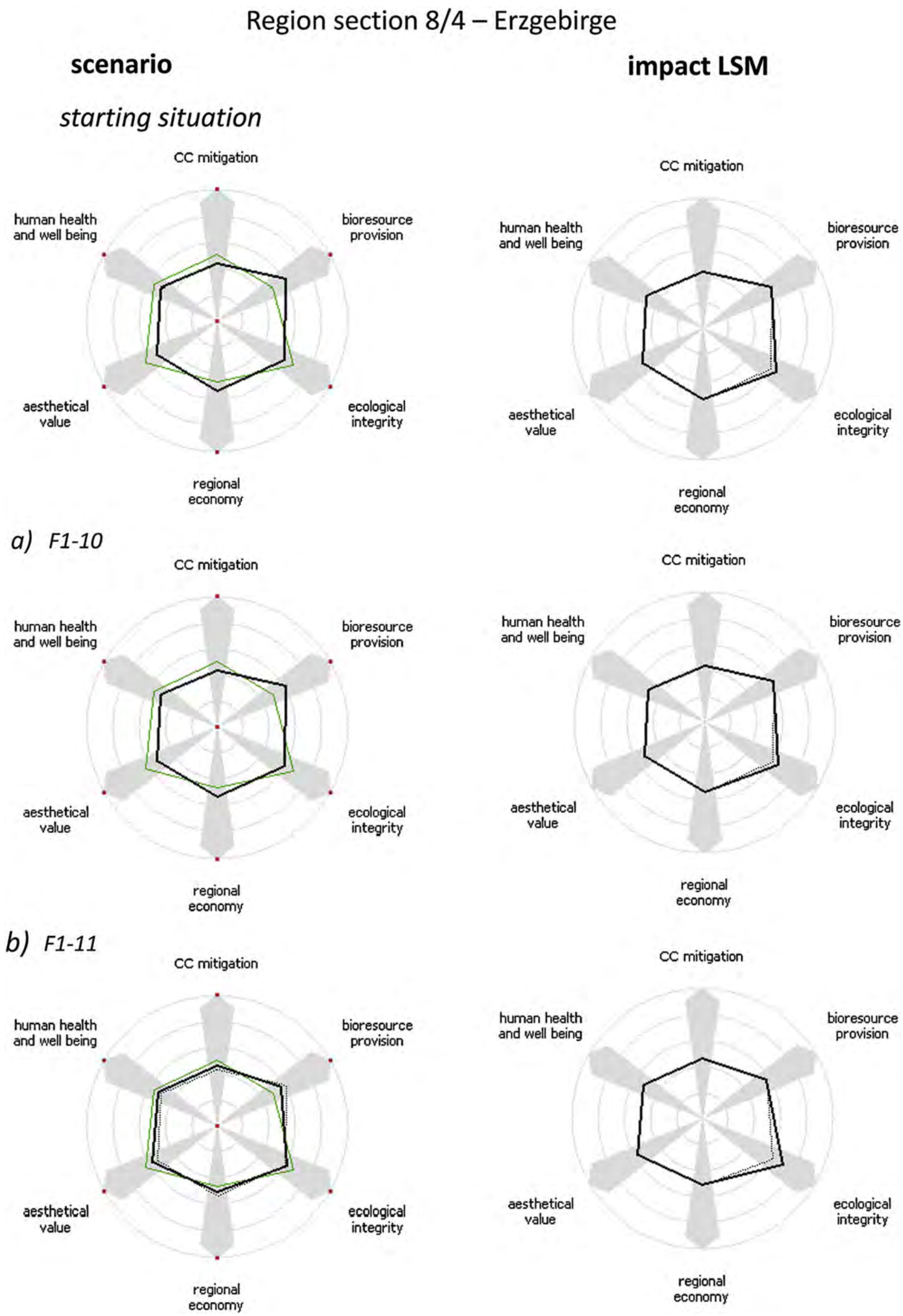

Fig. 9. Results from spatially explicit testing of the afforestation scenarios F1-10 and F1-11 as well as the scenarios ecomax (F4) and lignomax (F5) for the section 8/4 (Erzgebirge). The structure of the figure follows Fig. 8.

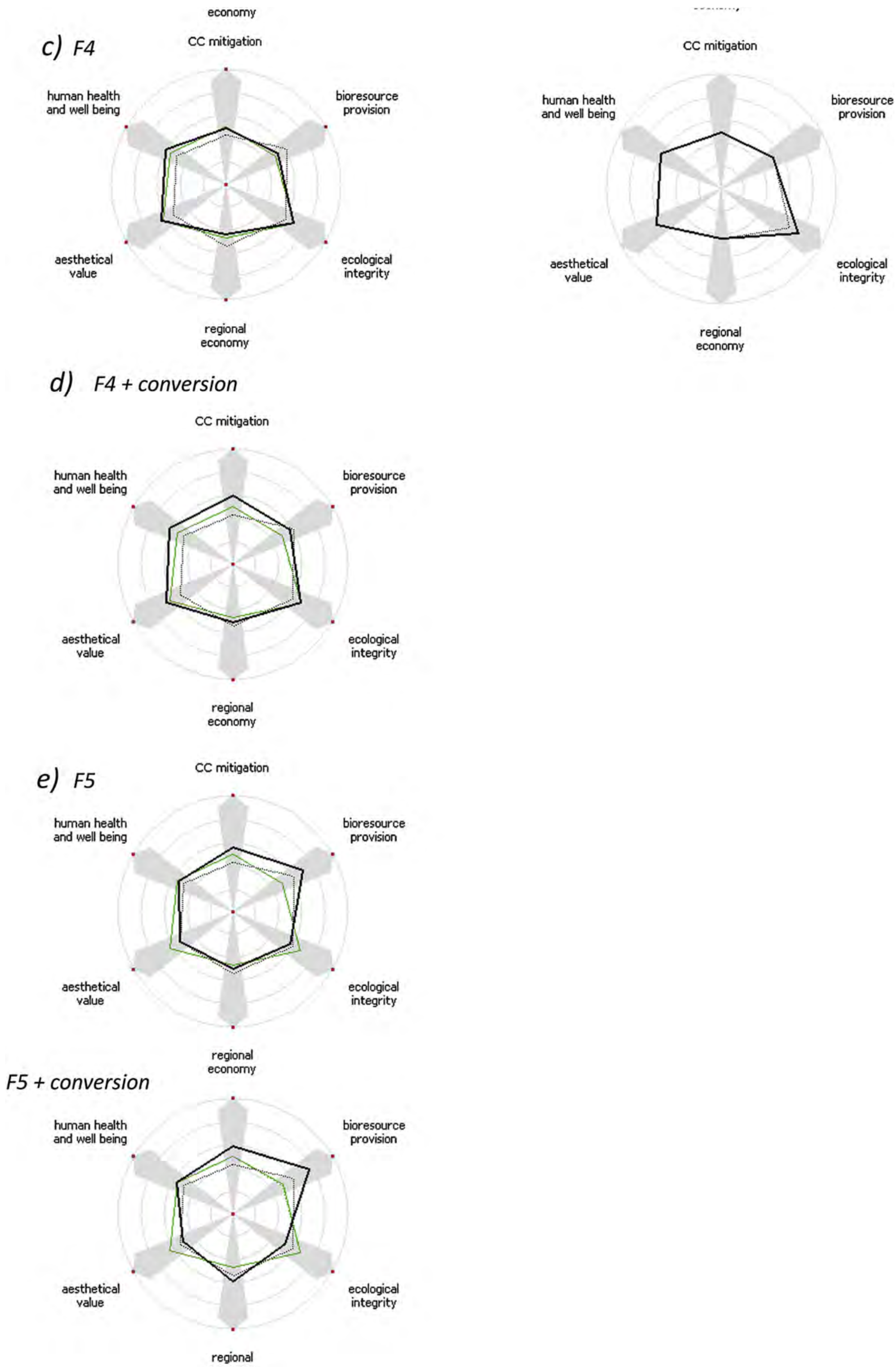

Fig. 9. (*continued*).

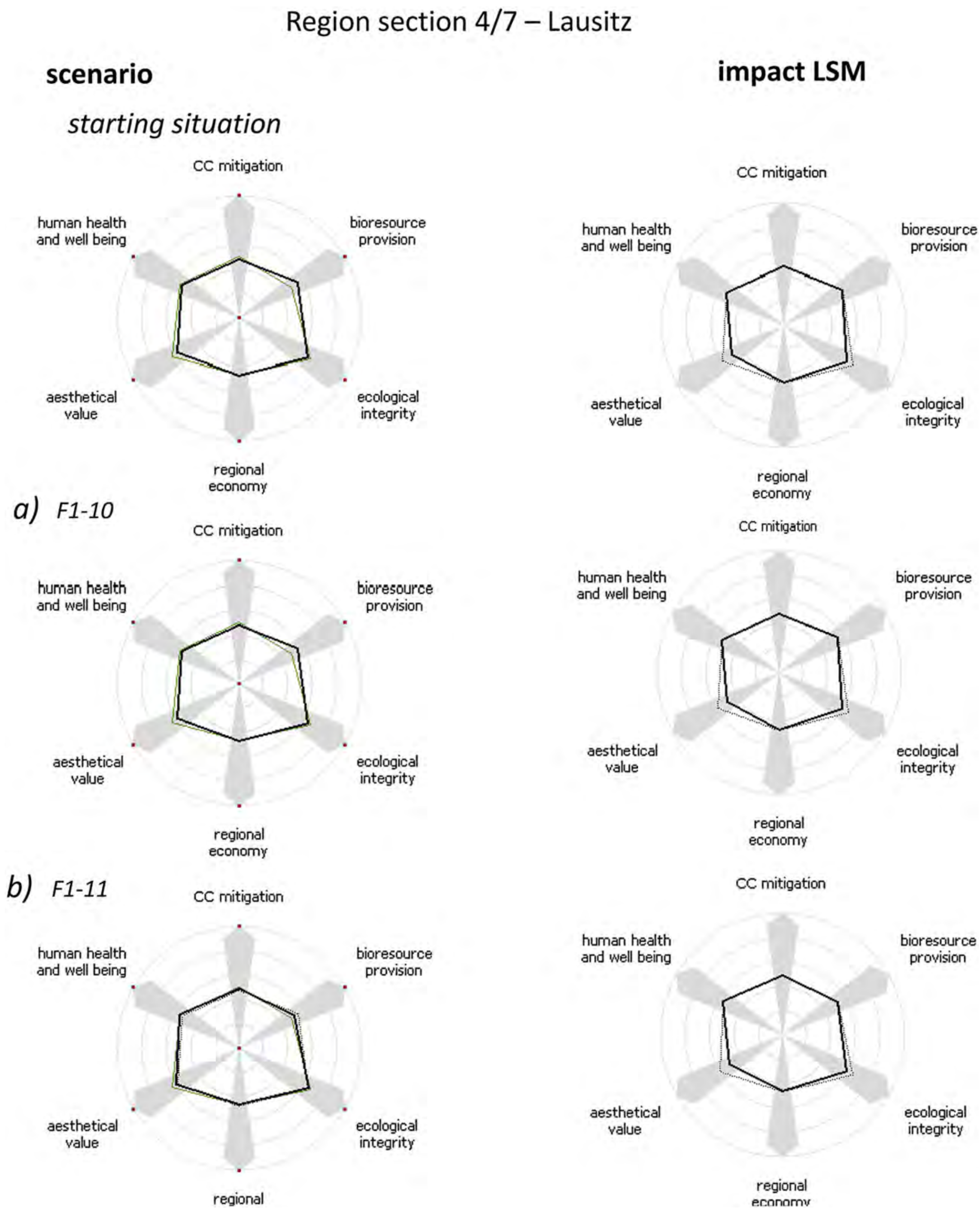

Fig. 10. Results from spatially explicit testing of the afforestation scenarios F1-10 and F1-11 as well as the scenarios ecomax (F4) and lignomax (F5) for the section 4/7 (Oberlausitz). The structure of the figure follows Fig. 8.

scenarios. The highest impact can be observed for the section 4/3. For instance, our test reveals that the recommended afforestation of 29.7% (F4) for section 4/3 would even lower the Shannon Wiener diversity index compared to a scenario in which only priority areas for afforestation and for nature and environment are involved (F1-11). The same applies for the sections 4/7 and 8/4.

In the case of sections 4/7 and 8/4, the starting situation is already characterized by a more diverse land use mosaic. In consequence, the impact of an increasing share of forest land (Table 5) on the provision of our ecosystem services and also the range for the additional correction of the services' aesthetics and ecological integrity by landscape metrics (Figs. 9 and 10, right columns) is much lower. In both cases, a combination of maximum afforestation and multifunctional conversion (F4) or establishment of a short rotation coppice area and economic conversion (F5) would result in an improvement in the balance of the ecosystem services provision (Figs. 9 and 10, left columns). Comparable to section 4/3, the ecomax scenario seems to be recommendable for both sections as it results in the most balanced provision of all services.

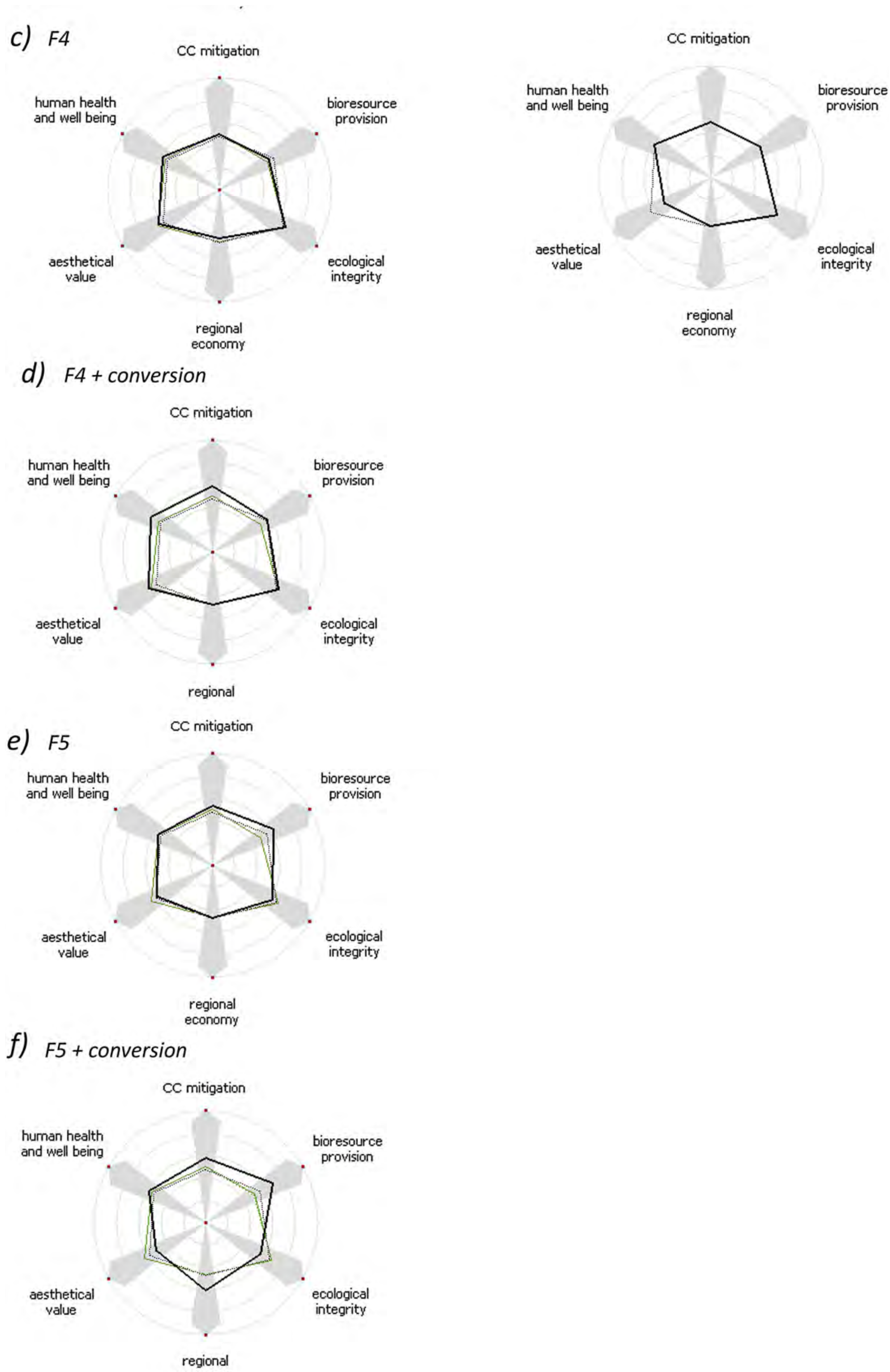

Fig. 10. (*continued*).

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Table 5
Values of the applied landscape metrics for the afforestation scenarios F1-10 and F1-11 and the ecomax scenario (F4) compared to the starting situation for the three sections 4/3, 4/7 and 4/8.

Section	Scenario	Proportion of functionally connected habitats %	Core area of natural land use types %	Av. unfragmented open areas km^2	Median shape index	Shannons diversity index	Patch density/km^2
4/3 Lommatzscher Pflege	Starting situation	0.00	0.00	4.38	1.47	0.41	0.31
	F1-10	0.00	0.00	4.38	1.30	0.50	0.56
	F1-11	9.66	3.61	4.38	1.26	0.81	0.95
	F4	18.43	9.27	4.38	1.20	0.76	1.32
4/8 Lausitz	Starting situation	27.53	16.68	3.32	1.30	1.29	0.44
	F1-10	27.53	16.68	3.32	1.30	1.29	0.43
	F1-11	27.53	16.68	3.32	1.30	1.30	0.44
	F4	37.13	23.63	3.32	1.33	1.15	0.48
8/4 Erzgebirge	Starting situation	18.81	10.07	5.15	1.30	1.36	0.61
	F1-10	18.81	10.07	5.15	1.30	1.36	0.61
	F1-11	18.81	10.07	5.15	1.28	1.39	0.67
	F4	32.14	16.28	5.15	1.30	1.23	0.72

Focusing on our landscape metrics (Table 5), changes are highest in section 4/3, where the ecomax scenario (F4) would lead to an increase in our landscape metrics to the same order of magnitude as in the starting situation of section 8/4. While in section 4/3 an increase in the forest (or short rotation coppice) area by 29.7% is needed for this result, the requested increase in the forest (or short rotation coppice) area in section 4/7 would amount to 14.4% and in section 8/4 to 23.6% instead of a requested average increase in the forest area by 34% as calculated in the spatially inexplicit testing. Gains for improving the structural diversity on the landscape scale expressed by our set of landscape metrics are highest for the currently unstructured Loess areas (section 4/3) and lowest for the already well-structured mountainous regions (section 8/4).

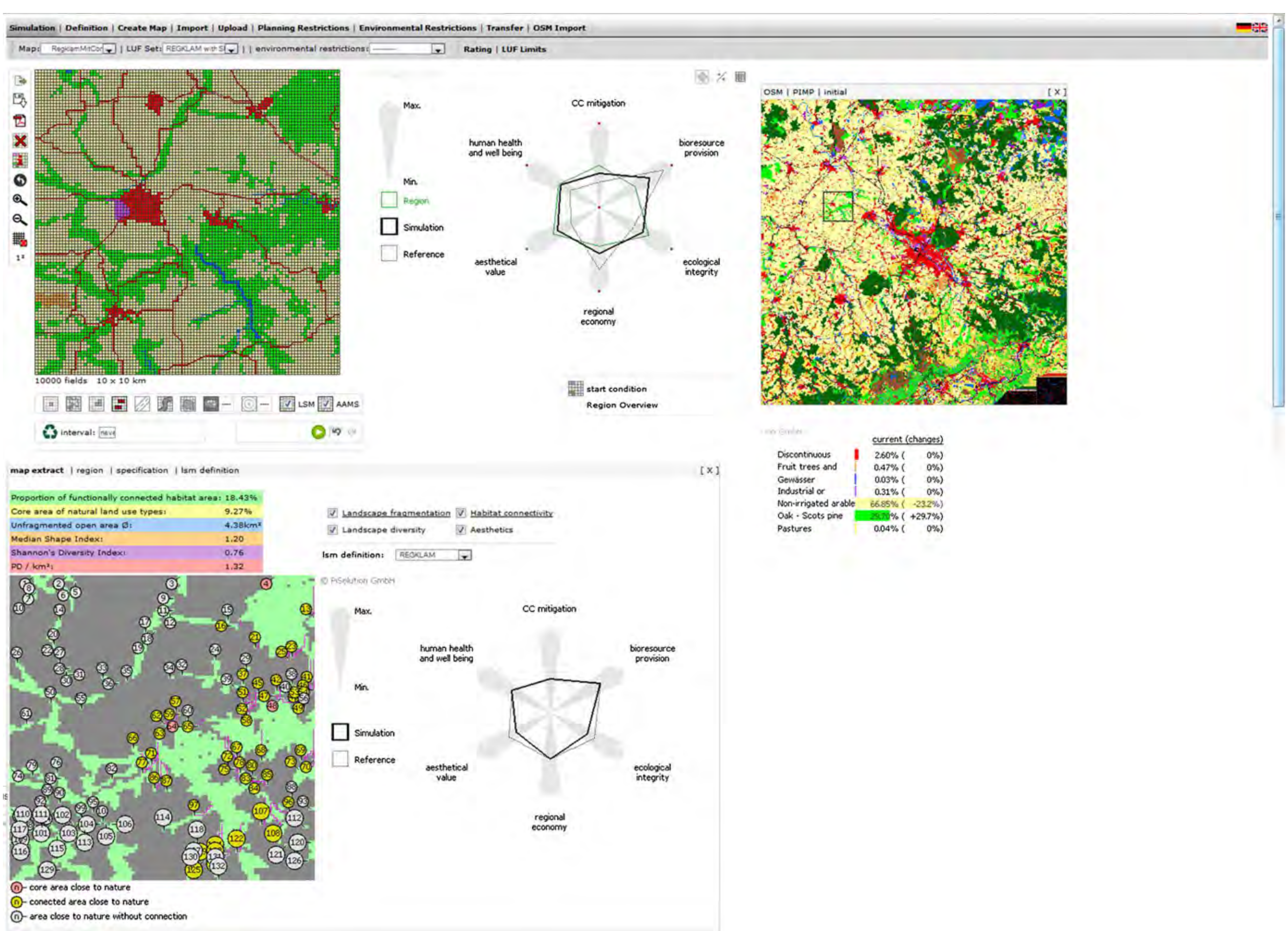

Fig. 11. Results of the ecomax scenario for section 4/3. An afforestation of 29.7% would lead to a well balanced provision of all ecosystem services despite losses in bioresources provision and ecological integrity (star diagram at the head). The starting situation for this section is displayed in the star diagram by the dashed black line, the result are displayed by the solid black line. The green line shows the impact of the changes in the section on the total model region. The visualization below the map of the region and the star diagram to its right side show the impact of the ecomax scenario on the landscape metrics and on the spatial localization of connected and not connected close to nature areas (green color) compared to areas, which are not close to nature (gray color). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

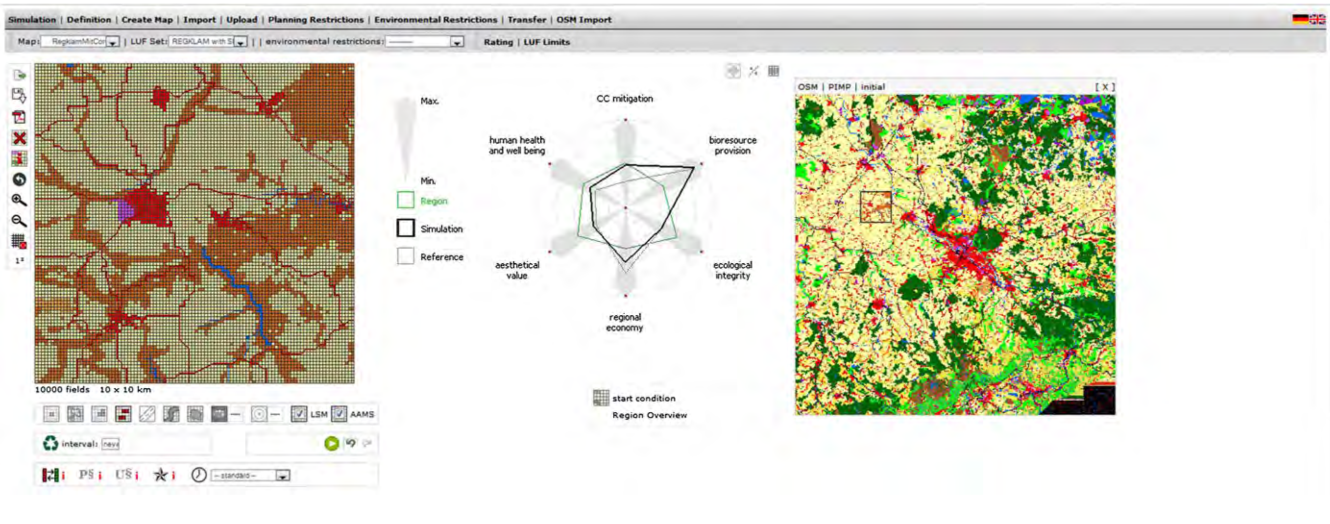

Fig. 12. Results of the lignomax scenario for section 4/3. The starting situation for this section is displayed in the star diagram right to the map by the dashed black line, the result are displayed by the solid black line. The green line shows the impact of the changes in the section on the total model region. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Taking the ecosystem services provision and the impact of the landscape metrics under our different scenarios into account, efforts for enhancing afforestation or the establishment of short rotation coppice should be focused primarily on the Loess areas in our model region, while conversion is absolutely sufficient compared to the afforestation impact in the hilly and mountainous parts of or model region (sections 4/7 and 8/4). This runs counter to the current trend in our model region, where the highest efforts are spent on afforestation in the mountainous regions, while a better structuring in the Loess areas is totally neglected.

4. Discussion

4.1. Assumptions and simplifications

To adapt our evaluation basis and to come to results at the landscape scale, some simplifications were necessary, among them the transformation of all indicator values on the scale from 0 to 100, the reclustering of our land use types to classes of naturalness for the landscape metrics calculation and the transformation and aggregation of the landscape metrics values into a qualitative corrective for ecological integrity and aesthetics. These assumptions and simplifications were the result of a mutual learning process with our regional actors, which comprise experts as well as practitioners from totally different land use sectors. In consequence, we had to develop a consensus system which supports communication between the actors and supports also the understanding to what extent land use changes might impact the provision of ecosystem services; this replaces in our case study provision more detailed information on the impact on single indicators which were often not understood by our actors. Also other systems such as Manuela (von Haaren et al., 2008), MODAM (Zander and Kächele, 1999; adapted e.g. by Sattler et al., 2012) or DEXiPM (Pelzer et al., 2012), which are used for assessing farming practices, work with such simplifications. They succeed in addressing the land user because they intend to make the consequences of decision alternatives more comprehensible. This improved comprehensibility, however, might reduce the transparency of the information behind our approach or comparable approaches (e.g. Janssen et al., 2010). Therefore, we attempt to thoroughly document and also provide (on demand for our actors) the results for single indicators (see 4.2) and how they are merged to arrive at the results.

A weakness in the approach as presented here might also be that we intend to assess on the one hand the impact of real management opportunities (here exemplified for forestry) on the provision of ecosystem services, but that we have to renounce this detailed information when coming to the landscape metrics correction. We should omit that it is considerably easier to obtain information from literature, modeling or our own measurements on the impact of a specific land use on the provision of a service. In contrast, research on the land use pattern and its relevance for the provision of ecosystem services is rare (Frank et al., 2011) and we could not find a sufficient validation basis for our landscape metrics' range of values if our management related classes in forestry are additionally integrated. The concept of naturalness (hemeroby), which is merely used in a German research context (Grabherr et al., 1998; Granke et al., 2004), offered therefore a practicable compromise to involve landscape metrics in the assessment of the regional potential to provide ecosystem services, but to account at the same time for our limited knowledge base on the impact of structural effects. However, the use of this concept might also constraint the transferability of our approach to regions, where naturalness cannot be assessed in comparable manner and thus, different concepts to aggregate forest and agricultural land use classes must be tested and probably integrated into the assessment routines in the future.

4.2. Land use classification

One of our major intentions was to improve the consideration of management (i.e. use) concepts in the assessment of the provision of ecosystem services. Demonstrated for forestry, we did not develop completely new classes, but tried to base them upon concepts that are already in use in forest planning practice (Eisenhauer and Sonnemann, 2009). This however entailed another problem: our forest ecosystem types as they are applied by administrative regulation in Saxony (SMUL, 2005), are an artificial construct that involves the development of actual stand types derived from forest inventory into the described ecosystem types. In consequence, assessment of the impact of the forest ecosystem types is not directly possible as they do not yet exist in reality and as there are, in consequence, no monitoring data and measured or modeled growth and yield data available. Their evaluation was therefore based on existing values – tree species wise – and was corrected then by expert knowledge. This evaluation compromise might provoke some artifacts in the evaluation: the "future" ecosystem types "are expected" by the experts to deliver an improvement in provision of ecosystem services. In consequence, a level of uncertainty, which is difficult to specify, remains in our evaluation. This might question the benefits of a more detailed land use classification. On the other hand, the Corine Land Cover Classification does by far not deliver information that enables an impact assessment of land use strategies on a meso scale. For instance, classes such as "coniferous", "deciduous" or "mixed" forest do not inform on the tree species and their mixture as such. In consequence, even simple aspects such as productivity cannot be assessed.

4.3. Spatially inexplicit/explicit testing

For testing the possible benefit provided by the GISCAME platform, we applied two different testing strategies, a spatially inexplicit and a spatially explicit one. Though we spent much effort in evolving the spatially inexplicit testing matrix to ensure that all imaginable driving factors that could lead to modifications in the ecosystem portfolio are considered, the results were not as satisfactory as basis for better focusing the spatially explicit testing as expected. In the end, only serious changes in the share of forests or short rotation coppice areas would have had a more visible positive or negative impact on the ecosystem services and it was not possible to come to realistic recommendations on "best practices". We could only conclude that an increase in the share of forests by 2% as foreseen in the state regional plan is by far not enough to have any impact and that an increase by 34% as in the ecomax scenario would go along with severe losses in biomass productivity and regional economy and is therefore not realistic.

In spatially explicit testing, the results were much more differentiated according to the different starting situations in our three sections. However, in this case information on the ownership types in forestry, which might have been of high relevance to account for the applicability of our scenarios, was not available as the cadastral maps are not accessible, not even for scientific purposes. In our three sections, the ecomax scenario tended out to be the most beneficial strategy and – parallel to the findings in the spatially inexplicit testing, the lignomax scenario provides an arguable alternative with regard to fewer trade-offs for biomass provision and regional economy. In all three cases, the requested increase in the share of forests or areas for short rotation coppice areas was much lower than in spatially inexplicit testing and we could prove that if we account additionally for different forest ecosystem types (sections 4/7 and 8/4 – F4 and F5 + conversion) the positive impact on the provision of ecosystem services could be considerably increased even far beyond the gain by an improved land use pattern. In summary, we found that the spatially explicit analysis of adaptation strategies in land use in combination with a more detailed land use classification gave us an improved basis for assessing different possible planning strategies and to enhance the communication between – in this case – forest management planners and regional planners. The benefit of integrating land use knowledge was much less visible in the case of spatially inexplicit assessment, which – however – is the more common approach to formulation of planning targets for state regional planning.

Noteworthy however – and going far beyond what could be shown in a paper – is not only the iterative test of the strategies shown here, but also of others for all sections of our model region and a final integration into recommendations for specific areas in our planning region differentiated according to their specific natural (soil-type/topography) situation and for the overall model region.

5. Conclusions

Our case study has shown that spatially explicit working systems such as GISCAME can contribute to a more comprehensive assessment of the impact of land use changes and the additional impact of changes in the land use pattern on the provision of ecosystem services. At the interface between forest and agricultural land use planning and regional planning, the spatially explicit testing helped to reveal additional benefits from alternative land use strategies, which were hidden if the same strategies were tested in a spatially inexplicit way. Together with our actors we learned that simplifications in the evaluation system and assumptions regarding the manner in which land use impacts the provision of ecosystem services are accepted and even necessary to ensure that actors with different disciplinary backgrounds and levels of expertise can communicate in the planning process. However, we also learned that the development of such approaches as the one presented here is always a bit like tightrope walking between the intention to aggregate information and to reduce complexity on the one side and the need to provide valid results and to face the complexity of ecological-economics systems in land use on the other. For instance, a sensitivity or uncertainty analysis of the GISCAME outcomes was not possible, as (a) comparable models that involve the impact of single land use classes and landscape metrics to estimate the provision of ecosystem services at meso scale are not available and (b) measured or modeled data even for single indicators address mostly only single land use classes but not all classes that occur at regional scale. Even in our case study, the information base for assessing the impact of land use types and especially of our additional forest ecosystem types was not so good that we could exclude additional uncertainties by adding more detailed land use classes. On the other hand, regional planners were pleased to be provided with a much more detailed planning basis, which helps them to more readily account for land use opportunities to which they had no knowledge based access before.

However, it should be mentioned that there are still some open questions for the further development of our assessment approach. The scenarios tested in the case study, were completely "designed" and elements such as random events (extreme events) or the haphazardness of land owner decisions to change a land use or not, are not yet included. They will be accounted for by introducing land use class specific transition probabilities and a fuzzy logics approach where to start and stop transition processes. The consideration of other aspects such as the resilience of land systems and the adaptive capacity of specific regional land use constellations to processes such as climate change are also part of our ongoing research.

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#11 Fürst, C., Helming, K., Lorz, C., Müller, F., Verburg, P. (acc.): **Integrated land-use and regional resource management – A cross-disciplinary dialogue on future perspectives for a sustainable development of regional resources**;. Journal of Environmental Management, Elsevier.

Integrated land use and regional resource management – A cross-disciplinary dialogue on future perspectives for a sustainable development of regional resources

Christine Fürst[1*], Katharina Helming[2], Carsten Lorz[3], Felix Müller[4], Peter H. Verburg[5]

Highlights

- The special issue presents operational methods and approaches that are tested and applied in integrated land use planning in diverse national or regional planning contexts.
- Different perspectives on the contribution of integrated land use planning approaches to overcome menacing resource scarcity are demonstrated.
- As an outcome, we present an integrated analytical framework.

Integrated land use and regional resource management – A cross-disciplinary dialogue on future perspectives for a sustainable development of regional resources

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Abstract

Our paper introduces objectives and ideas of the special issue “Integrated land use and regional resource management – A cross-disciplinary dialogue on future perspectives for a sustainable development of regional resources” and provides an overview on the contributions of the single papers in the special issue to this topic. Furthermore, we discuss and present major challenges and demands on integrated land use and regional resource management and we come up with an analytical framework how to correspond these demands.

Keywords: integrated land use; regional resource management; regional planning; analytical framework for integrated planning; sustainable regional development.

Integrated land use and regional resource management – introduction and objectives of this special issue

Land is one of our most important and most limited resources to provide essential goods and services to society. The degree of freedom to change the land use pattern or to intensify land use by innovative land use strategies that increase the provision of natural resources is governed by legal and administrative regulations, land ownership rights, socio-cultural conditions and natural restrictions arriving from climate or edaphic conditions (Irwin and Geoghegan, 2001; Krausmann et al., 2003).The provision of natural goods and services from the land cannot be studied by only looking at single ecosystems in isolation, without understanding their interplay in a specific regional context. Furthermore, complex interactions that characterize socio-ecological systems to which integrated land use planning refers, lead to great uncertainty in predicting their evolvement, taking ecosystem and human responses to climate change as an example (Mohamed et al., 2000).

Therefore, a precondition for sustainable regional resource management as main task of regional planning is an integrative viewpoint on land use. Spatial planning at country level (=state regional planning) addresses explicitly different scales in decision making and knowledge integration. Regional planning, that has to break down policy objectives from state regional planning in spatially explicit manner, faces the problems (a) to bring together the local knowledge on land use and related management practices, and needs of society as a whole to (b) provide requested resources and services while ensuring private property rights at the same time.

Concepts such as ecosystem services (MEA, 2005), land use functions (Perez-Soba et al., 2008) or landscape services (Temorshuizen and Opdam, 2009) provide a framework to translating characteristics of the land system relevant to human well-being into more aggregated terms that can be communicated and used in integrated land use planning. Furthermore, benefit might arise from using these concepts in so far as they help to identify and consider also those services and potential future threats in their provision, which are not of current interest for the planning actors. Examples are regulating or cultural ecosystem services that are often neglected in planning due to more urgent pressures such as ensuring food-security or enabling economic development (see e.g. Gómez-Baggethun and Barton, in press). Operationalizing the concepts of ecosystem services, land use functions or landscape services in the context of integrated land use planning requires the inclusion of aspects and planning objectives that are relevant to a specific regional context (Koschke et al., 2012).

The papers in this issue originate from the conference RegioResources 21-2011 that started a cross-disciplinary dialogue on how to ensure the sustainable provision of natural resources at regional scale.

Objective of our special issue is to provide examples of operational methods and approaches that are tested and applied in integrated land use planning in diverse national or regional planning contexts.

We intend to present different perspectives on the contribution of integrated land use planning approaches to overcome menacing resource scarcity, taking conflicting topics such as enhanced use of renewables for energy provision and food security or irrigation in arid areas for agriculture and provision of drinking water as examples.

Challenges of integrated land use planning

A problem when making use of the ecosystem services concept or comparable approaches for integrated land use planning is that existing monitoring or survey networks are not prepared to deliver information that is requested to assess and monitor the provision of services (Chapman, 2012). Related is the question of the selection and interpretation of suitable criteria and indicators which enable an integrated assessment of ecosystem and land system processes and their impact on services provision (Koschke et al., 2012).

Besides, knowledge on ecosystem interactions and how these contribute to performance of land systems in providing resources and services for society is so far limited. Processes in ecosystem compartments couple back with processes at global scale, taking global warming and GHG emission from permafrost soils an example (VijayaVenkataRaman et al., 2012). Abundance of rare species and species diversity is dependent from the existence and quality of specific habitats, but also of their spatial context and connectivity (Nagendra et al., in press). Regional water availability is impacted by land use at the scale of management planning units, but also by the share of land use types, and the spatial and temporal land use pattern as a driver of the evapotranspiration in the regional and transregional water cycle (Giertz et al., 2005).

In addition, also temporal dynamics within the single ecosystems cause a high variability in the delivery of ecosystem services. Taking agricultural land use as an example, especially arable farming can react intra-annually on altered environmental or economic conditions that force to switch, for instance, to other crops and crop rotations (Olesen et al., 2011). Sealing of open areas or waste land in vicinity to urban systems can even happen on a daily time scale (EC, 2012). In contrast, changes in stand structure and tree species composition in forests might take decades and centuries, and once made decisions cannot easily be revised within short term (Fürst et al., 2010). Interactions between such different ecosystems are therefore also time dependent and in consequence demanding to be assessed by suitable monitoring or survey approaches.

Beyond, integrated land use planning has to involve stakeholders in a multi- and transdisciplinary manner. These stakeholders refer to different scales and have therefore conflicting or incompatible interests. Concerned land owners argue from micro-economic point of view. Actors such as water providers might address catchments as spatial entities. Nature conservation organizations might have both scales in their mind, the rare habitat at micro scale or the unique character of a landscape at meso scale. In all cases, the prior use or protection interest of a party limits the success of each other party to accomplish their land use interests (e.g. Pravat and Humphreys, in press). Increasing demands for public goods such as recreation, scenic beauty and experiencing nature add additional conflicts in integrated land use planning decisions (see e.g. Rakodi, 2001). All these aspects make it difficult to answer simple questions, such as ´whose and which demands to consider primarily at the interwoven spatial scale levels? ´.

Corresponding to the challenges

If we try to figure out how to conceive an analytical framework for addressing at least partially the described challenges, we can identify a number of basic requirements (Fig. 1).

- We need solutions that help to integrate management knowledge from the different land use sectors, and assessment approaches from landscape ecology and social sciences. Such solutions should be designed as open modular platforms combining software tools, economic assessment routines and approaches for stakeholder involvement.

- We need to define one specific spatial reference scale for being able to harmonize and integrate different data sets and formats and instruments to account for land use interactions and processes that go across the landscape. Land use type specific characteristics and relevant environmental or socio-economic parameters could be integrated at level of the management planning unit or pixel that plays at meso scale the role of the smallest, interacting entity. Further aspects such as pattern of patches with homogeneous land use, and connecting or fragmenting linear elements could be accounted by use of landscape metrics. Fluxes and processes that cross management planning units or patches, such as hydrological or matter cycles could be involved at patch, catchment or hydrological response unit level, while global processes can be considered as drivers for such processes including back-coupling with land use changes (see e.g. Flügel, 1996).

- The knowledge provided by our modular platform solutions, must be transformed in a way that enables planning actors to make use of it to test their own planning ideas and communicate them with other actors. This includes the provision of standardized assessment concepts such as ecosystem services, land use functions or landscape services and the underlying assessment criteria, indicators and methods. This should also include the opportunity to combine, modify and adapt such approaches and give support for integration of factual knowledge and expert opinion.

- Finally, support should be provided in drafting integrated land use scenarios which can range from multiple drivers dependent land system transformation processes, agent-based land use changes in cultural landscapes to scenarios where actors actively design their landscape. The therefore necessary interaction between the planning actors, the assessment concepts and the scenario building itself should be supported by visualization features and simple entry and feed-back mechanisms.

Fig. 1 provides a schematic approach how such an analytical framework could be conceived to support integrated regional planning at regional (meso) scale.

Fig. 1 approximately here.

Examples for systematically integrative approaches as drafted in our integrative analytical framework, were, for instance in this issue, successfully tested and adapted in The Netherlands (Eikelboom and Janssen, acc.), Brazil (Lorz et al., acc), in a set of developing countries (König et al., acc) or Germany (Fürst et al., in press). All of them face of course the problem of uncertainties originating from the available data base, the implemented modeling approaches as such and the way how land use change scenarios were drafted (Verburg et al., acc).
Validation of the outcomes and realistic prediction of changes in the provision of services that cannot only be based on biophysical indicators, but involve also a social component, such as provisioning or cultural services is almost not possible (Nidumolu et al., 2006). However, the great added value of such tools and approaches for integrated regional planning is that they help us to better reflect our understanding of socio-ecological systems and their behavior, that we can better share this understanding with regional actors and that we can better open up this understanding to additional input from multiple research disciplines and from practice.

Structure of the special issue

Referring to the requirements for building our analytical framework and presenting integrative solutions for them, contributions to the special issue address three major questions:

(a) how to optimize resource management at regional scale by means of improved planning instruments?

(b) potentials of integrated land use approaches for an optimized regional resource management – how to assess and how to go beyond indicators?,

(c) potentials and limits of regional resource management tools, and approaches - how to integrate chances, risks and uncertainty?

Answers to question (a) - how to optimize resource management at regional scale by means of improved planning instruments - are greatly dependent from large scale drivers such as climate change and their perception by those who are participating in or are affected by planning decisions. Eikelboom and Janssen (acc.) demonstrate how interactive spatial support tools such as drawing, simulation and evaluation tools can contribute to develop climate change sensitive planning strategies at regional scale together with multiple actors. Also Lorz et al., (acc.), give an example how to conceive a tool that serves for developing, testing and communicating integrated water management strategies for the Federal District Western Central Brazil. In the same regional context, Strauch et al., (in rev.) tested a Best Management Practices approach and how it will contribute to sustainable water resources management and soil protection. The authors used and adapted the Soil and Water Assessment Tool (SWAT) to study the impact on water and sediment yield in the intensively cropped meso scale catchment of the Pipiripau River. A big request in developing Best Management Practices in a regional context is to scale up applied agriculture and forest practices to meso scale for making them accessible to integrated land use planning. Lorenz et al., (in rev.) and Witt et al., (acc.) demonstrate for the Federal State of Saxony, Germany, how agricultural and forest land use practices can be made available and form a basis even for scenarios such as afforestation of agricultural sites.

(b) Going beyond indicators in integrated land use and regional resource management implies the development of approaches that are not restricted to a specific case study, but can easily be transferred to different planning contexts. König et al., (acc.) show for the FoPIA approach how a consistent framework for impact assessment can be transferred from its originally European context to development countries. Besides cross-national transferability, integrated approaches in regional planning and land use policies demand for a strong cross-sectoral coordination. For the example of the Natura 2000 formulation process in Slovakia, Sarvašová, et al., (acc.) reveal deficits in the policy process resulting from different policy beliefs concerning nature protection and forestry coalition.

To successfully assess, propose and implement integrated regional planning concepts, also indicator application should cross scales, going from indicators that address single land use activities and their impact on ecosystem services provision up to highly integrative landscape structural aspects that allow for assessing landscape responses on changes in the land use. Schaldach et al., (acc.) and Fürst et al., (acc.) present approaches how to assess the environmental impact of land use intensities in grazing, and of land use alternatives, such as forest conversion, afforestation or establishment of short rotation coppice.

A major concern in (c) - potential and limits of tools for regional resources management and integrated regional planning - is the question of uncertainty that derives from multiple sources in land use change modeling. Hou et al (acc.) provide an overview of the sources of uncertainty in landscape analysis and assessment. They concentrate on the valuation of ecosystem services and demonstrate the related uncertainties in a small case study. Verburg et al., (acc) show that translating macro-level uncertainties to uncertainties in spatial patterns of land change makes it possible to better understand and visualize the land change consequences of uncertainties in model input variables. Closely related is the question of uncertainties in the outcomes provided for integrated land use planning. Grêt-Regamey et al. (acc.) present therefore an approach for mapping uncertainties in ecosystem services assessment. Their results indicate that not only the total value of the bundle of ecosystem services is highly dependent on uncertainties, but that the spatial pattern of the ecosystem service values changes substantially when considering uncertainties. Going along with uncertainties on future ecosystem services provision is the problem how to estimate potential future trends of global land use and land cover change. Schüngel et al., (in rev.) present a method that applies a multi criteria analysis to automate the spatial downscaling of statistical land use census data to land-cover maps. Their analysis shows that uncertainties due to remote sensing products and data merging lead to considerable regional differences in accuracy, both in initial and scenario land use maps. A relevant potential of tools for integrated regional planning is their contribution to involve hazards and risks for landscape protection in regional planning approaches. La Rosa and Martinico (acc.) demonstrate for a case study in Sicily a landscape assessment methodology that reveals landscape hazards, values and risk for landscape transformations by new planned developments, intensification of urban sprawl patterns, loss of agriculture land and erosion. Another potential of integrative planning instruments is their contribution to a holistic assessment of strategies to cope with the future. Wenkel et al. (in rev.) introduce the LandCaRe decision support systems that was developed to test adaptation strategies in agriculture and regional land use management and that intends to support especially integration of agricultural adaptation opportunities to climate change at regional scale. A risk of integrated regional planning consists in a lack of later application of the planned measures. Kempa (acc.) investigates therefore demands on and incentives from the commercial market for environmental contributions of the farmers. Her results reveal that provision of financial support or contract-design between industry and farmers are seen as key to promote an environmentally friendly production.

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Figure captions:

Fig. 1: Scheme - analytical framework for integrated land use planning.

Figure

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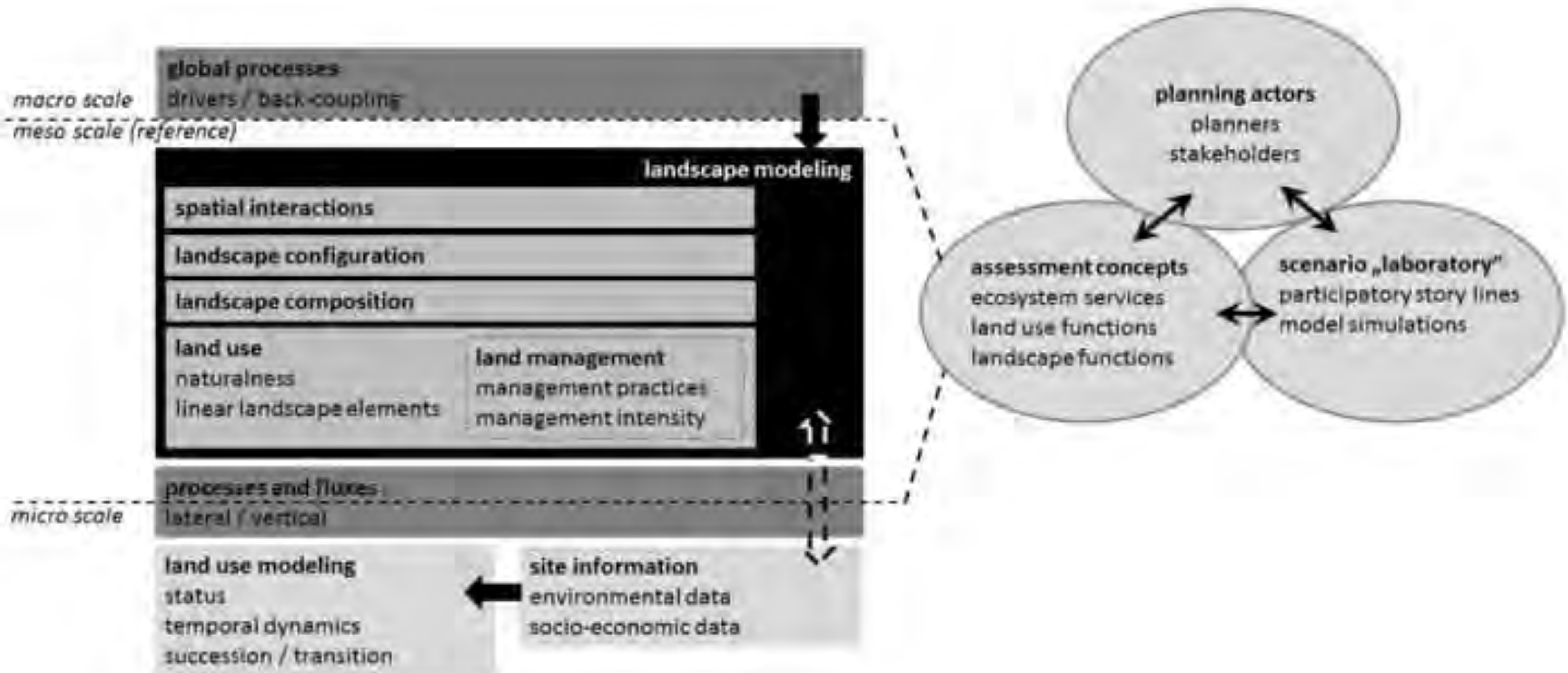

#12 Fürst, C., Flügel, W. (in rev.): **Impact of land-use changes on providing hydrological ecosystem functions (ESF) and services (ESS).** In: Chicharo, L., Müller, F., Fohrer, N., Wolanski, C.: “Ecosystem Services and River Basin Ecohydrology”, Springer publisher.

"Ecosystem Services and River Basin Ecohydrology", Springer

Chapter title

How to assess the impact of land-use changes on providing hydrological ecosystem functions (ESF) and services (ESS) – a conceptual framework

Betreff: INVITATION FOR CHAPTER ON SPRINGER BOOK "Ecosystem Services and River Basin Ecohydrology"
Von: "Luis Chicharo" <lchichar@ualg.pt>
Datum: 15.07.2012 18:10
An: <fuerst@forst.tu-dresden.de>
Kopie (CC): "'Luis Chicharo'" <lchichar@ualg.pt>

Dear Dr. Christina Fuerst,

We would like to invite you, as an acknowledged authority, to contribute with a chapter on "**Impact of land use changes on ecosystem service provision**", for the book "**Ecosystem Services and River Basin Ecohydrology**", to be published by Springer in 2013.

Ecohydrology is a new challenging approach to aquatic ecosystems management that considers that the dual regulation between biota and hydrology is the key to restoration and long term sustainability of aquatic ecosystems functioning. This book will highlight how ecosystem services, at the entire basin scale, are affected by improvement of aquatic ecosystem health and robustness through ecohydrology. See for instance

http://www.unesco.org/new/en/natural-sciences/environment/water/ihp/ihp-vii-themes/ecohydrology/

http://www.icce-unesco.org/

The book will have four main sections:
a) Ecosystem service provision in watersheds – an overview;
b) Methodology for evaluating ecosystem services and ecohydrological processes at the watershed scale;
c) Local pressures on ecosystem services in watersheds, and
d) Sustainable watershed ecohydrology and ecosystem service management: case studies

If you wish to enlist one or more co-authors, you may do so. Alternatively, if you decide that you are unable to contribute, it would be of great help to us if you could suggest a suitable replacement.

Authors will be expected to submit a paper by December 15, 2012, with an outline by August 30, 2012. Each paper should be 8,000 words or less, including references, plus 8-9 figures (no colour) and 3-4 tables at most.

For this initial submission of the manuscript, that will be reviewed, you do not need to typeset the manuscript. If possible please follow the layout of papers submitted the scientific journal Wetlands Ecology and Management.

We very much hope you will agree to participate in this exciting venture. Please indicate your willingness to contribute by replying to this invitation letter, by July 30, 2012.

If you have any questions about the article or the work please don't hesitate to contact me or any of the editors.

We look forward to hearing from you soon.

Yours sincerely,

Luis Chícharo *Felix Muller* *Nicola Fohrer* *Eric Wolanski*
Editors

Title Page

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Title

How to assess the impact of land-use changes on providing hydrological ecosystem functions (ESF) and services (ESS) – a conceptual framework

Abstract (150 – 200 words)

In this chapter, requirements for and lessons learnt from assessing the impact of land-use changes on the provision of hydrological ecosystem functions (ESF) and services (ESS) are analyzed. First, the potentials, limits and transferability of a detailed land-use classification scheme developed for a case study in Germany are explored. Second, an approach how to make use of landscape metrics to correct the assessment of ESF and ESS provision in land-use change impact assessment is presented that helps to better account for the heterogeneous land-use pattern. Third, the potential of the knowledge based regionalization concept of Hydrological Response Units (HRU) is assessed. HRU are applied as process related reference entities for ESF modeling and ESS assessment. Finally, a conceptual framework approach is proposed that builds on the HRU concept and merges the latter with a cellular automaton based land-use change assessment framework. The concept is discussed with respect to its potential application in eco-hydrology.

Keywords (4 – 6)

Ecosystem functions (ESF), Ecosystem services (ESS), Hydrological Response Units (HRU), Integrated land and water resource management (ILWRM), Distributed river basin modeling, Eco-hydrology.

1. Introduction

1.1 Challenges for assessing the impact of land-use changes on hydrological ecosystem functions (ESF) and services (ESS)

The assessment of the impacts of land-use changes on the provision of hydrological ecosystem functions (ESF) and ecosystem services (ESS) in river catchments is facing three major challenges. First, the assessment of changes is often restricted to land-cover classes and ignores the variability of land-use and land-management alternatives whose impact on ESF and ESS provision might exceed those of land-cover changes (Van Oudenhoven et al., 2012; Verburg et al. 2009; Dale and Polasky 2007). Examples can be found in agricultural and forest management systems. In agriculture, different soil management strategies (conventional tillage, conservation-till, no-till) can be applied to modify the provision of regulating and supporting services (e.g. van Capelle et al., 2012). Additionally, crop diversity in crop rotations, cash crops, mixed cropping and intercropping are concepts that help to modify the land-use impact (Zhang et al., 2007). Such well-known and approved agricultural management alternatives have more potential to contribute to an improved ESS provision than extensification of agricultural sites or afforestation. Reason is that their acceptance and implementation can be achieved much easier (Power 2010). In forestry, application of the concept of sustainable forest management that uses natural processes and works with mixed and multi-layered forests is sufficient for enhancing ESF and ESS provision (Fürst et al., 2011; Fürst et al., 2012).So far, conversion from coniferous to deciduous forests was often proposed as best practice (e.g. Spieker et al., 2004), but failed to be broadly applied in non-governmental forests mainly due to economic reasons (e.g. Knoke et al., 2005).

Second, the provision of ESS as described in the Millennium Ecosystem Assessment (MEA, 2005) is restricted to the scale of ecosystems under study. It does not account in sufficient detail for parameters such as the spatial heterogeneity of ecosystems or of processes related to catchment or landscape scale that both trigger the dynamics of particular ESF and the provision of related ESS (Frank et al., 2012; Fürst et al., 2012). An example for the impact of landscape heterogeneity on ESF and ESS provision are European cultural landscapes that developed over centuries with a heterogeneous structure of land-uses. Nowadays, this traditional land-use diversity is endangered to be lost due to economic development and migration processes (see e.g. Rounsevell et al., 2012; Eigenbrod et al., 2011). The structural change of cultural landscapes impacts hydrological processes such as runoff generation, groundwater recharge, water erosion, sediment transport or nitrate leaching through the unsaturated zone into the groundwater aquifer (Fink et al. 2007, Flügel 2011c). An increasing homogenization of land-use accompanied by growing average sizes of management units amplifies such processes. In response, this generates negative impacts on ESF and ESS, even, if cross compliance regulations and good management practices are applied (Poggio et al., 2012).

Third, a scale conflict arises when assessing ESF and ESS based on stakeholder needs and perceptions: ESF and ESS assessment cannot be restricted to administrative boundaries or river basins (Trabucchi et al., 2012) although regulating (flood control, water purification) or some provisioning (fresh water) services are directly related to draining catchments. Most provisioning services (wood and fiber, food and fodder), supporting services (primary production, soil formation) and cultural services (aesthetics, recreation) can only be analyzed in the context of the landscape or region as socio-geo-environmental assessment entity.

To better combine ESF and ESS with the concept of integrated land and water resource management (ILWRM), multi-scale regionalization concepts are required (Flügel et al., 2011a, b). The concept of process-based Hydrological Response Units (HRU; Flügel, 1996 a, b) provides a well-tested spatial reference that supports the integration of micro-scale (land-use at management planning unit level) and meso-scale aspects (catchment and region). So far, HRU are applied as model entities in distributed river basin models such as JAMS/J2000 (Krause and Flügel 2005, Krause et al. 2006, Fink et al. 2007, Nepal et al. 2012), but not yet in the context of landscape ecology or ESF and ESS assessment.

Based on this, the discussion paper will raise the following questions:

(a) What should be assessed when classifying land-use and how to better account for land-management impact when simulating and evaluating land-use changes and their relevance for ESF and ESS?

(b) How can land-use pattern and landscape heterogeneity be integrated more efficiently when assessing ESF and ESS with respect to the impacts of land-use changes?

(c) How to overcome scale differences in integrated land-use and ILWRM in ESF and ESS assessment?

1.2 Objectives and terminology

This chapter presents and discusses (a) lessons learnt from a case study in Germany that elaborated on how to improve the land-use classification for ESS assessment. (b) In this case study, a method was developed that applies landscape metrics to correct the assessment of ESS provision for land-use change scenarios and supports (“ecological integrity”) and cultural service (“aesthetics”). (c) Strengths and weaknesses of the approach and its transferability for hydrological ESF and ESS assessment are discussed. (d) Subsequently, the concept of HRU (Flügel, 1996 a, b) is introduced as knowledge based assessment methodology also for not directly watershed related ecosystem services. Hereon based, a conceptual framework for assessing the impact of land-use changes on ESF and ESS provision is proposed.

Special consideration is given to hydrological ESF and ESS defined as dynamic resource regeneration functions and dependent socio-economic services, both provided from river basins as spatial reference unit. Also, some other ESF and ESS are involved, whose provision is more related to the regional scale. The term region is understood as a historically developed, culturally and environmentally defined socio-ecological landscape system (Laszlo and Krippner, 1998). ESS are understood as a concept that puts qualitative or monetary value to ESF that, in turn, are assessed and quantified by means of process-based distributed models. Dependent on the assessment context and objective, ESS are regionally specific and cannot be transferred easily between regions and scales as they take into account macro-scale aspects such as expected population growth or climate change and related impacts on specific ESF.

2. Case study based ecosystem services assessment components

2.1 Land-use classification

The information quality in assessing the potential of landscapes to maintain ESF and to provide ESS is closely related to the modality how land-use or land-cover (LULC) are classified and how land-management is considered when applying LULC for ESS assessment (Dale and Polasky, 2007). Land-cover classification as applied, for instance, in Corine Land Cover (CLC) 2006 (www.eea.europa.eu/data-and-maps/data/) is a generic and transferable system, but remains descriptive and provides only crude details on aspects such as the spatio-temporal dynamics in land-use and land-management. Therefore, the challenge in ecosystem services assessment is to replace the land-cover classification by a more functional classification concept (Erb, 2012; Verburg et al., 2009) that better accounts for the relation between land-use and land-management, and processes both triggering the dynamics of ESF and the provision of ESS. Examples for more functional classification schemes in river basin modeling were, for instance, applied for assessing N and P loads to water systems (Bossa et al., 2012), for changes in hydrological regimes of catchments (Troy et al., 2007) or for flood regulation (Nedkov and Burkhard, 2012).

Another challenge is to interpret and analyze functional aspects. Land-use systems cannot only be understood as sum of interacting ecosystems, but as socio-ecological systems that include a strong cultural component (Lambin and Meyfroidt, 2010). In result, a “functional” classification cannot be restricted to a narrow ecological understanding, but has to consider the purpose of the assessment for which the classification is developed (Koschke et al., 2012).

To approach transferrable concepts for a functional land-use classification, the case study "Upper Elbe Valley – Eastern Ore Mts. (UEEO)" is introduced. In this case study, a detailed forest and agricultural land-use classification was developed for climate change adaptation and mitigation strategies related to land-use (Fürst et al., 2011).

In cooperation with Euromap GmbH, remote sensing and terrestrial data were combined to get the highest possible spatial and thematic resolution for land-use mapping (Euromap Land-cover Classification, EMLC). Problems were (a) the accessibility and spatial matching of the terrestrial data and (b) their association with specific land-management concepts.

2.1.1 Forest land-use classification

For forest land-use classification, the accessibility of terrestrial data is dependent on the type of land ownership. Data from a terrestrial forest inventory could only be acquired for governmental forests; meanwhile for non-governmental forests, biotope and land-use mapping (www.umwelt.sachsen.de/umwelt/natur/18615.htm) was the only accessible data source (Witt et al., in press).

Considering the spatial matching of these data sets, the forest inventory is done in the model region at the scale of the forest management planning unit (stand) as smallest ESF and ESS assessment entity (Anonymous, 2005) with a maximum spatial resolution of 100x100 m². In contrast, biotope and land-use mapping are available for all ecosystem types in Saxony in a resolution of 10x10 m². Both data sets were combined with other terrestrial data, namely forest site classification (Kopp and Schwanecke, 1994), soil classification (Sponagel et al., 2005), and the digital elevation model (DEM, 1:25,000). Subsequently, contextual information on site quality dependent silvicultural concepts (Eisenhauer and Sonnemann, 2009) was added. In result, a maximal spatial resolution of 25x25 m² was obtained and a thematic classification scheme that can be connected to the current silvicultural management concept in Saxony (Witt et al., in press; Fürst et al., 2011; 2012).

The latter foresees trajectories from current forest classes to a lower number of future classes, each characterized by a broader range of tree species and mixture forms compared to the present classes. Consequently, to simulate forest land-use changes, the current forest land-use classes were linked with spatially explicit information on the eligible future classes in form of an additional forest land-use layer (Witt et al., in press).

2.1.2 Agricultural land-use classification

In agriculture, terrestrial land-use data were available in form of statistics at Federal state level without spatially explicit reference. Accessible data describe average percentages of different crops broken down to the total agricultural area in the model region (e.g. Anonymous, 2010). Furthermore, data on cultivated crops were available at level of so called “field-blocks”. These field blocks are the smallest spatial entity for which agricultural practices must be reported to apply for agricultural funding within the frame of the European Agricultural Fund for Rural Development (EAFRD) program. Their size and shape is not standardized. They are delineated based on topographic, edaphic and infrastructural parameters (roads or settlement areas as borders) and they can be managed by several farmers (see e.g. Heinrich et al., 2009).

To harmonize the temporal dynamics of the different land-use systems in the case study region, a need was identified to define agricultural land-use classes that account better for inter-annual aspects and do not refer only to specific crops. Based on this demand, Lorenz et al. (in press) introduced the concept of regionally typical crop rotations. These crop rotations provide a thematic reference to current practices in arable and mixed farming including conventional and organic farming. They also allow for a better comparison of ESF and ESS provision between agriculture and forestry. Statistical data on cultivated crops from 2005 – 2010 were analyzed to identify regionally typical pre- and post-crops to key crops. For spatial transfer, the meso scale agricultural soil mapping (1:25 000) and field block data were used. Additionally, different soil management techniques (conventional, conservation till, no-till farming) were added as management attributes.

2.1.3 Overall classification result

In result, 85 land-use classes were differentiated (see Fig. 1 for the classification and their spatial distribution).They include 22 land-use classes derived directly from remote sensing such as urban fabric, water bodies, or urban green space, and 32 forest land-use classes that were added and linked for scenario simulation with 22 eligible future classes (not displayed in Fig. 1; Fürst et al., 2012; Witt et al., in press). For agriculture, 31crop rotations were added that represent most common management practices for diluvial sites (“D”), loess sites (“L”), and deeply weathered bedrock sites (“V”) (Lorenz et al., in press). The adapted classification has a maximum spatial resolution of 25x25 m² that supports the assessment of changes at management planning unit level (micro-scale).

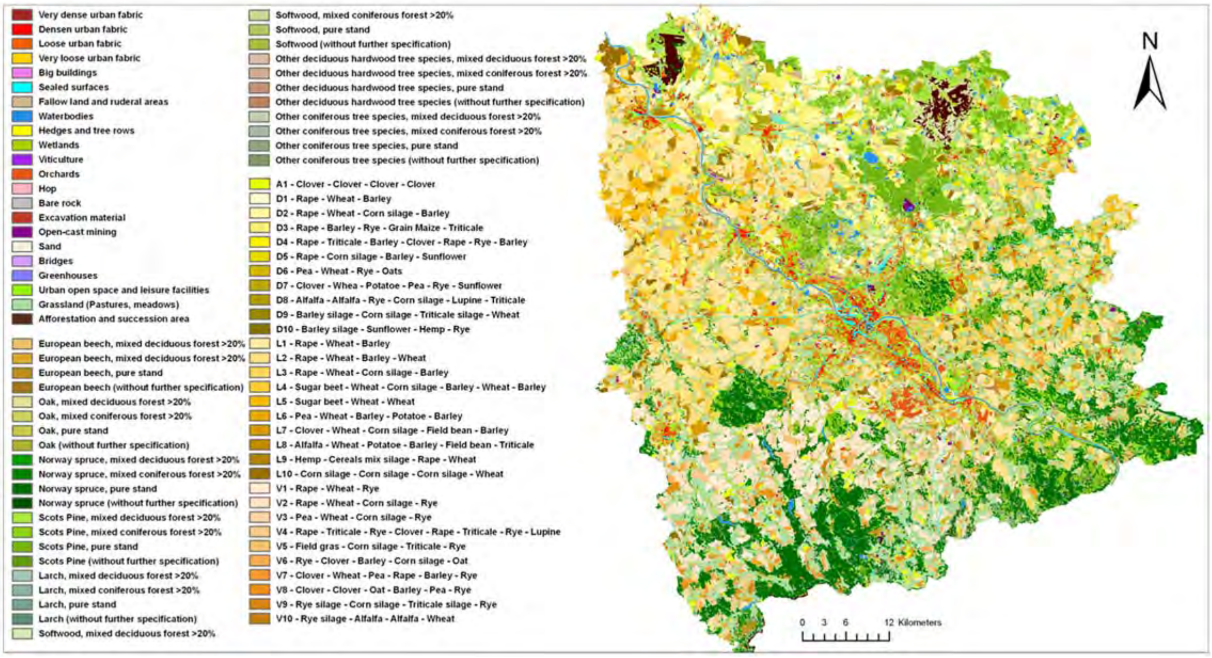

Fig. 1: Overview Euromap Land Cover Classification (EMLC) and map for the model region Upper Elbe Valley – Eastern Ore Mts (UEEO)

2.1.4 Applicability of the approach for ESF and ESS assessment

When using the UEEO data set for ESF and ESS assessment, it became obvious that models or monitoring data accounting for this high level of detail in land-use classification were not or only partially available.

Considering the forest land-use classes, it turned out that most forest models focus on few tree species and describe mainly the behavior of pure and single layered stands at micro-scale (e.g. Papst et al., 2008). Information on mixed and multi-layered stands could neither be obtained from forest yield tables (e.g. Schober, 1995).

In agriculture, crop rotations are applied in bio-physical process models or economic models on farm level to derive different environmental impacts (e.g. Janssen and van Ittersum, 2007; van Ittersum et al., 2008). However, the lack of empirical data remains a challenge (Schönhart et al. 2011a). Therefore the implementation of crop rotation-based modeling is often restricted to individual case studies, farm surveys or extracting expert knowledge (Belcher et al., 2004; van Ittersum et al., 2008; Rode et al., 2009). Crop rotations applied at regional scale remain unknown. Furthermore, spatial allocation of crop rotations or cropping systems plays a fundamental role, but is also a source of uncertainty in deriving environmental impacts on regional scale (see also Bell and Irwin, 2002).

For many of the other land-use classes, we experienced that models for ESF and ESS assessment are either missing, or knowledge about measured data for model calibration and about applicable model parameters is lacking. Consequently, detailed information on some well described land-use classes had to be used as reference for expert opinion based assessment on the impact of all other classes (Koschke et al., 2012). Critically spoken, the attempt to achieve improved understanding of land-use impact on ecosystem functions and processes by increasing the degree of detail in land-use classification did not necessarily provide a better basis for ESF and ESS assessment.

The problem of data availability gains in importance if land-use classification approaches should be transferred to other regions. Terrestrial information for training the interpretation of remote sensing data for land-use classification might not be accessible and only few remote sensing techniques provide data that are detailed enough to identify specific land-use types (e.g. Bach et al., 2006; Colditz et al., 2011). Furthermore an exact delineation of land-use entities that account for land-use and management practices such as mixed cropping, grazing or agro-forestry systems, and diversity of seasonally driven vegetation dynamics might not always be possible (see e.g. Gulinck and Wagendorp, 2002).

A lesson learnt from the case study was that land-use classification that supports ESF and ESS assessment should go more in detail than land-cover classification can do, but must respect limits in detailedness given by the availability of modeling, monitoring, and remote sensing data. A suitable approach involves a hierarchic concept in land-use classification that bases on standardized remote sensing information and should be kept compatible to existing land-cover classification sets such as CLC 2006. It should also provide interfaces to differentiate spatially or thematically the land-use information depending on the objective of the assessment and data accessibility (Fürst et al., 2012). Regional experts should be involved in land-use mapping campaigns, contributing their knowledge about typical regional land-use practices and available information on their impact on ESF and ESS provision (e.g. Hought et al., 2012; Kristjanson et al., 2005; Lebel and Rajesh, 2009). This demands for open technological solutions that allow for easy adjustment and modification of already interpreted land-use information.

2.2 Landscape metrics for ESS and ESF assessment

Most ESS and ESF assessment concepts relate to the ecosystem point of view but rarely include landscape structural aspects which impact the capacity of a region to sustain ESF and provide ESS (Frank et al., 2012; Syrbe and Walz, 2012). In this regard we understand “landscape structural aspects as the spatial constellation of different land-use types (landscape pattern, e.g. Bartel, 2000) and landscape elements such as hedge or tree rows, water courses or streets that connect or fragment a landscape (Hou and Walz, in press).

Research on landscape structural aspects often addresses issues such as species diversity or habitat connectivity (e.g. Dover and Settele, 2009; Lomba et al., 2011; Verdú et al., 2011), aesthetical landscape value (e.g. Uuemaa et al., in press), or the assessment of ecological sustainability as such (Renetzeder et al., 2010). Research approaches on how the spatial structure of land-use impacts ESF and ESS provision are still seldom (Frank et al., 2012; Lautenbach et al., 2011). This also applies for research on how land-use should be structured to ensure a maximum benefit for enhancing the provision of one or several ESF and ESS (Laterra et al., 2012).

Therefore, Frank et al., (2012) developed an approach in the UEEO case study for a standardized set of landscape metrics to assess criteria such as landscape fragmentation, habitat connectivity and landscape diversity. These criteria were considered to be decisive for the functioning of ecological processes. Landscape diversity was additionally evaluated as decisive for the perception of the beautifulness of a landscape. Objective in this case study was to derive recommendations for regional planning on how to improve the landscape structure by afforestation or alternatively by the establishment of short rotation coppices (Fürst et al., in press; Fürst et al., 2012).

To quantify landscape fragmentation, Frank et al., (2012) implemented the metrics core area index (von Haaren and Reich, 2006) and effective mesh size (Jaeger, et al., 2008). For assessing habitat connectivity they made use of the cost distance analysis (Zebisch et al., 2004). The latter was modified to include infrastructural elements (roads, highways, railways) which modify the maximum distance when moving from one potential habitat to the other. Considering landscape diversity, Frank et al. (2012) applied the shape index (Baessler and Klotz, 2006; Renetzeder et al., 2010), the Shannon-Wiener diversity index (Yeh and Huang, 2009; Kim and Pauleit, 2007), and the patch density per km² (Hein et al., 2004).

The indices were used to correct qualitative assessment results for the supporting service “ecological integrity” and the cultural service “landscape aesthetics” that were calculated for the case study region based on EMLC (see 2.1).

A transfer of this approach to hydrological ESF and ESS could be easily possible for runoff generation, water erosion and sediment transport. In case of water erosion, small scale structural aspects found already entrance in water erosion risk modeling (Volk et al., 2010). Lowicki (2012) proposes a landscape metrics based approach for runoff and water pollution regulation in agricultural areas. Also, control of water quality (Amiri and Nakare, 2009) and sediment delivery ratio (Vigiak et al., 2012) are already based on landscape metrics assessment.

Problems in such approaches are related to the land-use classification and scale. Uuemaa et al., (2005) demonstrate, for instance, the scale and spatial resolution dependency of a landscape metrics based approach for assessing water quality. When testing our EMLC set (see 2.1) in comparison to CLC 2006, the same phenomenon was observed. Another problem – also in the presented approach – is the consideration of the spatio-temporal variability of the land-use pattern especially in agricultural areas. Winter or summer aspect in temperate zones or rain period and dry season in the subtropics could lead to completely different results in landscape metrics based ESF and ESS assessment within a year. The consideration of such seasonal vegetation dynamics and the resulting differentiation in soil vulnerability require a modification of the landscape metrics based assessment. For instance, Zhou et al. (2012) recommend the combination of a cellular automaton with landscape metrics analysis to better account for land-use change trajectories in regions threatened by salinization. For up-scaling of hydrological processes and related ESF and ESS, a link between landscape ecological approaches such as landscape metrics and process-based models is indispensable (e.g. Seppelt et al., 2009).

2.3 Scaling approach – using HRU in ESF and ESS assessment

The challenge of scale in hydrological river basin rainfall-runoff modeling has been addressed by Flügel (1996a, b) who proposed the regionalization concept of Hydrological Response Units (HRU) implemented by means of an Integrated Environment System Analysis (IESA). The concept is generating synergy by integrating physiographic landscape features and land-use classification into a knowledge-based analysis of the hydrological process dynamics of each HRU. Per se, the HRU concept is not scale related as the size of each HRU depends on the spatial and thematic resolution of the land-use and physiographic landscape features applied in the IEAS. The concept provides process based HRU as distributed model entities for hydrological water balance modeling in multi-scale landscape drainage systems (Flügel, 1996a, b).

As shown in Fig. 2 for a schematic landscape segment, HRU represent distributed landscape units, each defined by an individual setup of land-use and associated topo-pedo-geological features. They control the transformation of precipitation input into evapotranspiration output, soil moisture storage, groundwater recharge, and surface and subsurface runoff components ultimately generating the river runoff response. Consequently, each HRU has a priority ranked surface and subsurface water resources regeneration dynamics that relates to respective ESF and ESS provision.

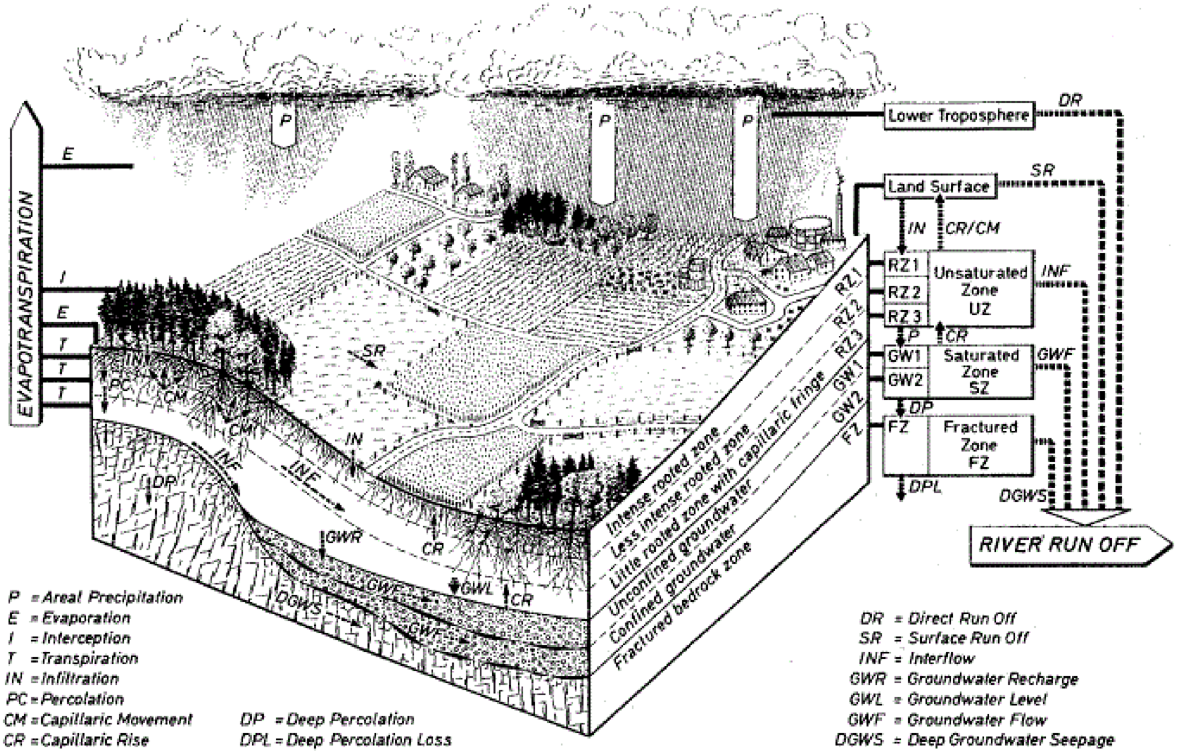

Fig. 2: HRU are defined by individual setups of land-use and associated topo-pedo-geological landscape features controlling the hydrological process dynamics and the provision of related ESF and ESS.

HRU are delineated by means of GIS analysis and, as shown in Fig. 3, land-use and the different landscape features are represented by GIS data layers. The process understanding obtained from the IESA is transferred into process-based logical HRU selection criteria applied in GIS overlay analysis. The latter provide HRU as process-based landscape units that comply with the defined selection criteria and differentiate the landscape drainage system in individual HRU polygons. Applying the digital elevation model (DEM), a topological model is generated within the GIS that networks all HRU by defining the gradient driven topology between neighboring HRU for water, nutrient or sediment transport routing within the drainage system (Wolf et al., 2009 a, b).

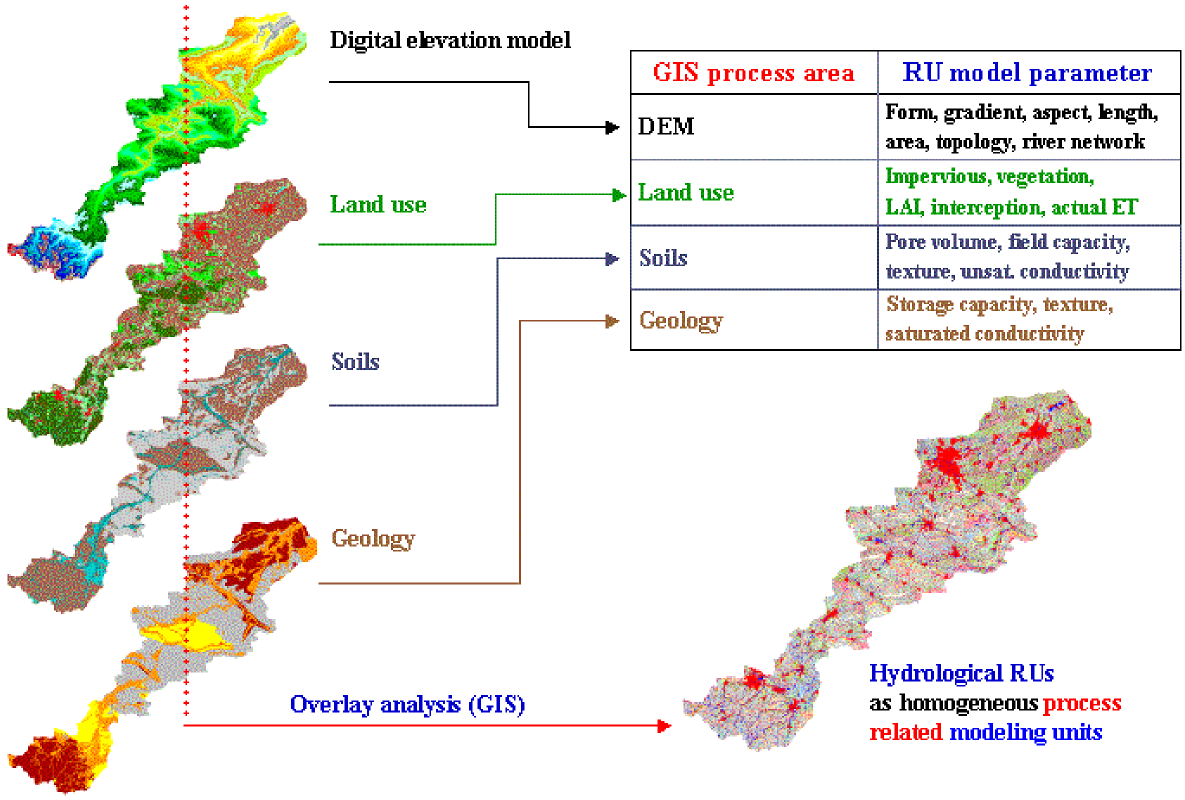

Fig. 3: Scheme for the GIS-based delineation of HRU.

Hydrological process dynamics and related ESF in each HRU are quantified by means of a distributed rainfall-runoff model named JAMS/J2000 that is calibrated and validated by measured time series (Kralisch et al. 2007, Krause et al., 2005; 2007, Fig. 4). The model represents all processes shown in Fig. 2 by physically based mathematical equations and empirical parameterization for each HRU. In result, JAMS/J2000 provides insight and quantification of the distributed regeneration dynamics of subsurface and surface water resources within the river catchment. Also, it supports a scenario based impact analysis for the impact of land-use changes on ESF and ESS provision (Bende et al. 2007; Fink et al., 2007; Nepal et al., 2012). JAMS/J2000 is meanwhile a component of the Integrated Land-management System (ILMS) platform (Kralisch et al. 2012).

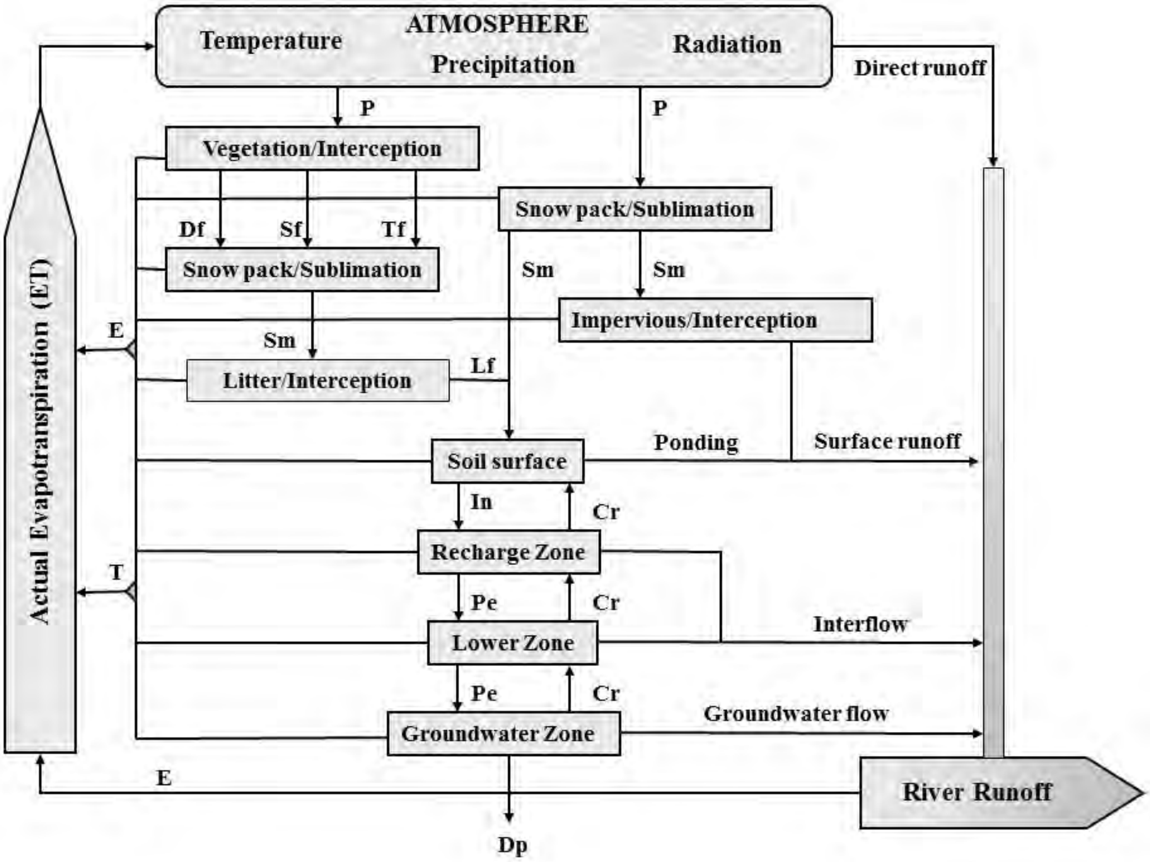

Fig. 4: JAMS/J2000 flow chart.

A restriction in the HRU model application so far is, that only few land-use classes, namely agriculture, forestry, rangeland and impervious areas can be differentiated, whose historically developed spatial distribution is related to topographical aspects that drive soil formation. The use of this classification scheme was needed to reduce land-use diversity to a degree that allows for a realistic parameterization of functional HRU model entities. At present, land-use changes within a HRU, such as urban sprawl, afforestation or succession cannot be considered. A detailed land-use classification as described for the UEEO case study would probably lead to the delineation of too small and highly inefficient modeling entities for the regionalization of hydrological processes. In conclusion, an approach is needed that makes use of the process based HRU concept, but likewise allows for a more detailed assessment of land-use aspects for ESF and ESS provision. Recent research in hydrological modeling addresses therefore an improved representation of changing land-use and land-management as variable HRU attributes and statistic cluster analysis of the landscape morphometry for multilateral flow simulation (Pfennig et al. 2009).

3. Conceptual framework for ESF and ESS provision in catchment scales

Based on the concept of HRU (Flügel, 1996 a, b), and the software platforms ILMS (Kralisch et al., 2012) and GISCAME (Fürst et al., 2010 a, b), we propose the concept of a networked distributed river basin modeling approach (Fig. 5). The original idea of the HRU to account for soil-vegetation-atmosphere interactions as drivers for processes shown in Fig. 2 could be enhanced by the consideration of more land-use alternatives including their spatial and temporal dynamics and landscape metrics assessment. In this framework, ILMS (see 2.3) is needed for the HRU delineation and GISCAME for the integrated land-use change simulation and impact assessment. ILMS provides process understanding and quantification of hydrological ESF meanwhile GISCAME combines GIS features for handling environmental information with a cellular automaton (see Cochinos 2000) and a multi-criteria evaluation framework for ESS assessment. A cellular automaton is a mathematical model that is used in GISCAME for the simulation of local and regional land-use changes. The cells hold information on the land-use and other attributes provided by the GIS. They also hold knowledge regarding the properties of each other cell. Thereby, they can simulate the interdependences between neighboring land-uses and account for the impact of the land-use pattern by including a set of landscape metrics (see 2.2). The cell attributes are also relevant for deciding on likely and unlikely land-use change trajectories within scenarios. Main application area of the combined ILMS and GISCAME toolsets could be the assessment of impacts of LULC change scenarios in support of regional planning (Fürst et al., 2011;Fürst et al., 2012; Fürst et al., in press) and in ILWRM (Flügel 2011b, Kralisch et al. 2012).

The smallest functional entity in our proposed framework is the cell. The latter is defined as bio-pedo-topological reference unit. Each cell has one specific land-use type as basic attribute, whose impact on ESF and ESS provision is locally dependent from physiographic site factors (soil, exposition, climatic water balance, etc.). If associated with the cells, land-use type specific models and empirical data can be applied to obtain insight in ecosystem processes and the related potential of a land-use types that contribute to ESF and ESS provision (Koschke et al., 2012). At meso-scale, our cells can be integrated within the HRU modeling entities.

So far, both approaches, cellular automaton and HRU, produce different spatial delineation results for the modeling entities. In case of the cells, these are usually square shaped (Cochinos et al., 2000), while HRU can also be polygons (Flügel et al., 1996a, b). To achieve spatial compatibility of the two modeling approaches, the cell borders could be adapted to pedo-topo-geological conditions and get an irregular shape. Or, physiographic HRU features could be adapted to obtain regular shaped modeling entities. We propose square shaped modeling entities which provide the following two advantages: first, a raster with square shaped modeling entities as mostly applied in the cellular automaton approach provides spatial reference units which are standardized in size and which are invariable over time. This facilitates the comparative simulation and spatially explicit assessment of the impact of land-use change scenarios on ESF and ESS provision (e.g. Norman et al., 2012). Second, approved concepts such as the Moore or v. Neumann neighborhood can be applied for the assessment of interactions between different land-uses, which are not available for irregularly shaped modeling entities (e.g. Itami, 1994).

Bringing cellular automaton approach and HRU concept together will support to account for cell-to-cell relations within an HRU, which modify land-use type specific ecosystem processes (Verburg et al., 2004). An example related to hydrological processes is nitrate leaching in forests neighbored or surrounded by agricultural fields. Furthermore HRU and landscape metrics can be merged by use of the cellular automaton approach as land-use types at cell level and their patches are an important analytical assessment entity for landscape metrics. Patches are defined as areas of spatially connected (neighbored) cells with homogeneous land-use type. Assessing their shape, size, spatial distribution and spatial constellation within a HRU or bridging several HRUs could contribute to better account for the impact of the land-use pattern on hydrological ESF and ESS provision (Frank et al., 2012) and enhance the gradient based topological model for routing water, nutrient or sediment transport between the HRU. In addition, the connecting or fragmenting effects of linear elements such as roads, highways, railways or hedge rows can then be included in the analysis by taking them as cell attributes which impact hydrological processes such as water erosion and runoff generation.

In result, the proposed framework could provide an improved interface to transform bio-physically modeled ESF into ESS as basis for ILWRM and regional land-use planning scenarios. Reference scale for the hydrological ESF and ESS assessment in our approach is the catchment (meso-scale), for other ESF and ESS the regional scale. The approach is also applicable, for macro-scale river basins where it supports the regionalization of ESF and ESS provision.

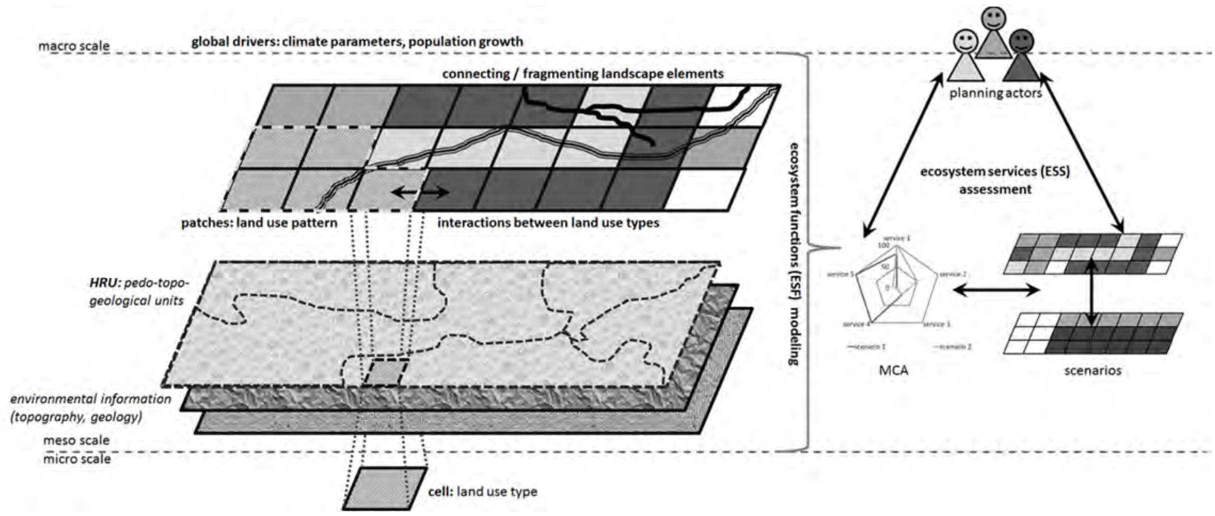

Fig. 5: Conceptual framework overview.

4. Applicability of the framework

A problem in making hydrological ESF and ESS compatible for regional land-use planning decisions is the integration of hydrological processes that cross and link ecosystems and occur on different scales compared to other ESF and ESS. The concept of HRU provides a broadly validated and applied methodology for involving a process-based component in ESF and ESS assessment (e.g. Immerzeel et al., 2008; Quintero et al., 2009; Welderufael et al., 2013).It furthermore has potential to be enhanced towards eco-hydrological response units (EHRU; see e.g. Hörmann et al., 2005) that integrate ecological aspects such as vegetation and land-use dynamics in process modeling and analysis.

A research challenge in our framework is the harmonic interaction of different modeling approaches. Micro-scale land-use models are validated for their specific application area (e.g. .g. Pretzsch et al., 2002 for forest models; Schönhart et al., 2011b for agriculture). However, they cannot take into account lateral interactions and processes at landscape level. Here, benefit could be taken from river basin modeling, where this is already done by generating topological routing schemes between HRU model entities (JAMS / J2000; Pfennig et al., 2009). When down-breaking of such lateral process on cell level the interactions between cells could only be represented empirically as little research has been carried out so far that would allow for a more detailed parameterization and validation (e.g. Schulp and Veldkamp, 2008). Also, the landscape metrics based assessment of land-use pattern impact on ESF and ESS within or cross HRU can so far not be validated as comparative studies are missing (Frank et al., 2012).

Another research challenge might come up from the modeling effort. Using land-use type specific models within our framework to feed the cells within a HRU with spatially explicit quantitative or qualitative information including temporal land-use dynamics requires the use of many models. They must be parameterized and validated for various site conditions. Pre-processing for cell parameterization or stepwise modeling to generate larger spatial modeling entities could contribute to reduce this work load. However, these strategies provoke either less flexibility in simulating land-use change scenarios or lower precision in the considerations of micro-scale site variability. Also, models or measured data are not available for all potential land-use types and there are still knowledge gaps that can only be closed by the analysis of empirical data and stakeholder or expert knowledge (Fürst et al., 2010a, b; Koschke et al., 2012).

Furthermore, the interplay of data and modeling dependent uncertainties considering ESF and ESS assessment cannot always easily be analyzed and considered (Grêt-Regamey et al., 2012). Test, comparison and validation of the outcomes requires harmonized environmental and hydrological monitoring approaches that are land-use and land-use pattern sensitive (Fürst et al., 2012b, Fink et al. 2012)).Our proposed conceptual framework will contribute to detect and describe future monitoring needs and help to improve iteratively the quality of ESF and ESS assessment.

5. Conclusions

Land-use changes have a significant impact on the provision of hydrological and other ESF and ESS. So far, impact assessment is mostly done on basis of land-cover classes or HRU. These modeling entities do not allow for simulating land-use changes within them. We propose therefore a conceptual framework that brings HRU together with a cellular automaton based approach. A benefit of this approach is that it supports a much more detailed consideration of land-use dynamics within the HRU modeling entities. Our proposed framework will also contribute to link hydrological modeling with land-use modeling and landscape ecological assessment methods such as landscape metrics. Ultimately, it provides an improved basis for integrating hydrological ESF and ESS in regional planning decisions and for sustainable ILWRM. Our future research will test the framework in well equipped test basins to explore its potential for land-use change impact assessment and to give feed-back on data demands and the adaptation of environmental and hydrological institutional monitoring networks.

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A multi-criteria approach for an integrated land-cover-based assessment of ecosystem services provision to support landscape planning

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ABSTRACT

The article presents a multicriteria assessment framework for the qualitative estimation of regional potentials to provide ecosystem services as a prerequisite to support regional development planning. We applied this approach to a model region in Saxony, Eastern Germany. For the estimation of the potentials of the model region to provide ecosystem services, we used a modified approach compared to the Millenium Ecosystem Assessment (2005). We then employed a benefit transfer and a purely expert driven approach to assess contribution of the land cover classes in our model region to the provision of ecosystem services. In a subsequent step, the services in our set were combined to ecosystem services groups that were designed together with regional actors, while considering their ideas, concerns and experiences in regional decision making. The latter was analyzed in a weighting experiment, in which different weighting approaches were tested. Based upon this, we analyzed the performance of the model region to provide ecosystem services and generated ecosystem services distribution maps. We could show that the different data gathering methods "benefit transfer" and "expert-based assessment" have a considerable impact on the evaluation outcomes.

The results of our study show that the combination of selected services and land cover data can contribute to regional planning by communicating the effect of land cover change on ecosystem services groups, especially when applied as an evaluation basis in the tool *Pimp Your Landscape* (PYL). The approach supports also the assessment of the performance of a region to provide ecosystem services and the comparison of regions towards this aspect. Finally, we discuss the limitations of our approach that are related to coarse land cover data, lacking knowledge on the provision of ecosystem services at a landscape scale, and the difficulty to make relevant the ecosystem services concept in regional planning processes.

1. Introduction

1.1. Background

As a consequence of global increase of economic and societal prosperity, ecosystems and natural resources have been substantially exploited, degraded, and destroyed in the last century (MA, 2005). To prevent further abatement of the quality of ecosystems, the ecosystem services concept has become a central issue in conservation planning and environmental impact assessment (Burkhard et al., 2010; Fisher and Turner, 2008). The environment provides food, fodder, wood, raw material, and other natural resources, but also non-material services such as carbon sequestration, water purification, and aesthetic values that are embraced by the term ecosystem services (MA, 2005). The ecosystem services concept emphasizes not only provisioning services (mainly marketable goods), but also supporting, regulating, and cultural services. It is supposed to be useful for communicating the manifold ways natural systems contribute to human well-being and to highlight the (monetary) value of ecosystem services and natural capital (de Groot et al., 2010; Lautenbach et al., 2011; MA, 2005; TEEB, 2010; Wallace, 2007).

Regional planning authorities face the problems of (a) planning for whole landscapes and (b) finding a consensus for multiple societal needs and demands, which provoke conflicts in using the same piece of land for different purposes and different prior services. Use of the ecosystem services concept in landscape planning is still largely missing, although its consideration could inform regional planning authorities in finding solutions that respond to competing social needs and demands. One can conclude that tools are needed that integrate ecosystem services at an early stage in regional planning and decision-making processes (Daily and Matson, 2008; Rannow et al., 2010). Assessment of the potential for landscapes to provide ecosystem services is regarded as an important instrument for dealing with the current difficulty to systematically consider ecosystem services in landscape management and land-use

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planning (Bastian et al., 2011; Bolliger and Kienast, 2010; Burkhard et al., 2009; Lautenbach et al., 2011; Müller et al., 2011).

1.2. Analysis of existing approaches

Existing methods of ecosystem services assessment often draw attention to (model-based) up-scaling of monitoring data that has been assessed at the level of the management planning unit (forest stand/field), at the level of an economic entity (forest district/farm) or at a catchment scale to become linked to an ecosystem service (Balvanera et al., 2005; Dale and Polasky, 2007; Lautenbach, 2010; Nelson et al., 2009; Pert et al., 2010; Posthumus et al., 2010; Sandhu et al., 2008). Such studies are necessary to investigate the number and quality of ecosystem services produced by the individual ecosystems and to increase knowledge about appropriate methods of quantification and mapping. In studies that focused on a regional or landscape scale, spatial distribution of specific ecosystem services has been mapped (Egoh et al., 2008; Lautenbach et al., 2011). Such approaches require the inclusion of manifold different data sources, spatial reference units, and advanced analysis methods, and are therefore difficult to be transferred from the original case study to other areas, where the access to respective data might be more limited.

1.3. Shortcomings of existing approaches

Ecosystem services research is struggling with the clear identification, definition and quantification of services as a consequence of a lack of knowledge on ecosystem functioning. Many investigations still focus on a few selected ecosystem services and exclude trade-off analyses (Ring et al., 2010). Assessments of ecosystem services tend to be tailor-made to respond to the scale level of analysis and goal of the case study, making the comparison of different study outcomes difficult (Müller et al., 2011). As a result, scientifically focused ecosystem services assessments (Seppelt et al., 2011b) are often too complex and thus too complicated to be directly used in practical application, such as eco-audits or environmental impact assessments. Consideration of ecosystem services in regional planning processes, as another example wherein practical application might be easy to realize, is still problematic. Especially in the case in which different land cover scenarios should be compared, immediate and easily understood feedback regarding changes in the provision of ecosystem services might not be provided to the decision-maker by means of current approaches. The scale level of ecosystem services assessment might not match the scale level of regional planning decisions (Meinke et al., 2006). Availability of data for an assessment of ecosystem services provision on a regional scale is often very limited to some ecosystems, or better to say land cover classes, while large gaps exist for others. As a consequence, up-scaling of detailed data from lower scales does not always contribute to an improvement in the data base on a regional scale. Furthermore, knowledge of the interactions between different ecosystems or land cover classes is rather limited and impacts the credibility of up-scaled modelling results from single ecosystems or land cover classes. Here, literature and expert-driven approaches for bundling knowledge on the provision of ecosystem services on the landscape scale might be a solution (Bolliger and Kienast, 2010; Eigenbrod et al., 2010). As an example, Kienast et al. (2009) and Burkhard et al. (2009) tested qualitative approaches to assess landscape functions and ecosystem services, respectively. For mapping functions and services, they used binary assignments to land cover types and expert estimations. Additionally, problems occur in communicating the ecosystem services concept to the relevant planning actors (Meinke et al., 2006; Opdam et al., 2009). Application-oriented studies that have focused on integrated sustainability and impact assessments in conservation planning have faced these challenges (Bell et al., 2003; Helming, 2009; Pérez-Soba et al., 2009; Seppelt et al., 2011b; Zerger et al., 2011). They used participatory and multi-criteria approaches to solve the problems of data integration and communication.

1.4. Objectives of the case study and the paper

In the context of the case study REGKLAM (www.regklam.de) in Saxony, Eastern Germany we aim at supporting regional planning processes and strengthening the interface between forest and agricultural management planning and regional planning (Fürst et al., 2010a,b, 2011).

The objective of this paper is to present a conceptual framework for how to assess the actual and potential future capacity of the REGKLAM model region to provide ecosystem services. With this framework, we attempt to provide an instrument that contributes to closing the gap between the ecosystem services concept and regional planning.

To develop an applicable framework, we compared first two methods of a CORINE Land Cover Classes (2006) based assessment of ecosystem services provision on the regional scale. To do so we have taken a set of eleven ecosystem services from the Millennium Ecosystem Assessment (2005) approach to which we added two economy-related services that were proposed by regional actors in the case study region. The resulting thirteen ecosystem services were assessed through (a) a benefit transfer approach, and (b) a qualitative assessment based on expert interviews.

A problem we found in our study was that the original ecosystem services were not fully understood by our regional planning actors. Therefore, the second step was to develop a multi-criteria assessment framework for how the previously described ecosystem services can be aggregated to better represent the specific regional understanding of benefits that should be provided to society by natural systems. Multi-criteria approaches (MCA) are formal approaches to address a problem in a structured way. The considered goals or targets are usually too complex to be properly assessed by a single criterion or indicator. Therefore, multiple relevant criteria or indicators are considered at the same time. MCA offer the possibility to use quantitative and qualitative information as obtained, for example, from expert judgments. Thus, data of divers sources can be applied in an aggregation framework allowing for an examination of the initial problem (Belton and Stewart, 2002; Mendoza and Martins, 2006). To involve stakeholder preferences in terms of the services to be provided and the indicators and criteria to assess the services, we conducted weighting exercises. Within the presented study, we tested different weighting approaches to find an easily applicable and solid method. Further, we used the different weighting results to examine the sensitivity of the overall assessment results to the services weights.

For the evaluation of land cover change scenarios and for ecosystem services assessment, we develop and apply a GIS-based software platform called Pimp Your Landscape (PYL, now renamed in GISCAME). We show how the outcomes were introduced into the system and what differences occur while assessing the provision of ecosystem services with PYL based on our different assessment methods (Fürst et al., 2010a,b; Koschke et al., 2010).

Finally, we discuss the strengths and weaknesses of our approach regarding its suitability to facilitate the integration of the ecosystem services concept into regional planning processes, and the feed-back and experiences of the regional actors in using the approach.

1.5. Definitions

Within this paper we use several terms, for which the meanings and definitions are given below:

- Region/regional scale: a region/regional scale is understood in this paper as a spatially distinct administrative district in a German Federal State, whose spatial development is mapped and described in a regional development plan.
- Stakeholder: a stakeholder is a member of an organization or group with interest in the way a particular ecosystem service is used, enjoyed, or managed on the regional scale. In our case stakeholders are regional planners and regional managers, land owners (farmers, foresters), representatives of administrations or public enterprises (Saxonian State Agency for Environment, Agriculture and Geology; Saxonian State Forest Enterprise "Sachsenforst"), representatives from NGO's (nature protection, tourism).
- Expert: An expert is any person who is a specialist, recognized in a special scientific domain relevant to the topic. He or she should not necessarily live in the case study region. Experts we addressed within the study come from university or public research institutions in Saxony and have different scientific backgrounds. They are mainly geographers, forestry and agricultural scientists. Because of their expertise and experience, we consider experts to be capable of making informed judgments and decisions, even in situations that lack information.

Fig. 1. Location of the REGKLAM region within Germany.

2. Methods

2.1. Case study REGKLAM and data base

In the case study REGKLAM (www.regklam.de) we want to assess alternative strategies of an integrated land-use with regard to their potentials to mitigate climate change effects and their trade-offs for regionally highly important ecosystem services. The tested strategies comprise, among other aspects, also changes in the land cover pattern such as afforestation, introduction of short rotation plantations or agroforestry systems on agricultural sites.

The study region is located in Saxony, Eastern Germany (Fig. 1) and has a total area of 4778 km^2. We used the CORINE land cover (CLC) 2006 data with a resolution of 100 m × 100 m as a reference standard. Of the initial 44 classes that are available for EU-27, 25 are present in the study region. For simplification and because of their small share, we regrouped some classes, which resulted in a final set of 19 classes. Fig. 2 shows the current (2006) land cover pattern.

For qualitative appraisals such as ours, a number of assumptions have to be formulated. Since real land use within a grid cell (100 m × 100 m) in CORINE land cover is unknown and environmental or management impacts on indicator values cannot be accounted for, we assume that the provision of individual services does not vary within a land cover type, although big variations are very likely (e.g. Meersmans et al., 2008; de Groot et al., 2009).

2.2. Application of the ecosystem services concept and indicator selection

Within the REGKLAM project the participation of regional stakeholders plays a major role. At the beginning of the project we identified together with regional actors from land use, regional planning and regional management a set of six ecosystem services groups to be considered within the project (Fürst et al., 2010a,b, 2011). We speak of "groups of ecosystem services" as the services which turned out to be relevant based on the opinion of our stakeholders are not identical with the original ecosystem services in the Millenium Ecosystem Assessment (2005), but integrate several single services into a larger context. We modified and partially extended the ecosystem services concept and its terminology to account for the needs regional stakeholders expressed. We achieved consensus with our stakeholders to consider supporting services (in our case *contribution to ecological integrity*), cultural services (*aesthetic value*), provisioning services (provision of fresh water and air, defined in the case study as contribution to *human health and well-being*; *bio-resource provision* including timber, food, and fibres), and regulating services (formulated as *mitigation of climate change impact*). In the discussion process with regional working groups and with actors participating in the creation of regional development plans, we recognized the need to

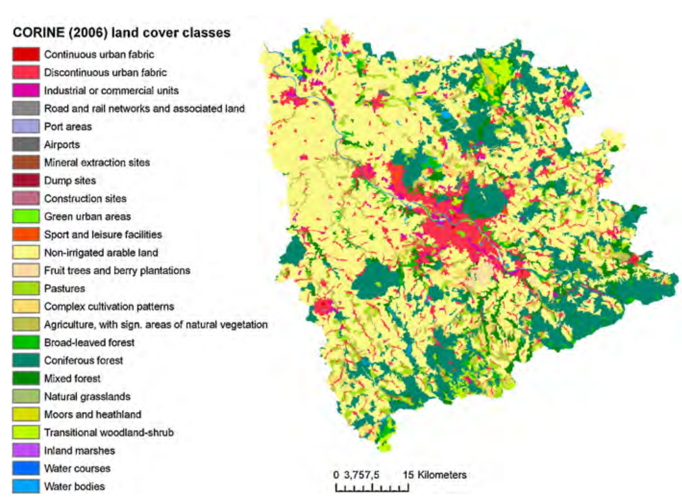

Fig. 2. Map of the CORINE land cover (2006) pattern in the REGKLAM region.

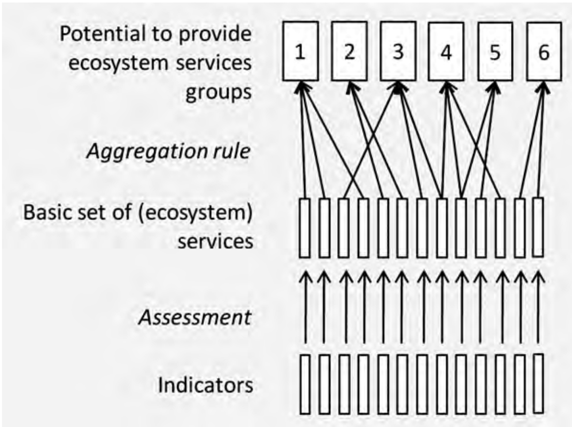

Fig. 3. Scheme of the hierarchical structure of the analysis (modified according to Bastian and Schreiber, 1999).

incorporate economic aspects of land use. Hence, beyond "traditional" ecosystem services groups as provided for example by the MA (2005), we incorporated *regional economy*. The latter might also be attributed to provisioning services. *Regional economy* was introduced to account for the (measurable and marketable) economic outputs that land use (mainly agriculture and forestry) can generate. The introduction of "regional economy" supported discovering trade-offs and conflicts as they appear in real regional planning situations where, for instance, economic interests and conservation measures are often in opposition. Human health and "well-being" was identified as one ecosystem service group, although, according to the cascade of Haines-Young and Potschin (2009), it is the ultimate purpose of ecosystem services to provide well-being to people.

Our method is based on a hierarchical assessment of the provision of ecosystem services (Fig. 3). In order to assess the ecosystem services groups at the top, we selected first suitable ecosystem services from literature (Burkhard et al., 2009; Costanza et al., 1997; de Groot et al., 2010; MA, 2005). This set comprises (1) provision of food and fodder, (2) provision of wood/timber, (3) clean air provision, (4) local climate regulation, (5) global climate regulation, (6) water balance regulation, (7) clean water provision, (8) soil erosion protection, (9) recreation and ecotourism, (10) aesthetic value, and (11) biodiversity. With respect to the ecosystem services group *regional economy*, we added two services that we called (12) income/returns from land-based production and (13) contribution to the overall added value. These two services are no original ecosystem services, but stand for the potential economic value of land cover types. They may be defined as proxies that account for the land-based as well as non-land-based (financial services, industrial services, etc.) contribution to the regional added value. Hence, in the assessment we discriminate between ecosystem services as defined for instance by Costanza et al. (1997), de Groot et al. (2010), and MA (2005) and economic services. The above described ecosystem and economic services were in a second step validated by our regional actors. In a third step, we came to a consensus on the final set of ecosystem services to be bundled into our ecosystem service groups (Table 1).

In a subsequent step we revised other investigations on ecosystem services and the related indicators (e.g. Costanza et al., 1997; MA, 2005; Burkhard et al., 2009). From these investigations and through discussion within the research group we derived one suitable indicator for each ecosystem service (Table 1). Precondition for the selection of an indicator was that it can be related to our 19 land cover classes, which excluded in many cases the use of statistical data or biophysical indicators.

2.3. Data gathering methods

For applying our indicators, we used (a) an indicator-based benefit transfer, and (b) a pure expert-based assessment.

2.3.1. Benefit transfer

In a first step, we used a benefit transfer method (see e.g. Plummer, 2009; Troy and Wilson, 2006), which can be described as an up-scaling of data assessed on smaller spatial units to larger areas that are assumed to be homogenous. This included a meta-analysis of primary studies and look-up tables to provide the indicator values.

We focused on data from regional investigations and tried to select studies that provide values for different land uses. In most cases values were available only for the main land cover classes such as arable land, forest, grassland/pasture. Therefore, we estimated lacking values for other land cover types on the basis of these values (semi-quantitative assessment). A detailed data compilation and rule-based estimations of indicator values can be found in the Supplementary material.

We standardized the values obtained from literature to a relative scale (0–100 value points). This was done by using Eq. (1), where I_{norm} is the indicator value for a given land cover class, I standardized to a score between 0 and 100, and I_{min} is the value of the indicator assigned to the observed land cover class. I_{min} and I_{max} correspond to the minimum and maximum of indicator values.

$$I_{\text{norm}} = \left(\frac{I - I_{\text{min}}}{I_{\text{max}} - I_{\text{min}}} \right) \times 100 \qquad (1)$$

If the value of an indicator was negative, such as in the case of the indicators N-export with seepage water and run-off coefficient, we applied Eq. (2).

$$I_{\text{norm}} = \left(\frac{I - I_{\text{max}}}{I_{\text{min}} - I_{\text{max}}} \right) \times 100 \qquad (2)$$

Take notice that the services (9) recreation and ecotourism, (10) aesthetic, and (13) contribution to the overall added value were assessed by expert based opinion (Section 2.3.2).

2.3.2. Expert-based assessment

Here, we asked experts to assign values ranging from 0 (no relevant contribution) to 100 (maximum possible contribution) in a scoring exercise with 10 point steps to all land cover classes. In addition to an assessment table which translated the evaluation categories into verbal meanings, we provided the experts with a short description of ecosystem services and indicators to increase consistency with the benefit transfer results. The 12 experts in this exercise were 6 physical geographers, 3 forestry scientists and 3 environmental engineers. According to the number of land cover classes (19) and services (13), the assessment matrix offered 247 fields the experts had to fill in. We used again standardized mean values to have a data matrix that can be compared with the one obtained from the benefit transfer assessment.

2.4. Multi-criteria aggregation framework

2.4.1. Bundling of ecosystem services to groups

Finally, we applied a MCA (see e.g. Belton and Stewart, 2002) to aggregate our single services to the six ecosystem services groups previously defined.

The ecosystem services groups were assessed by integrating the following services:

- *Ecological integrity*: Water (balance) regulation (6), clean water provision (7), biodiversity (11),

Table 1
Selected ecosystem services (MA, 2005) and indicators that are used in the assessment framework to estimate the capacity of each land cover class to provide ecosystem services. Besides ecosystem services, additional economic services and corresponding indicators are depicted to be used for assessments/evaluations. The arrows indicate the use of expert estimations for the assessment of indicated services within the (a) benefit transfer dominated approach in comparison to the (b) expert-based assessment.

	Ecosystem services[a]	Reference	State (s) and performance (p) indicators	Scale of measure	Assessed through	
					(a) Benefit transfer[b]	(b)Experts
1	Food and fibre	a,b,c	(p) Harvest/Yield [dt ha^{-1} a^{-1}]	Interval	x	x
2	Wood/Timber	a,c	(p) Harvest/Yield [m^3 ha^{-1} a^{-1}]	Interval	x	x
3	Clean air provision	–	(s) Green volume [m^3 ha^2]	Interval	x	x
4	Climate regulation (local)	b,c	(p) Cool air production [m^3 ha^{-1} h^{-1}]	Interval	x	x
5	Climate regulation (global)	a,b,c	(s) Storage of C in vegetation [kg C ha^{-1}]	Interval	x	x
6	Water (balance) regulation	c	(s) Surface roughness [Mannings n]	Interval	x	x
7	Clean water provision	b	(s) N-export with seepage water [kg N ha^{-1} a^{-1}]	Interval	x	x
8	Soil erosion protection	c	(s) Run-off coefficient [Ψ]	Interval	x	x
9	Recreation and ecotourism	c	(s) (Suitability for outdoor recreation)	Ordinal	←	x
10	Aesthetic	a,b,c,d	(s) (Scenic beauty, visual quality)	Ordinal	←	x
11	Biodiversity	d	(s) Number of vascular plant species	Interval	x	x
	Economic services	**Reference**	**State indicators**	**Scale of measure**	**Data source**	
12	Income/returns from land-based production	–	(p) Contribution margin [€ ha^{-1} a^{-1}]	Interval	x	x
13	Contribution to overall value added	–	(p) Regional tax revenue, trade tax [€ ha^{-1} a^{-1}] (non-land-based production)	Ordinal	←	x

[a] Provisioning services (No. 1, 2, 3, 7), regulating services (No.4, 5, 6, 8, 11), cultural services (No. 9, 10) (MA, 2005).
[b] Benefit transfer from literature and look-up tables accompanied by linking of values to CLC classes (for detailed compilation of data, data sources and assumptions see Appendix 1) (a) Costanza (1997), (b) MA (2005), (c) de Groot et al. (2010), (d) Burkhard et al. (2009).

- *Aesthetic value*: Recreation and ecotourism (9), aesthetic value (10),
- *Human health and well-being:* Clean air provision (3), clean water provision (7), recreation and ecotourism (9),
- *Mitigation of climate change impact*: Local (4), and global climate regulation (5), water (balance) regulation (6), soil erosion protection (8),
- *Bio-resource provision*: Food and fibre (1), and wood/timber provision (2),
- *Regional economy*: Income/returns from land-based production (12), contribution to overall value added (13).

Our concept considers that a single ecosystem service can be applied to one or more ecosystem services groups. This implicates that there exist interrelations between some ecosystem services groups which one should bear in mind during examination of the results.

2.4.2. Weighting methods

The use of hierarchical multi-criteria techniques requires the implicit or explicit application of weights. We applied explicit weights as the importance of the various ecosystem services might differ with respect to the context, the included stakeholders, and the investigated region. Therefore, we used (i) pairwise comparison of services as described in the Analytical Hierarchy Process (AHP; Saaty, 1977), (ii) Likert categories, and (iii) equal weights of our ecosystem services/economic services. The aim was to obtain a prioritization of the services that have been assigned to the six ecosystem services groups, and to reflect the importance of the services weights for final assessment of the performance of the model region in providing ecosystem services.

2.4.2.1. Regional stakeholder weighting using the Analytical Hierarchy Process (AHP). We applied the AHP because it supports the acquisition of relative weights in situations where a ranking of decision alternatives or evaluation criteria is desired and helps also to formalize public participation in decision making processes (Ananda and Herath, 2003; Mendoza et al., 1999).

For each of the six ecosystem services groups, we asked regional stakeholders, to compare each service with every other service on the AHP measurement scale ranging from 1 to 9, one indicating equal importance of services, 9 indicating strong preference of one service over the other (Saaty, 1977).

Our analysis focused on two smaller sub-regions in the model region, called ILE (ILE: integrated rural development) regions, "Dresdener Heidebogen" and "Silbernes Erzgebirge". These sub-regions were chosen because they provided us with good access to regional and local actors in working groups focusing on land use management and regional development (Fürst et al., 2011). The weighting exercise was carried out in a number of workshops and in a public information event. The actors came from regional development planning (4), forestry (non-governmental forest owners and state forest enterprise) (3), agriculture (farmers) (4), and citizens/laymen with different educational backgrounds and interests (9). We obtained weights using AHP software (www.expertchoice.com) providing also a consistency index as a measure of coherence of comparisons.

2.4.2.2. Stakeholder weighting using the Likert scale. In this weighting procedure 61 stakeholders from regional scale and national scale participated during a public event in the model region. We asked them to state their preferences towards our 13 ecosystem services referring to a Likert scale of 1 (not at all important to me) to 5 (very important to me) categories. As a result, we calculated relative weights of the single services in comparison to any other service.

2.4.2.3. Equal weights. Finally, we applied balanced weights as a third weighting method. Here, weights are simply generated by dividing 1 by N, where $N = 13$ is the number of the services. This approach was done as sensitivity analysis to test whether or not weighting exercises with stakeholder involvement led to significant differences in the context of the aggregation of ecosystem services to our ecosystem service groups.

2.4.3. Aggregation procedure

In order to obtain an overall performance value for each alternative land cover class against each of the six ecosystem services groups, we used a linear additive value function (Eq. (3)) to combine individual services.

$$S_{ij} = \sum_{k=1}^{n} w_{kj} s_{ikj} \quad (3)$$

S_{ij} represents the overall score (or total utility) of a land cover class i according to the ecosystem services group j; w_{kj} is the estimated weight of service k contributing to ecosystem services group j, and s_{ik} is the score (or partial utility) of land cover class i with respect to ecosystem service k. The weights (w_{kj}) represent the relative importance of ecosystem service k for ecosystem services group j. The sum of the weights adds up to 1 ($0 \leq w_{kj} \leq 1$ and $\sum w_{kj} = 1$ for all kj). By multiplying the score for each service with the corresponding weight and adding all services, the overall performance of a land cover class can be calculated for the ecosystem services groups.

Fig. 4 summarizes the steps necessary for producing an overall value per land cover class and ecosystem service group. We took the data that we collected though benefit transfer and-if necessary-expert questioning (steps 1 and 2) and standardized them within step 3. In step 4, we attributed a weight to each of the selected services. Using formula 3, we aggregated the standardized services values and weights to an overall value per land cover class with respect to each ecosystem services group (step 5). Thus, the results of both assessment methods could be combined. Prior to their application, a further standardization of the produced aggregated values was needed to have as final output value scores ranging from 0 to 100 (step 6).

The results of this mixed-method approach were compared with outcomes from the exclusive use of expert-estimations. Finally, we compared the results of the three weighting exercises.

2.5. Data analysis and visualization of results

We compared the results of the different data gathering methods to detect convergences and divergences. This was done through application of Spearman's rank correlation coefficient with SPSS version 17.0.

To communicate and discuss the results with our stakeholders and experts, we used the tool *Pimp Your Landscape* (PYL) (Fürst et al., 2010a,b). This software combines a cellular automaton with GIS features and a multi-criteria assessment approach. PYL enables one to assess and visualize in real time the impact of the current or a simulated land cover pattern on the provision of ecosystem services. We entered the values per land cover class and ecosystem services group that resulted from our aggregation procedure into PYL and obtained radar charts for each of the weighting results showing the overall assessment results (Fig. 5).

In addition, we visualized the results of our two assessment approaches by "ecosystem services performance maps" created in the GIS (ArcMap 9.2) to better reveal possible consequences for the estimation of the potential of our model region to provide ecosystem services. This is shown exemplarily for the ecosystem services groups *ecological integrity* (Fig. 6a and b) and *mitigation* of *climate change impacts* (Fig. 7a and b).

3. Results

3.1. Data gathering results

Basic indicator values from literature, values that we estimated in a rule-based manner, and final values of the services for every land cover class are displayed in Table S1 in the Supplementary material in the online version of this article. The final, standardized values per land cover class and service obtained by the benefit transfer approach are also shown in Table 2, while Table 3 displays the standardized values obtained from the expert opinion assessment. The land cover class "non irrigated arable land" was estimated to perform less well by the benefit transfer method. Based on the chosen indicators, even discontinuous urban fabric and industrial and commercial units, ports etc. perform better.

A comparison of the methodologies was limited to services that could be quantified in the benefit transfer method. Of the services that could be compared, good to very good correlation between both assessment methods was found for all ecosystem services except biodiversity by application of Kendall-Tau and Spearman-Rho (Table 4). For the service biodiversity, the difference of the final scores (mean values) obtained from our two methods amounted on average 36 points over all land cover classes (maximum 86 points), whereas average difference of all services was only 20 points.

3.2. Performance of the REGKLAM area towards ecosystem services groups

For aggregating our ecosystem services to the ecosystem service groups, we applied different weighting methods. The weights we obtained from stakeholder weighting can be found in Table 5.

Using the AHP software, a consistency factor is given as a measure for the logical rationality of responses. A factor of lower than or equal to 0.1 is considered satisfactory (Saaty, 2005). Consistency of the ecosystem services groups *aesthetic value*, *bio-resource provision* and *regional economy* was perfect (0.0) since only two services have been compared (only one decision). For the ecosystem service group's c*ontribution to ecological integrity*, *human health and well-being*, and *mitigation of climate change impact* mean inconsistency of weights was 0.276, 0.141, and 0.132, respectively. The mean standard deviations (SD) of services weights were 0.19 (*ecological integrity*), 0.27 (*aesthetic*), 0.16 (*human health and well-being*), 0.15 (*mitigation of climate change impact*), 0.23 (*bio-resource provision*) and 0.24 (*regional economy*). SD of weighted services show that ambiguous judgments of services have been made mainly within the ecosystem services group's *aesthetic value* and *regional economy*. In contrast, people have been more coherent comparing services used to assess *human health and well-being* and *mitigation of climate change impact*.

The results of the stakeholder based weighting using the Likert scale showed a slight prioritization for recreation and ecotourism (9) in comparison to aesthetic (10) within the ecosystem services group *aesthetic value*. Concerning *human health and well-being*, clean air provision (3) was prioritized. As to *bio-resource-provision*, food and fodder (1) was more important for the respondents than the provision of wood/timber (2). The variance of stated importance was highest for recreation/ecotourism (9) and aesthetic (10), followed by the economic services (12, 13), and local climate change mitigation (4).

The trends of the distribution of weights were similar for both weighting methods. Most notably was the preference of stakeholders towards recreation and ecotourism (9) compared to aesthetic (10) in the ecosystem service group *aesthetic value*, and the provision of food and fibre (1) in comparison to wood/timber (2) in the ecosystem service group *bio-resource provision*.

Table 6 shows that the impact of both weighting exercises on the assessment of the ecosystem service groups in our model regions is negligibly small for the final result obtained from the two different data gathering methods. Therefore, we dropped the results of the weighting exercise from the subsequent analysis of the differences between the data gathering methods.

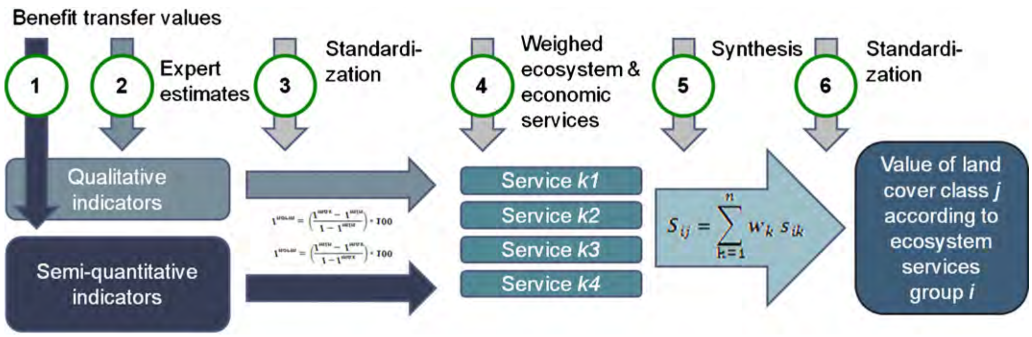

Fig. 4. MCA aggregation scheme for the combination of assessment data.

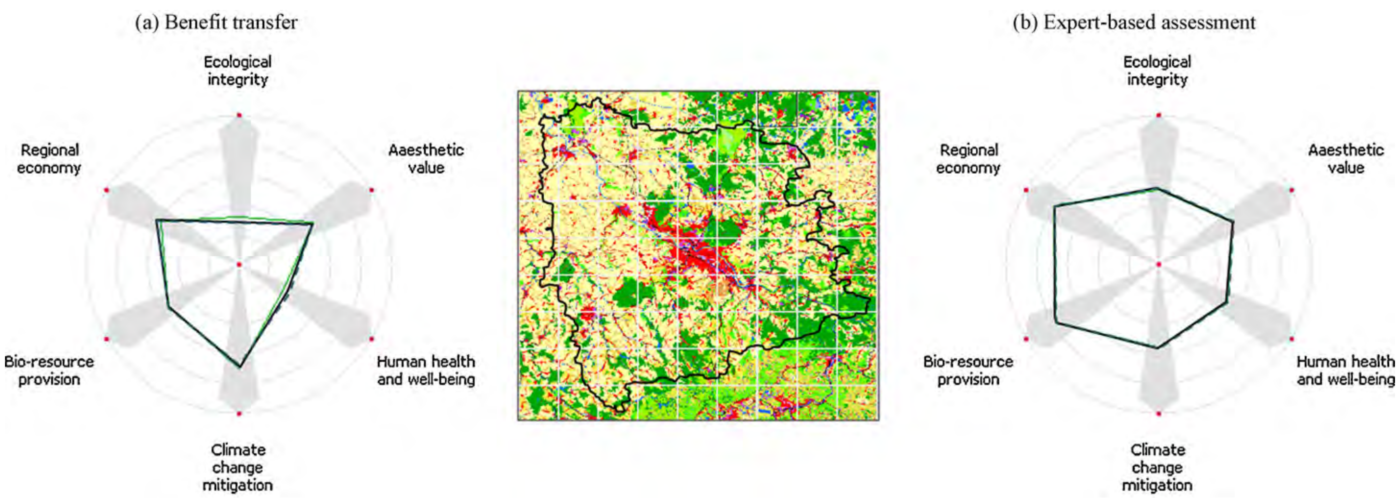

Fig. 5. Radar charts displaying the assessment results of the study region (map in the center) according to the six ecosystem services groups. (a) Results from use of mixed data derived mainly from benefit transfer. (b) Resulting radar charts when only data of the expert questionnaire are used. Lines indicate application of weights from AHP (grey), and Likert scale based preference elucidation (black). Results from aggregation with equal weights are shown as well (dashed line). Screenshots have been taken from PYL.

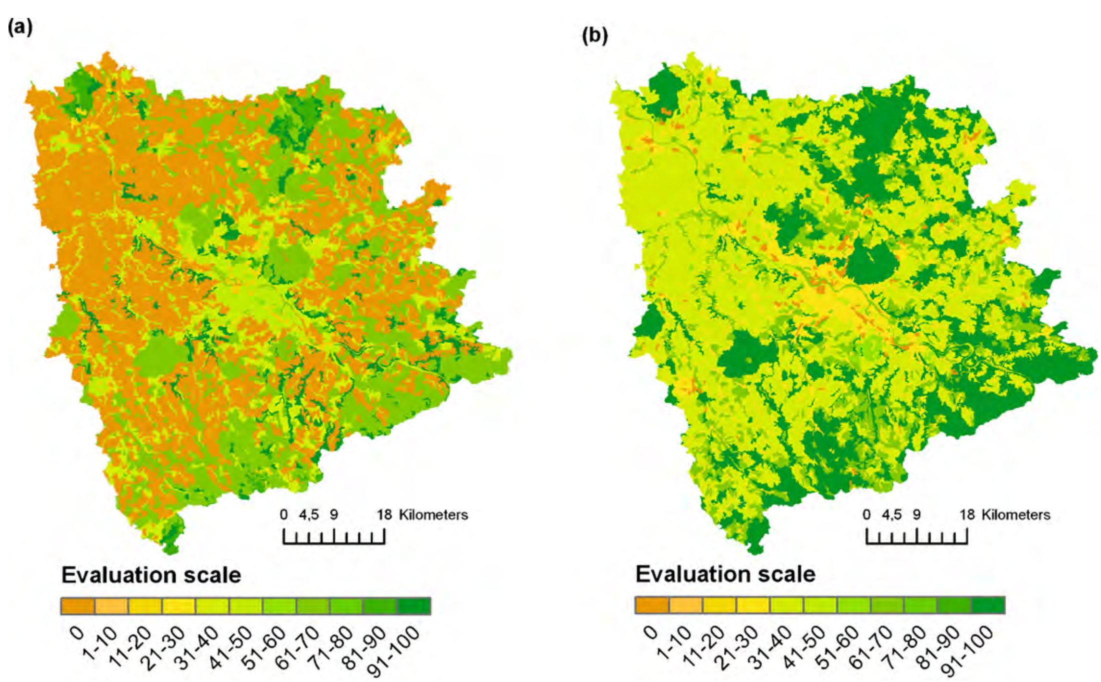

Fig. 6. Spatial distribution of the potential of the study region according to *contribution to ecological integrity* as a function of water balance regulation (6), clean water provision (7), and biodiversity (11), (a) benefit transfer, and (b) expert-based assessment.

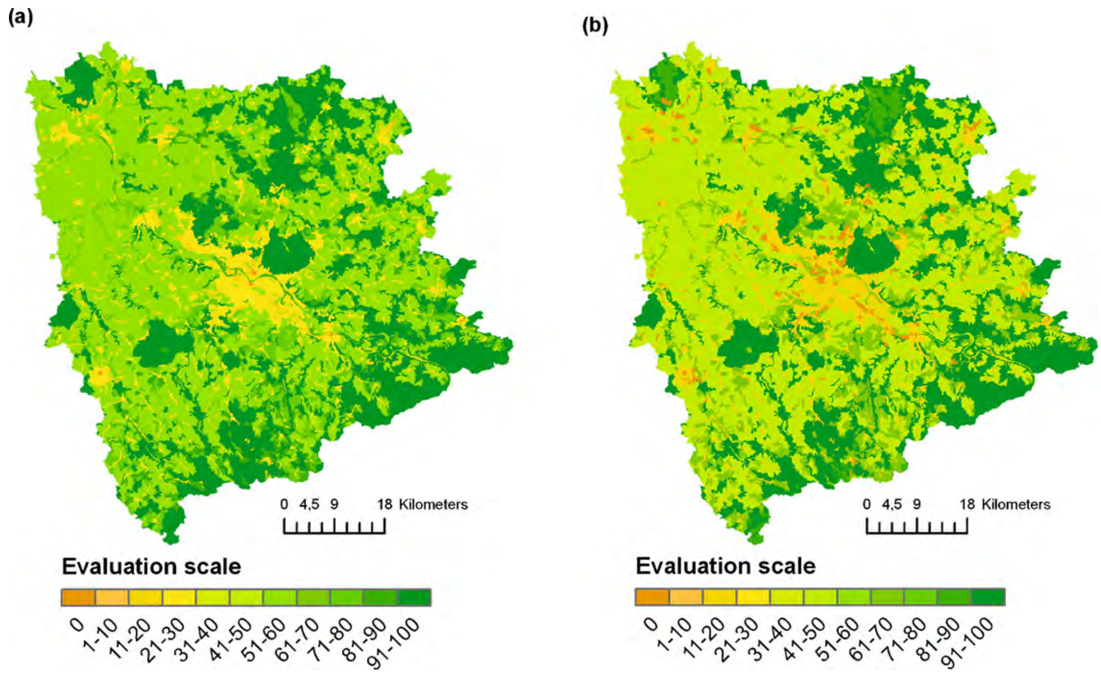

Fig. 7. Spatial distribution of the potential of *mitigation of climate change impact* in the study region as a result of aggregation of equally weighted services local climate regulation (4), global climate regulation (5), water balance regulation (6), and soil erosion protection (8), (a) benefit transfer data and (b) expert-based assessment.

Table 2
Applied services and their standardized indicator values (0–100) to assess ecosystem services and economic service on the basis of slightly regrouped CLC land cover types. Basic values were derived from data sources such as modelling and investigation results found in literature and look-up tables.

CLC-classes	Food and fibre 1	Wood/Timber 2	Clean air provision 3	Climate regulation (local) 4	Climate regulation (global) 5	Water (balance) regulation 6	Clean water provision 7	Soil erosion protection 8	Recreation and ecotourism 9	Aesthetic 10	Biodiversity 11	Returns from land-based pr. 12	Contrib. to overall value added 13
Continuous urban fabric	0	0	0	0	0	10	20	0	-	-	3	0	-
Discontinuous urban fabric	0	0	1	6	0	17	66	50	-	-	18	0	-
Industrial or commercial units, ports	0	0	0	6	0	3	20	25	-	-	26	0	-
Road and rail, construction sites	0	0	0	25	0	3	20	6	-	-	27	0	-
Mineral extraction sites	0	0	0	6	0	5	20	69	-	-	27	0	-
Dump sites	0	0	0	6	0	0	20	69	-	-	33	0	-
Urban green, sport and leisure facilities	0	0	3	81	25	40	66	69	-	-	26	0	-
Non-irrigated arable land	56	0	1	81	6	21	0	81	-	-	3	100	-
Fruit trees and berry plantations	100	0	29	56	50	50	60	88	-	-	35	100	-
Pastures	36	0	3	81	36	81	70	88	-	-	4	40	-
Complex cultivation patterns	28	0	11	100	14	38	35	88	-	-	9	32	-
Land princip. occ. by agriculture	28	0	3	100	14	21	56	88	-	-	8	32	-
Broad-leaved forest	0	78	100	56	100	90	71	100	-	-	77	11	-
Coniferous forest	0	100	82	56	100	80	49	100	-	-	23	10	-
Mixed forest	0	89	88	56	100	100	60	100	-	-	100	11	-
Natural grasslands	12	0	3	81	22	92	100	88	-	-	14	11	-
Moors, heathland, inland marshes	0	0	3	56	23	46	100	100	-	-	14	0	-
Transitional woodland-shrub	0	26	16	56	50	100	100	100	-	-	14	0	-
Water courses, water bodies	0	0	0	100	0	0	39	100	-	-	0	0	-

Table 3
Results of the qualitative expert questionnaires. Experts estimated according to eleven assessment categories that ranged from 0 (no relevant contribution) to 100 (maximum contribution). Depicted are the standardized mean values of all judgments.

CLC-classes	Food and fibre 1	Wood/Timber 2	Clean air provision 3	Climate regulation (local) 4	Climate regulation (global) 5	Water (balance) regulation 6	Clean water provision 7	Soil erosion protection 8	Recreation and ecotourism 9	Aesthetic 10	Biodiversity 11	Returns from land-based pr. 12	Contrib. to overall value added 13
Continuous urban fabric	0	0	0	0	0	0	0	0	0	26	6	0	89
Discontinuous urban fabric	10	10	10	11	0	10	5	15	5	37	22	5	78
Industrial or commercial units, ports	0	0	0	0	0	0	0	0	0	0	0	0	100
Road and rail, construction sites	0	0	0	0	0	0	0	0	0	0	0	0	50
Mineral extraction sites	0	0	0	0	0	5	0	0	0	0	6	45	44
Dump sites	0	0	0	0	0	0	0	10	0	0	0	0	11
Urban green, sport and leisure facilities	5	15	45	53	21	30	30	35	53	53	33	10	6
Non-irrigated arable land	100	25	35	42	42	35	20	30	26	26	28	100	44
Fruit trees and berry plantations	100	20	50	63	47	50	50	60	58	58	50	90	39
Pastures	60	10	50	58	47	60	50	60	63	68	61	60	22
Complex cultivation patterns	70	25	60	63	47	55	50	60	74	89	72	70	33
Land princip. occ. by agriculture	60	10	50	63	53	55	50	65	74	68	61	60	22
Broad-leaved forest	10	90	90	100	100	100	100	100	95	95	89	65	28
Coniferous forest	10	100	100	95	100	100	90	100	84	79	72	75	28
Mixed forest	10	100	100	100	100	100	100	100	100	100	100	70	28
Natural grasslands	15	0	50	63	68	80	80	90	84	89	94	20	0
Moors, heathland, inland marshes	5	15	50	63	74	90	85	90	95	95	100	0	0
Transitional woodland-shrub	10	30	70	68	74	75	80	95	95	95	94	25	0
Water courses, water bodies	30	0	20	68	21	70	45	0	95	95	44	35	22

Fig. 5 shows the differences in the estimation of the ecosystem service group provision resulting from the application of both methods (radar charts) for the total model region. The benefit transfer approach (left side) resulted generally in lower values for provision of the ecosystem services groups compared to the expert based assessment (right side).

The scores for the ecosystem service group's *contribution to ecological integrity*, *human health and well-being,* and *bio-resource provision* differed considerably. The benefit transfer method estimates them to be lower by 21, 15, and 25 points, respectively. Considering the ecosystem service group *contribution to ecological integrity*, the study region performed with 26 (benefit transfer-based) against 47 (expert-based) points. In contrast, *mitigation of climate change impact* scores 10 points better when the benefit transfer method is applied. Note however, that the data for the services recreation and ecotourism (9), aesthetic (10), and contribution to overall added value (13) could only be obtained from the assessment of expert-based assessment (Section 2.3.2). Therefore, comparison of *aesthetic value* and *regional economy* is biased and, strictly speaking, Fig. 5 is no true comparison of the two data gathering methods.

Ecosystem service group potential maps that illustrate the spatial differences of the two assessment approaches for the ecosystem services group's *contribution to ecological integrity* and *mitigation of climate change impact* are given in Figs. 6 and 7. In general, in the Southern and North-Eastern part of the study area, a concentration of the ecosystem services provision potential can be observed, while there is lower potential in the central part and especially in the North-West. Fig. 6a shows that using the benefit transfer method, the spatially explicit regional potential to contribute to ecological integrity are estimated to be lower compared to the expert estimation shown in Fig. 6b. In the case of the contribution to climate change mitigation, the results are vice versa: here, the benefit transfer method (Fig. 7a) estimates spatially explicit a higher regional potential compared to the expert assessment based results shown in Fig. 7b. These findings result mainly from the spatial distribution of the land cover class non-irrigated arable land and its different evaluation outcomes in both data gathering

Table 4
Correlation analysis of indicator-based and expert based data.

	Food and fibre 1	Wood/timber 2	Clean air provision 3	Climate regulation (local) 4	Climate regulation (global) 5	Water (balance) regulation 6	Clean water provision 7	Soil erosion protection 8	Biodiversity 11
Kendall-Tau	0.737	0.583	0.881	0.443	0.806	0.646	0.550	0.728	0.012
Spearman-Rho	0.819	0.652	0.956	0.603	0.899	0.781	0.720	0.780	−0.026

$N = 19$;Correlation is significant at the 0.01 level (two-tailed).

Table 5
Basic services used to assess the six ecosystem services groups defined in the REGKLAM region. Stakeholder weights that have been calculated from pairwise comparisons (AHP) and from an application of five evaluation categories (Likert Scale) are given, as well as standard deviations (SD). In addition, equal weights were used to test sensitivity of final evaluation of the six ES groups as a result of aggregation.

		AHP		Likert		Balanced (1/n)
	Service	Weights	SD	Weights	SD	Weights
Contribution to ecological integrity						
6	Water (balance) regulation	0.321	0.150	0.307	0.056	0.333
7	Clean water provision	0.434	0.237	0.351	0.041	0.333
11	Biodiversity	0.246	0.193	0.342	0.049	0.333
Aesthetic value						
9	Recreation and ecotourism	0.588	0.272	0.520	0.092	0.500
10	Aesthetic	0.412	0.272	0.480	0.092	0.500
Human health and well-being						
3	Clean air provision	0.426	0.192	0.353	0.045	0.333
7	Clean water provision	0.389	0.174	0.350	0.048	0.333
9	Recreation and eco-tourism	0.185	0.126	0.297	0.054	0.333
Mitigation of climate change impact						
4	Climate regulation (local)	0.255	0.178	0.249	0.083	0.250
5	Climate regulation (global)	0.196	0.165	0.253	0.056	0.250
6	Water (balance) regulation	0.218	0.114	0.248	0.055	0.250
8	Soil erosion protection	0.330	0.157	0.249	0.052	0.250
Bio-resource provision						
1	Food and fibre	0.659	0.226	0.553	0.073	0.500
2	Wood/Timber	0.341	0.226	0.447	0.073	0.500
Regional economy						
12	Income/Returns from land-based production	0.626	0.240	0.535	0.089	0.500
13	Contribution to overall value added	0.374	0.240	0.465	0.089	0.500

methods. Conversely for both data gathering methods, forest areas (land cover classes deciduous forests, mixed forests and coniferous forests) were estimated to be of highest importance for the provision of our two exemplary ecosystem service groups.

4. Discussion

Since there was the need to merge information sources of different origin and quality, the assessment of the REGKLAM ecosystem services groups was designed within a multi-criteria framework (cf. Helming, 2009; Kangas et al., 2001; Mendoza and Prabhu, 2003; Pérez-Soba et al., 2009; Schetke and Haase, 2008; Sheppard and Meitner, 2005).

Within this framework, the applicability of the benefit transfer approach for an integrated assessment was limited because of a lack of indicator data that matched the CORINE land cover classes. Indicators were only available for the land cover classes arable land, forests, pasture/grassland. The contributions of land cover types with minor regional importance for which very often no data could be found (e.g. fruit trees and berry plantations, complex cultivation patterns, land principally occupied by agriculture, with significant areas of natural vegetation, transitional woodland-shrub) could not be estimated. However, they might contribute considerably to the regional potential to provide ecosystem services – even more depending on their spatial distribution (Frank et al., 2012). The reduction of the real land use to land cover classes, such as they are provided by the CLC data set, can be considered as an important source for inaccuracy in this assessment approach (cf. Plummer, 2009). Furthermore, considering the often poor correlation of proxy data with primary data, it is very likely that benefit transfer as a basis for ecosystem services assessment leads to substantial error (Eigenbrod et al., 2010).

In contrast, expert based assessment reflects potentially the variety of possible land uses within a land cover class, management options within a land use practice, and also individual perception and experiences (de Groot et al., 2010). These factors led in our case to differences in the evaluation of services potential within a land cover class and to differences in the estimation of the regional potential to provide ecosystem services (Figs. 5–7).

As an example, *the contribution to ecological integrity* as shown in Fig. 6 was less well evaluated based on the benefit transfer method. Indicator-based values suggest here a rather negative performance of arable land, whereas in fact land use practices within this land cover class are subject to very detailed regulations considering good agricultural practices in the context of cross-compliance regulations. In Saxony, approximately 30% of agricultural land is managed with no-till practices, which reduce enormously the water erosion risk and contribute considerably to biodiversity (Anonymous, 2011). Also urban areas were evaluated too positively in benefit transfer due to a lacking applicability of indicators for this land cover class. This can indicate that expert based assessment can be more precise in assessing the impact of real land uses.

However, most recently critical reflections on the involvement of stakeholders in ecosystem services studies were published e.g. by Menzel and Teng (2009) and Seppelt et al. (2011a). In the ideal situation, all stakeholder and expert types should be evenly represented in order to prevent one stakeholder or expert type dominating the process and biasing the results (Pascual et al., 2010). Even if participation of stakeholders is an important part in studies related to ecosystem services and sustainable land use development (Hein et al., 2006; König et al., 2010; Menzel and Teng, 2009; Paracchini et al., 2009; Sheppard and Meitner, 2005) this requirement can be difficult to accomplish, at least from our experience.

We tested two weighting methods with different applicability. We identified two reasons that led to the use of the simpler Likert-scale method instead of the AHP. First, it turned out that people often had problems in discriminating between similar or related services, which may be assigned either to shortcomings in the design of the services list or to a lack of familiarity by the respondents with the services and/or the ecosystem services concept. Stakeholders articulated their frustration since it was difficult for them to decide if service x is more important than service y, even in a regional context. Accordingly, we observed low consistency ratios of AHP weights. Given that an inconsistency ratio of

Table 6
Assessment results of the study region according to the six ecosystem services groups. (a) Results from use of mixed data derived mainly from benefit transfer. (b) Resulting value points when only data of the expert-based assessment are used.

Ecosystem services groups	(a) Benefit transfer						(b) Expert-based assessment					
	Ecological integrity	Aesthetic value	Human health and well-being	Climate change mitigation	Bio-resource provision	Regional Economy	Ecological integrity	Aesthetic value	Human health and well-being	Climate change mitigation	Bio-resource provision	Regional Economy
AHP-weights	28	48	30	67	56	63	46	48	47	53	81	79
Likert-weights	26	48	31	63	56	65	47	48	47	54	81	80
Balanced weights	26	48	32	62	56	66	47	48	47	53	81	81

0.1 or less may be considered as satisfactory (Saaty, 2005), the inconsistency values were critical. Second, we got the feed-back that there was little motivation to participate in such a weighting experiment, which could be a result from of the numerous, time-consuming pairwise comparisons we asked to make. Stakeholders felt not motivated to spend more than a couple of minutes with such exercises. In comparison to the AHP method, the Likert-scale weighting method helped to avoid impossible prioritization of different services. The weighting was easier to accomplish and less time-consuming, which motivated more people to participate and yielded valid services weights as well. Because of its easier applicability and larger stakeholder acceptance, the Likert-scale weighting method turned out to be preferable.

Most participants at the AHP experiment and a considerable part of participants at the Likert-weighting were not willing to state personal data (professional background, etc.) for later analysis of stakeholder groups. Hence, we could neither address stakeholder groups to elaborate on reasons for differences of weights, nor could we ensure a balanced composition of stakeholder groups.

However, the preferences of stakeholders for services were not reflected in the overall assessment results as the impact of ecosystem services weights on the final values turned out to be negligible. The number of cells and the value of each land cover class had a greater effect on the overall values for the six ecosystem services groups calculated within PYL.

We have drawn two conclusions from the results and our experiences in the two applied data gathering methods and weighting approaches. First, an expert-based information basis can be of equal value compared to extended but inhomogeneous data compilations. Hence, we intend to apply for assessment of the regional potential to provide ecosystem services in the future expert-based assessments in combination with substantial information of the experts on indicator values to allow them to refer their estimations on a broad knowledge base. Second, we will exclude weighting of single ecosystem services or also indicator or criteria as this does not provide the expected information depth. The contribution of stakeholders might be more valuable in the initial phase of problem structuring and service definition. Here, it could be interesting to analyze stakeholder groups and their perception of issues or key ecosystem services at different (decision-making) levels. A simple and concise qualitative approach appears advantageous to keep the assessment transparent and to intensify and enhance the participation of stakeholders. This might contribute to a better understanding of the essential importance of ecosystem services to land-use planners and decision-makers for land use change.

Considering regional planning objectives, the importance of ecosystem services often differs between study regions and regional planning units. This makes necessary a prior analysis of regional priorities which might be defined in reference to the ecosystem services concept. Besides, there are other issues that are relevant for planning decisions but not captured within the ecosystem services concept, for example regional economy. To make the latter relevant for planners we attempted to incorporate economic services. This conceptual change is critical. First, the impact of ecosystems and their services on regional economy is difficult to assess. Second, apart from marketable and non-marketable ecosystem services there are economically important contributions (significant for the regional GDP) that are not related to ecosystems. These contributions appear to be very important for regional planning and land use decision making as they clearly impact regional economy. Therefore, the concept of landscape services might be more suited to support planning authorities (Bastian et al., 2011).

Objectives in regional planning are related to the question of how much area is needed for very specific (but not ecosystem related) services and which areas are available (and not needed for nature conservation, etc.). The ecosystem services concept is difficult to apply in regional planning because ecosystem services are often not directly relevant for area-related decisions. They tend to be related only indirectly to planning targets. Therefore, planning targets have to be translated to match landscape services and ecosystem services have to be linked to the demand for land needed in order to ensure their provision. To date there are no approaches available that could help to establish a link between ecosystem services provision and land requirements, e.g. for natural habitats, settlement area, and infrastructural area. Also, practice-oriented methods and tools to assess the ability of landscapes as reference units to provide ecosystem services are so far sparsely available and PYL therefore intends to close the gap between conceptual assessment frameworks and practical planning processes.

5. Conclusion

We applied a multi-criteria assessment framework, where different data gathering and weighting methods were exercised to assess the potential of a model region to provide ecosystem services-or in our case-ecosystem services groups. Based on the CORINE land cover data, we were able to demonstrate the impact of the two different data gathering methods on the spatially explicit estimation of the regional potentials, while the weighting approaches turned out to deliver negligible results. A benefit from our study was the opportunity to integrate both, expert based opinion and literature values. Integrative approaches are considered to be useful for communicating possible consequences of land use/land cover change. They are needed to take into account ecosystem services in spatial decision making (Bastian et al., 2011; Daily, 1997; Müller et al., 2011).

Also, most studies that aim at assessing or evaluating ecosystem services focus only on a few land cover classes, whereas we attempted an assessment including all present land cover types. Furthermore, mapping the allocation of ecosystem services is important because prior to developing conservation plans the location of ecosystem services provision is important (Daily and Matson, 2008; Naidoo et al., 2008). By producing maps that show spatially explicit the regional potential to provide ecosystem services, areas of conflicting goals could be identified. A problem we could reveal however is that different data gathering approaches lead to different appraisals of such areas. Based on our experiences, we conclude that expert estimation might be the more appropriate approach to estimate the regional potential to provide ecosystem services though the representativeness of expert or stakeholder groups in such an assessment was a problem we could not solve. The integration of regional actors (and experts) will remain an important component within further research activities, since the demand for transdisciplinary assessments increases, for instance in strategic environmental planning and environmental impact assessment (Clavel et al., 2011; European Parliament, 2001; Kienast et al., 2009; König et al., 2010; Menzel and Teng, 2009; Metzger et al., 2006)

However, there are a number of weaknesses which limit the applicability of our approach. The shortcomings are due to the several sources of uncertainty, which are related mainly to the highly aggregated information of the land cover data set, and missing data impacting the significance of the results. The use of coarse CLC land cover data remains a major challenge for working on ecosystem services. Data on the actual composition of forested areas or the management practices on agricultural sites, and knowledge of their impact on the provision of ecosystem services could probably be more useful to contribute to regional development planning. Therefore, an approach which combines high resolution land cover data and information on actual land management might be advantageous (c.f. Fürst et al., 2011). We agree that simplifications and reductions in information are a necessary tribute and have to be accepted for achieving a comprehensive picture of complex systems such as landscapes (Bastian et al., 2011; Daily, 1997; Müller et al., 2011).

When combined with complementary evaluation approaches with focus on land use practices and on the spatial allocation of land cover classes and land use types within the visualization and planning support tool PYL (Frank et al., 2012; Fürst et al., 2011), the presented approach to assess land cover classes is worthwhile and meaningful to support regional planners and resource managers to come to a sustainable and adapted landscape composition, to detect undesirable patterns, and, finally, to estimate the impacts of land use policies. The approach is suited for a generic comparison of different regions based on easily accessible CLC data. It could be of considerable significance to encourage discussion among stakeholders and communication of possible effects of land cover changes. Experiences we have made so far with regional planners show broad acceptance for qualitative assessments and the willingness to take into account conclusions that can be drawn from them, for example the prioritization of planning scenarios. Our actual work focuses therefore on testing alternative planning scenarios for afforestation and short rotation coppice corridors to contribute to an up-date of an exemplary regional plan in Saxony. In the process of up-dating the plan, we want to refine our methodology and learn how to make improved use of the ecosystem services concept as rationale for the prioritization of planning alternatives.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ecolind.2011.12.010.

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Research Highlights:

- A set of 30 regional specific crop rotations for a model region in Saxony was derived.
- We developed a procedure to classify regional agricultural land use.
- The procedure was integrated into a spatial Decision Support System.
- We could identify areas of high potential soil erosion risk and the reduction potential of different soil protection techniques.

A methodological approach how to combine regional crop sequences and agricultural management as input data for regional assessment systems

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Abstract

Against the background of global changes in relation to climate, economy, ecology or population, for example, assessment of the impacts of different land use practices on regional and landscape scale is of increasing interest. Especially to assess agricultural practices several approaches and models exist. Mostly they depend on the assessment of single crops or statistical data of crop cultivation. Information of applied crop rotations is scarce and highly aggregated in most cases. Therefore considerable uncertainties exist in relation to crop rotations and management data. Based on this, more or less general conclusions about the impact of agricultural practices could be drawn and regional specifics are often neglected or rather could not be considered in an appropriate way.

To manage future sustainable developments by assessing agricultural practices, a procedure was developed to (i) derive representative regional crop rotations as a basis for the agricultural production systems, by combining different data sources and expert knowledge, (ii) regionalise agricultural practices and systems on landscape scale on the basis of a variety of field data and the corresponding crop rotations, tillage systems and field management and (iii) integrate innovative cropping systems like no-till techniques, energy crops or organic farming, including different soil tillage, soil management and soil protection techniques.

The developed procedure to classify regional agricultural land use was integrated in the spatial decision support system (sDSS) GISCAME to derive and assess the regional environmental impacts. In this paper the procedure, data requirements as well as first results for a study area around the city of Dresden (Saxony, Germany) were described.

Keywords: crop rotation; agricultural practices; soil protection; climate change

1. Introduction

As part of the research on climate change, land use, land use change and the corresponding regional consequences on landscape scale have received increasing attention. Among others (forestry, urban and infrastructural areas) agricultural land use is worldwide one of the main land uses: about 38 % of the global land area (FAO-Stat 2012) and over 40 % of land in the EU is used for agriculture (EuroStat 2012). In Germany, the agricultural area amounts to 48 % (FAO-Stat 2012) and in Saxony to 49.6 % (LfULG 2011a), respectively. Agriculture is mainly characterised by different practices in relation to crop rotation, soil tillage techniques, fertilizer management etc. Therefore, assessment of the impacts of different land use and management practices on regional and landscape level are of increasing interest.

Particularly for the assessment of agricultural management practices, several different approaches and models exist. Usually they depend on the assessment of single crops and statistical data of crop cultivation. On the other hand a variety of models is available to derive crop rotations by so-called expert knowledge (e.g. Rode et al. 2009) or combinations of statistical data and expert knowledge (e.g. Schönhart et al. 2011, Castellazzi et al. 2008, Bachinger & Zander 2006, Dogliotti et al. 2003 Stöckle et al. 2003). However, information regarding applied crop rotations is scarce and highly aggregated in most cases.

Generally, applications of crop rotations can be found in bio-physical process models or economic models on farm level (Janssen & van Ittersum, 2007, Renton & Lawes 2009). Most bio-physical process models use crop rotations to derive different environmental impacts (e.g. Bechini & Stöckle 2007, van Ittersum et al. 2008), whereas economic farm models optimise farm economy and management (Rounsevell et al. 2003, Dogliotti et al. 2003; Piorr et al. 2009). Auerbacher & Dabbert (2011) presented a method to bridge the gap between farm management models and bio-physical process models in generating crop rotations by using maximum entropy and Markov chains.

One of the main problems in using crop rotations in integrated land use modelling frameworks is the lack of empirical data (Schönhart et al. 2011). Therefore the implementation is often based on selected case studies, farm surveys or expert and modeller knowledge (e.g. Belcher et al., 2004; van Ittersum et al., 2008; Rode et al., 2009), whereas the real applied crop rotations, especially on regional scale, are unknown. Furthermore, the spatial scale of land use models varies from single farm level to catchment, sub-regional or regional level and it pursues different objectives (e.g. varying environmental impacts, economic benefits, management strategies and optimisation etc.)

Additionally, spatial allocation of crop rotations and cropping systems play a fundamental role, but is also a tender point and a source of uncertainty in deriving environmental impacts on regional scale. A variety of approaches and models exist on farm and regional level (e.g. Rounsevell et al. 2003, Castelazzi et al. 2007, Thenail et al. 2009, Dury et al. 2010, Leenhardt et al. 2010).

Hence, considerable uncertainties in the models in relation to crop rotations and management data, as well as to their spatial allocation exist. Based on this, more or less general conclusions about the impact of agricultural practices could be drawn and regional specifics are often neglected or rather could not be considered in an appropriate way. On the other hand reliable assessments of the impacts of different land use practices and land use patterns on landscape scale were necessary to assess, plan, manage and control future sustainable developments.

Furthermore, agricultural land use has to fulfil a variety of duties, responsibilities and objectives (e.g. sustainable production of high quality food, provision of environmental- and ecosystem-services). Additionally, agricultural production is subject to many requirements and restrictions e.g. with the aim of preventing harmful impacts on the environment.

To represent these objectives and effects, a procedure was developed to classify agricultural management practices and cropping systems on regional and sub-regional scale. As a basis of the agricultural production systems, regionally specific crop rotations were derived and combined with corresponding tillage systems and field management. Furthermore, these agricultural practices and systems were regionalised on landscape scale on the basis of a variety of field data, including crop rotations, tillage systems and field management. Together with other land uses (e.g. forestry, urban and infrastructural areas) the procedure was integrated in the spatial decision support system (sDSS) GISCAME (Fürst et al., 2010 a, b; Fürst et al., in rev.) and thus the regional impacts of agricultural land use on ecosystem services can be derived and assessed.

2. Material and methods

2.1. Study area and agricultural sub-regions

The study area is located in Saxony in the eastern part of Germany around the city of Dresden with an area of 4,800 km^2 (figure 1). The model region is very heterogeneous in terms of different soil, climate, altitude, relief, precipitation and water conditions, from diluvial sandy dry regions in the north to low mountain conditions in the south (cf. table 2). This results in a broad variety of agricultural land use and management systems, depending on and adapted to the basic conditions.
According to Winkler et al. (1999) Saxony can be divided into 12 sub-regions by basic natural terms and conditions for agricultural production, e.g. soil conditions, climate, water supply, altitude, relief and other factors with relevance for agricultural production (figure 1).

Figure 1: Location and agricultural sub-regions of Saxony (according to Winkler et al. 1999)

The model region cuts off parts of the sub-regions (1) Lausitzer Heide- und Teichgebiete, (2) Lausitzer Platte, Oberlausitzer Bergland, (3) Elbsandsteingebirge und Zittauer Gebirge, (4) Nördliche Erzgebirgsabdachung, (5) Erzgebirgskamm, (7) Mittelsächsisches Hügelland and (8) Mittelsächsische Platte, respectively.

Due to the requirements of preliminary planning of agricultural structure and the analysis of agricultural statistics, Winkler et al. (1999) has aggregated the 12 sub-regions to 5 **r**egions of **s**imilar **a**gricultural **s**tructure (RSAS; table 1), by merging a very detailed planning level with a more imprecise structural planning.

Table 1: Aggregation of 12 sub-regions to 5 regions of similar agricultural structure

Within the procedure of classifying agricultural land use, crop rotation data is aggregated from sub-regions (SR, higher resolution, see figure 1), over regions of similar agricultural structure (RSAS, see table 1) to soil type regions (STR, see also figure 2). The main characteristics, region related risks and impacts of climate change of the STR´s are shown in table 2.

Table 2: Characteristics of the main agricultural soil type regions (STR) in the study area (according to LfULG (2009), Bernhofer et al. (2009), Mirschel et al. (2010))

Considering the application of our agricultural practices classification approach, we focussed on the three STR´s in the entire model region. Only for validating the results, a comparison to previously un-used statistical data (LfULG 2011b) of sub-region 3 (Elbsandsteingebirge) is conducted. Sub-region 3 was used, because it is the only sub-region which is completely present (a) in our model region and (b) in all available statistical data from agriculture (see chapter 3.3).

2.2. Methodological approach

To integrate the developed procedure to classify regional agricultural land use into the sDSS GIS-CAME (Fürst et. al 2010 a, b) some system-based requirements have to be taken into account, for instance, effects of periods less than a year can not be considered in the simulation and assessment of land use / land cover changes and spatial resolution is limited to maximally 625 m² per grid cell in the system specific raster presentation of the land use / land cover pattern. The main focus of GIS-CAME is a multi-criteria, long-term impact assessment of different land use systems on landscape and regional scale. Therefore the agricultural classification is based on different requirements:

1. The regional differentiation of the basic requirements for agricultural production by Winkler et al. (1999) was integrated in the system.
2. Different available data-bases and expert knowledge were used to determine i) the regional specific crop rotations ii) the share and distribution of single crops in the observed sub-regions and iii) the interaction between crops (allelopathy, effects of previous crops, e.g. soil conditions, fertilizer efficiency, disease management etc.) by using an expert knowledge-based crop rotation table (Kolbe 2008). Additionally, different farm types (cash crop farms, mixed farms, as well as organic farming) in relation to their crop rotation were considered.
3. The variety of regional crop sequences was combined with soil tillage techniques (i.e. ploughing, conservation tillage, no-till) and other management measures, and was regionalised on landscape scale on the basis of a variety of field data to analyse and assess their environmental impacts (e.g. soil erosion).

Figure 2: Scheme of the methodological approach (procedure: italic, results: bolt)

2.2.1 Crop rotations

Crop rotations play a central role in agricultural land use systems. They affect the economic benefits and the environmental impacts of cropping systems as well and are important for the application and implementation of sustainable agricultural systems (Leteinturier et al. 2006). Crop rotations influence the whole agricultural management, for example nutrient supply and efficiency (Smith et al. 2008), nutrient leaching (Broussard and Turner 2009), suppression or promotion of pests and diseases and type and technique of soil tillage. Furthermore, a diverse and regionally adjusted crop rotation can split and lower the farm risks due to weather-related extreme events (Howden et al. 2007).

To (i) bridge the gap between crop rotations derived from statistics and expert knowledge and those derived from real applied crop rotation experience, and (ii) to identify crop sequences with high spatial representation, different data sources were combined:

1.) statistical data

The available statistical data were used as basic input for the classification procedure (a) and validation of its results (b).

a) The Federal State Office of Statistics Saxony provides annual data about agricultural statistics of crop mixes in Saxony (e.g. StaLa 2010). The spatial resolution of most data is limited to the entire state of Saxony.

b) Average observed crop mix data from 2005-2010 have been derived from the AFISS-system (agriculture and forestry information system of Saxony), which includes a nearly full representation of arable land in Saxony. Data are available on the level of the mentioned sub-regions (see figure 1) and were used for validation.

Figure 2 shows the relative share of crops in Saxony from both data sources (1a. StaLa 2010 and 1b. AFISS system (LfULG 2011b), on the level of sub-regions).

Figure 3: Shares of single crops in Saxony (StaLa 2010, AFISS 2011) and in the sub-regions (SR, AFISS 2011)

2.) Field data

To derive crop rotations with a high regional and spatial representation, a huge variety of different field data (~ 8000 arable fields; LfULG 2010) were examined in relation to their crop sequences, pre-crop – main-crop (pc-mc) combinations and the share of single crops. Therefore available data from the years 2003-2009 (LfULG 2010) were analysed. The data were generated from permanent observation plots, agricultural assistance, agricultural advisory and different research projects.

3.) Expert knowledge-based crop rotation table

Considering the classification of crop rotations, a variety of more or less regionally specific crop rotation tables is already available (e.g. Schönhart et al. 2011, Vullioud 2005, Kolbe 2008). These tables were primarily derived from expert knowledge of crop cultivation and management in the observed region and generally provide recommendations for pc-mc combinations. Differences in pc-mc combinations between crop rotation tables result from different recognition of the impact of factors such as sowing and harvesting dates, nutrient availability and use, pest and disease transmission etc., regionally specific differences and experiences as well as different background of the consulted experts (agronomy, ecology, economy etc.). For the conditions of Saxony, Kolbe (2008) developed a crop rotation table (see figure 4), which provides information on very favourable to impossible pc-mc combinations.

Figure 4: Crop rotation table (according to Kolbe 2008)

In addition to the crop rotation table, Kolbe (2008) provides complementary information, for instance, related to drought stress problems, intercropping as a measure against water erosion and nutrient leaching, optimal choice of pre-crops, repressing and promotion of pests and diseases, and on self-tolerance of crops.

2.2.2 Erosion risk

A main part of the GISCAME-tool is the consideration and integration of risk parameters. With a distinct spatial allocation, areas with high potential long–term soil erosion can be identified and target-orientated measures can be derived.

As an example for one of the observed environmental impacts in GISCAME, the method to derive spatial information of the soil erosion risk was described in the following.

Within the GISCAME-tool the long-term erosion risk was calculated (equation 1) by use of the universal soil loss equation (USLE/RUSLE; Wischmeier & Smith 1978, Renard et al. 1991, Schäuble 1999). The equation includes six factors: the rainfall erosivity factor (R), the soil erodibility factor (K), the topographic factors (L = slope length and S = slope steepness) and the cropping management factors (C = cover and management and P = support practice) to predict the long-term average annual soil loss (A; [t/(ha y)]):

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad \text{(equation 1)}$$

In GISCAME these factors were calculated for every single grid cell. Together with hydrological data the erosion and deposition of soil can be derived. Figure 5 shows the spatial information of the K and S factors (LfULG 2008) for the study area.

Figure 5: Potential long-term water erosion risk by spatial displaying of the K and S factors of the USLE/RUSLE for agricultural areas in the model region (according to LfULG 2008).

The R, K, L and S factor-layers in GISCAME are grid-cell-wise complemented with the agricultural land use (C and P factors), i.e. crop rotations in combination with different soil tillage techniques. To derive C-factors for the regional crop rotations (see table 3) the method of Hiller & Bräunig (2009) is used: in their approach, region and crop specific dates of sowing, emergence and harvesting, as well as the soil coverage ratio are used on a daily basis and are therefore not directly applicable within GISCAME. As a consequence, we used their data to calculate the C-factors for every single crop rotation in consideration of regional differentiations, temporal shares of R factors and different soil tillage techniques (ploughing, conservation tillage, no till).

Additionally, the water erosion tool considers linear elements like hedges or tree rows (according to Volk et al. 2010, Schäuble 1999) and erosion gullies (Voß et al. 2010).

3. Results and discussion

3.1. Classification scheme

To (i) summarize the main representative agricultural land use management on the basis of crop rotations combined with soil tillage techniques and field management on regional scale, (ii) derive reliable results for the environmental assessment and (iii) integrate the procedure in the GISCAME-tool, a classification of regional agricultural land use was performed. The classification scheme of agricultural land use systems is shown in figure 6.

Figure 6: Classification scheme of agricultural management systems

As a first and most important classification criterion to express the site potentials and the hereon based eligibility of crops and their sequences, we identified the soil type. From agricultural management point of view (productivity, nutrient and water availability) and with respect to the corresponding crop rotations, the model region is divided into three major soil types, namely sandy soils, loess soils and soils originating from deeply weathered bed rocks (LfULG 2009, cf. Table 2).

As second classification criterion, the farm type was selected due to its considerable influence on the de facto practiced crop sequences. For instance, cash crop farms tend to mainly focus on shorter and intensive crop sequences to optimise the biomass output and economic benefit, without livestock breeding. In mixed farms with livestock breeding, cash crops and fodder production define the cultivated crop sequences. In contrast, organic farms tend to multifaceted crop sequences to better make use of water and nutrient potentials and to enable pest management. Additionally to the classical farm types, the option of cultivating energy crops was included.
Based on these classification criteria, 10 favourable crop rotations were finally derived for each of the three soil type regions.
Finally, the set of crop rotations were combined with three tillage systems (ploughing, conservation tillage and no-till) to consider technical soil management impact on potential risks such as soil erosion or drought.
The limitation to 30 additional agricultural management classes was a consensus with regard to the parallel integration of additional forest management classes (Fürst et al., 2011; 2012) and intended to provide a proper base for assessing the impact of different agricultural and forest land management strategies on the provision of ecosystem services in qualitative manner on a scale from 0 (no / worst provision of services) to 100 (highest possible provision of services). A more detailed classification resulting in an even higher number of classes would have provoked problems in assessing the differences between the additional land use classes and compared to the Corine Landcover (2006) classes which are applied for non-agricultural and non-forest areas. However, the comparison to results of the crop rotation optimisation model CropRota (Schönhart et al. 2011) for the mentioned sub-regions of

Saxony shows a spatial representation of more than 80 % of the observed crop land for a limitation of 10 crop rotations (Lorenz et al. 2012).

3.2. Crop rotations

Regionally specific crop rotations are a basic requirement for deriving regional agricultural cropping systems and for regional assessment of the environmental impacts of agricultural land use. Mostly, statistical data at different spatial resolution are used as input data in several modelling frameworks (e.g. Schönhart et al. 2011, Castellazzi et al. 2008, Bachinger & Zander 2006). In this approach statistical data (see chapter 2.2.1) were applied for ranking the share of crops within the set of 30 crop rotations. Additionally, the huge variety of field data was bundled to identify (i) regional iterant crop sequences, pc-mc-combinations, length of crop rotations and the frequencies of crops and, with respect to the corresponding sub-regions, to ii) consider regional differences in agricultural cultivation, management and crop rotations

As an example of pc-mc combinations, figure 7 shows the shares of pre- and post-crops of winter-wheat (cf. figure 2), which is cultivated on around 30 % of the agricultural area of our model region and is also part of around 68 % of the available crop rotations. The dominating pre-crop of winter-wheat is winter-rape, mainly due to the excellent agronomic conditions and effects on winter-wheat, and the economic benefits of both crops. The main post-crop of winter wheat is winter barley. Silage corn plays a similar role as pre- and post-crop of winter wheat, but might provoke phyto-sanitary problems (Fusarium spec.), which are estimated to be increased in the future as a result of an augmenting benefit of this crop sequence due to the high demand in and the market prices for energy crops. Furthermore, the share of self-repetition of each crop in a crop rotation was analysed. For instance, on 4.2 % of the agricultural area in the model region, winter wheat precedes itself (see figure 7).

Figure 7: Share of pre- and post-crops of winter-wheat in the model region

Finally, we calculated how often each of the crops is included in the crop sequences for a seven year observation period and the entire model region. Figure 8 shows again results for winter wheat, which is used in most cases one or two times, only partly three times in the available crop rotations.

Figure 8: Share of winter-wheat on the corresponding crop rotations (7-years)

As a next step for the identification of regional crop rotations, figure 9 provides an overview on the eligible crops and their percentage distribution on level of the regions of similar agricultural structure (RSAS; Winkler et al., 1999). Comparing the eligible crops and their percentage distribution shows nearly similar results for RSAS 2 and 3 especially for the main cultivated crops (see figures 2 and 9). By contrast, the crops and their shares differ considerably for RSAS 1 and 4.

Figure 9: Percentage distribution of crops in the observed region in relation to sub-regions (SR) and regions of similar agricultural structure (RSAS).

So, the RSAS 2 and 3 were aggregated. As a result, 3 main agricultural regions can be distinguished in relation to the main basic requirements (cf. table 2).

Based on the information on the eligible crops per RSAS, their percentage distribution (Fig. 9) and the statistical analyses on pre-, major and post-crops and our three classification criteria, we could finally derive typical regional crop rotations, which can be assessed considering their economic and ecological impact. Table 3 provides an overview on our 30 crop rotations and gives information on the resulting C-factors related to different soil management techniques. In addition to the mentioned basic concept, one crop rotation was integrated to reproduce the conditions of perennial grass or fodder production on arable land (A1). As example clovergrass was chosen, because of its spatial representativeness in the model region.

Table 3: crop rotations and corresponding indicators of soil erosion (C-factors), (w: winter, s: summer)

Most of the crop rotations are only applicable for one of the soil type regions, but some of them such as winter rape – winter wheat – winter barley (D1, L1, V1) or winter rape – winter wheat – silage corn – summer barley (D2, L3, V2) are eligible in all three soil type regions. However, taking the C-factor as an exemplary indicator of the ecological-economic impact of the agricultural management practices (table 3), these apparently ubiquist crop rotations have to be assessed separately for each of the soil type regions.

3.3. Spatial allocation of the crop sequences

Within the sDSS GISCAME, the spatial allocation of regional crop sequences plays a fundamental role for the assessment of land use systems on regional scale. Empirical data on crop rotations are only available for a limited number of fields in the model region and the maximal spatial resolution of 625 m² in the spatial representation of the land use / land cover pattern in GISCAME limits the integration of finer details. To generate a suitable dataset for GISCAME, data of the main crop on field block level (field block: group of fields / management units) of the years 2007-2010 (LfULG 2010) was used to spatially allocate the best corresponding crop rotation. Crop information for field blocks was available for the entire study area. Furthermore, the occurrence and share of different farm types and existing biogas plants (LfULG 2010) were taken into account to allocate the set of crop rotations as close to reality as possible, considering the spatial representation of each crop and crop rotation in the sub-regions. For more than 75 % of the study area a semi-automatic spatial allocation of the derived crop rotations could be realized, whereas for the remaining area a manual fitting was conducted.
As a result an initial spatial distribution of the crop sequences could be derived (figure 10) and forms the reference (business-as-usual, BAU) for simulating changes in agricultural land use. It should be highlighted that the focus on meso-scale (region), the limited spatial resolution (625 m² / grid cell) and the raster representation of the land use in GISCAME exclude simulating agricultural strategies at farm scale.

Figure 10: spatial allocation of the derived crop rotations in the model region (see also table 2)

To validate our results, the derived crop rotations (table 3) were applied and spatially allocated in sub-region 3. The percentage distribution of crops was calculated for the entire sub-region and compared to previously unused statistical data of the AFISS-system for sub-region 3, RSAS 2 (figure 11).

Figure 11: Comparison of the results with statistical data of the AFISS-system in sub-region 3

In general, there was a sufficient coincidence between the different data sets. Differences were largest for winter-rape and summer-barley with a slight over-representation in the modelled data. This over-representation results from the combination of statistical data and real applied crop rotations, and from the use of a crop rotation table, which represents an optimisation tool for crop rotation design. The maximum deviation of the modelled data is 3 % of arable land for winter rape. The deviations are slightly higher in other sub-regions, because they are not completely represented in the observed model region (cf. figure 1), but in the maximum < 10 % of the particular arable land.

3.4. Erosion risk

To test the applicability of our crop rotations for assessing the ecological-economic impact of agricultural practices, we focussed on a 100 km² large test area in the sub-region 3, RSAS 2. The share of arable land in this test area is 56.7 % on deeply weathered bed-rock soils. Based on the business-as-usual reference, we simulated the impact of different crop rotation scenarios on water erosion including soil management techniques. To simplify the structure and assessment of the scenarios, we assumed that each of the eligible regional crop rotations was applied for the total agricultural land in the test area. To calculate the mean soil erosion, the mentioned C-factors of crop rotations (table 3) are grid-cell-wise complemented with the R, K, L and S factor-layers in GISCAME. Table 4 provides an overview on selected results.

Column B shows the mean soil erosion [t/(ha *y)] for the crop rotations depending on the three different soil management techniques. Column C shows the % reduction of the mean soil erosion by the three soil management techniques compared to ploughing. With ploughing the maximum difference of soil erosion between the crop rotations is 66 % (table 4). This is a result of how long, at which time period and how intensively soil is covered by the crops. Best results can be identified for crop rotations with only winter grains (e.g. V1). The highest soil erosion occurs for crop rotations with a high share of summer crops (e.g. V3), excluding the aspect of intercropping. With decreasing soil tillage intensity, the differences in soil erosion become smaller. The maximum difference between the crop rotations when applying conservation tillage is about 29 % and with no-till techniques about 8 %, with nearly similar soil erosion values for all crop rotations.

Table 4: Mean soil erosion [t/(ha*y)] of the regional crop rotations in the selected sub-study-area

Second, the differences between the soil management techniques “conservation tillage” and “no-till” were checked against the corresponding ploughing values. On average, a reduction in mean soil erosion of about 80 % can be achieved with conservation tillage and nearly 88 % with no-till techniques.

When upscaling to the total test area and considering also other land use types (e.g. forestry, infrastructural areas), a range of +19 % to -22 % in soil erosion can be achieved. This underlines the great influence of agricultural management decisions on soil erosion risk at regional scale.

4. Conclusions and outlook

So far, the great variability of agricultural practices complicates the assessment of positive or negative agricultural land use strategies. Often, detailed and spatially explicit information on cultivated crops, crop sequences and applied soil management techniques is missing. In consequence the benefits or risks arising, for instance, from a higher variability or homogenisation of agricultural practices in the cultural landscape cannot be assessed or are underestimated. This missing information and evaluation basis however hinders the assessment of regional development or funding policies and therefore might provoke a non-purposive allocation of public financial means. As a request, simplifications however with respect to spatial and statistical representativeness of the agricultural use have to be made. The presented approach how to classify agricultural land use by defining a limited number of representative crop rotations and corresponding agricultural management techniques supports to simplify and spatial allocate agricultural practices and to make them accessible for meso-scale impact assessment tools such as GISCAME. Furthermore, these are the essential requirements for deriving and assessing the impact of agriculture on the environment, e.g. soil erosion, and developing strategic targets for future sustainable development on regional and sub-regional scale. Based on our simulations, we could (i) identify areas of high potential soil erosion risk and (ii) analyse and assess the influence of agricultural land use systems on soil erosion at regional and sub-regional scale. Finally, different land use scenarios could be tested to come up with an optimisation of the agricultural land use pattern. The derived set of 30 regionally specific crop rotations offers a wide range for further model studies for the area of Saxony. The developed methodological approach can be transferred to other regions with comparable input data sources.

It should be pointed out, that a pure spatial optimisation of the agricultural land use with regard to water erosion risk might provoke negative trade-offs regarding the rural income situation and food and biomass security. Therefore, enhancement of the observed regional environmental impacts in relation to stability and development of crop yields, vulnerability to drought stress, nutrient leaching and changes in soil organic carbon content shall be implemented. Furthermore, an additional step is planned to integrate further soil protection techniques and agricultural practices like intercropping, strip tilling etc.

Based on this, the future impacts and effects of the stated agricultural land use systems (i.e. crop rotations combined with soil tillage, fertilisation etc. on regional and sub-regional scale) can be better derived and assessed.

6. Acknowledgements REGIOPOWER

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Figure captions:

Figure 1: Location and agricultural sub-regions of Saxony (according to Winkler et al. 1999)

Figure 2: Scheme of the methodological approach (procedure: italic, results: bolt)

Figure 3: Shares of single crops in Saxony (StaLa 2010, AFISS 2011) and in the sub-regions (SR, AFISS 2011)

Figure 4: Crop rotation table (according to Kolbe 2008)

Figure 5: Potential long-term water erosion risk by spatial displaying of the K and S factors of the USLE/RUSLE for agricultural areas in the model region (according to LfULG 2008).

Figure 6: Classification scheme of agricultural management systems

Figure 7: Share of pre- and post-crops of winter-wheat in the model region

Figure 8: Share of winter-wheat on the corresponding crop rotations (7-years)

Figure 9: Percentage distribution of crops in the observed region in relation to sub-regions (SR) and regions of similar agricultural structure (RSAS).

Figure 10: spatial allocation of the derived crop rotations in the model region (see also table 2)

Figure 11: Comparison of the results with statistical data of the AFISS-system in sub-region 3

Table captions:

Table 1: Aggregation of 12 sub-regions to 5 regions of similar agricultural structure

Table 2: Characteristics of the main agricultural soil type regions (STR) in the study area (according to LfULG (2009), Bernhofer et al. (2009), Mirschel et al. (2010))

Table 3: crop rotations and corresponding indicators of soil erosion (C-factors), (w: winter, s: summer)

Table 4: Mean soil erosion [t/(ha*y)] of the regional crop rotations in the selected sub-study-area

Figure1

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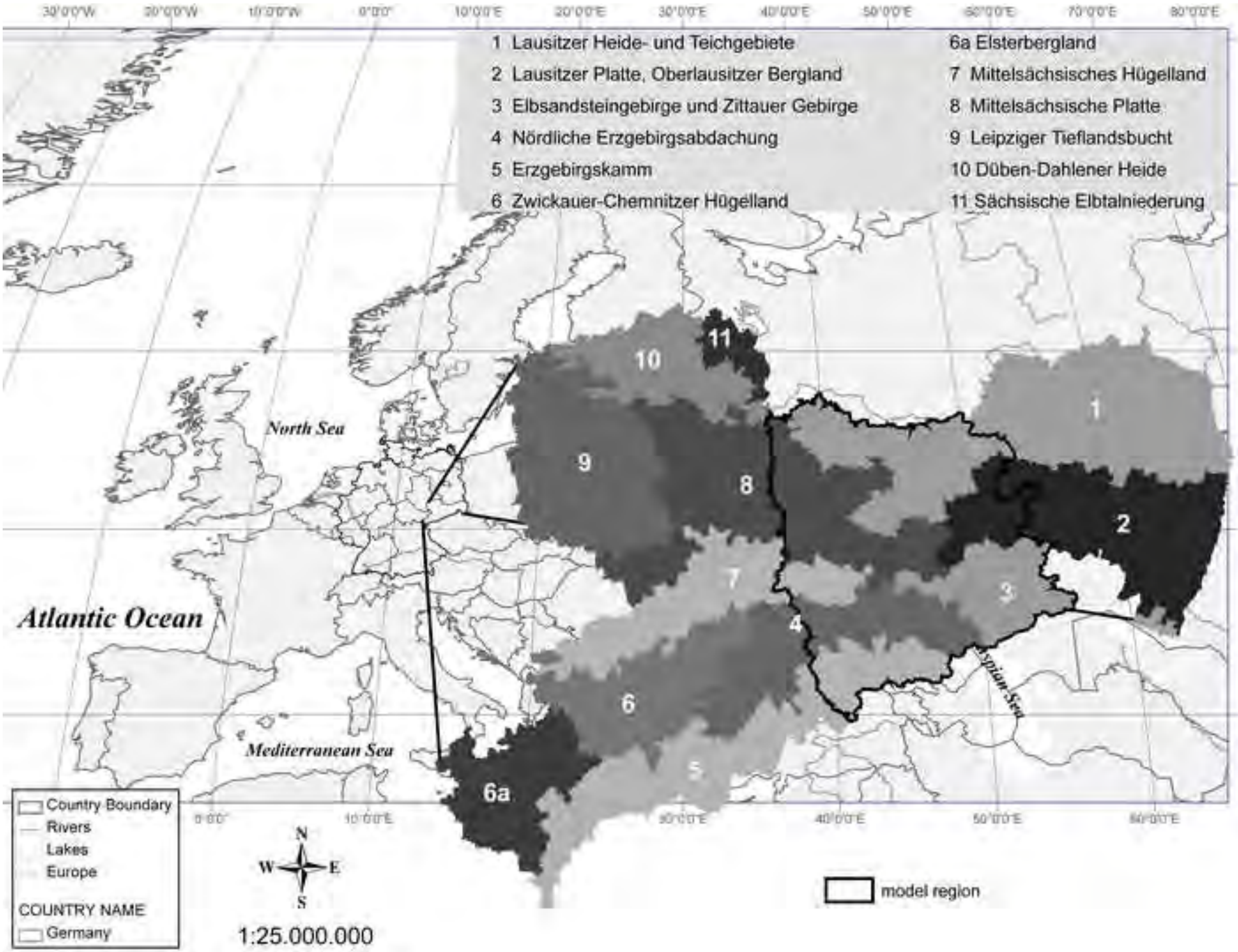

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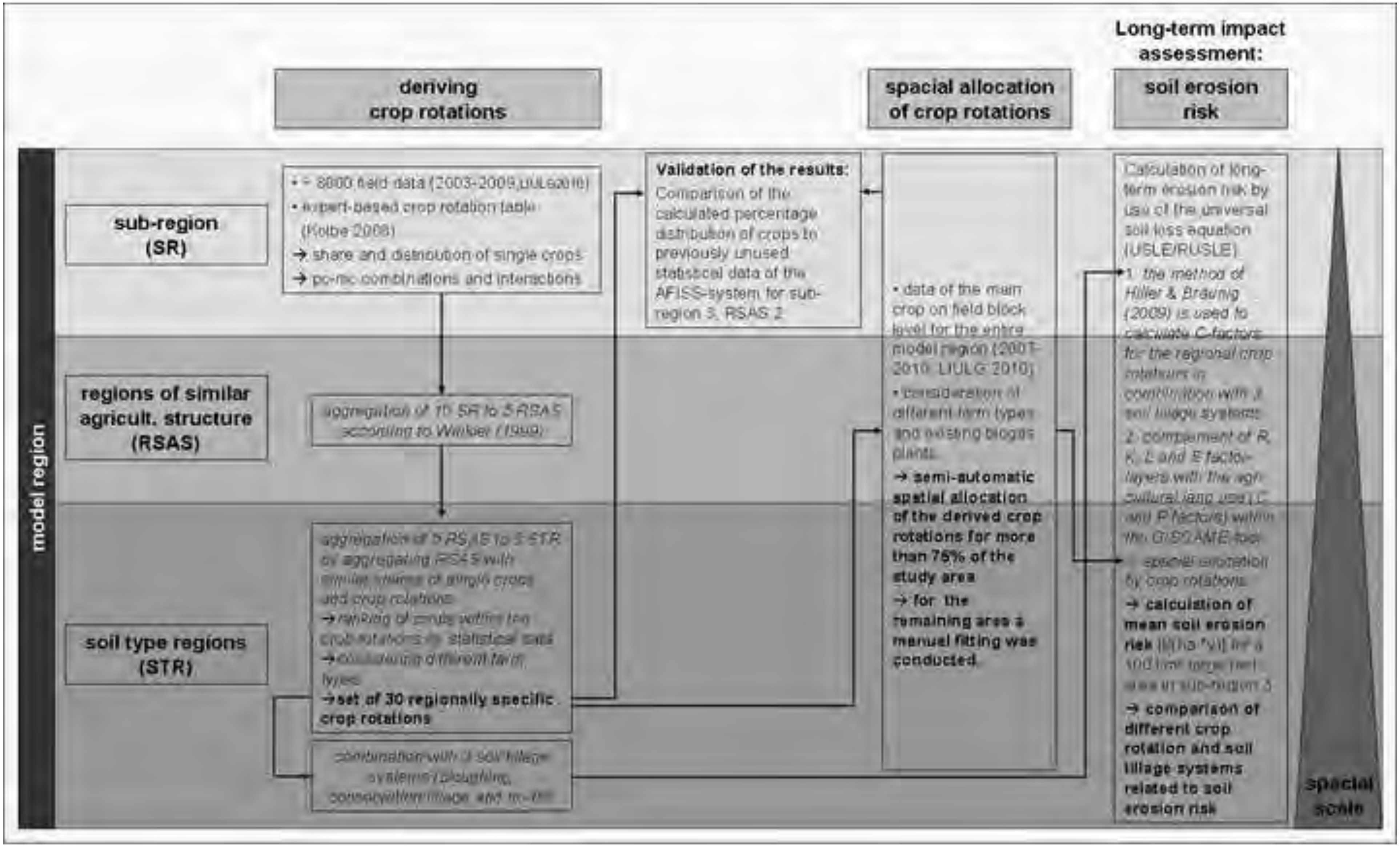

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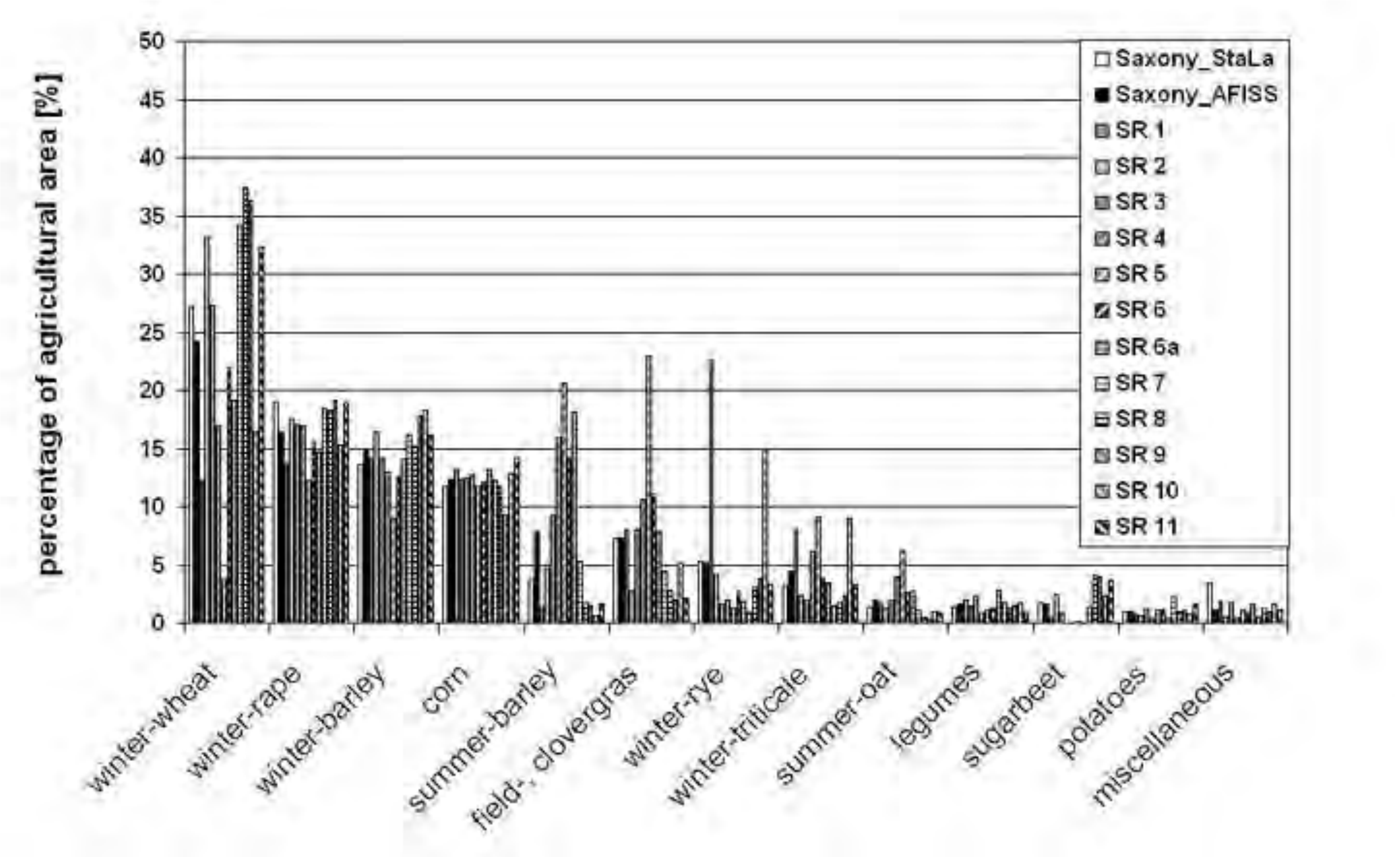

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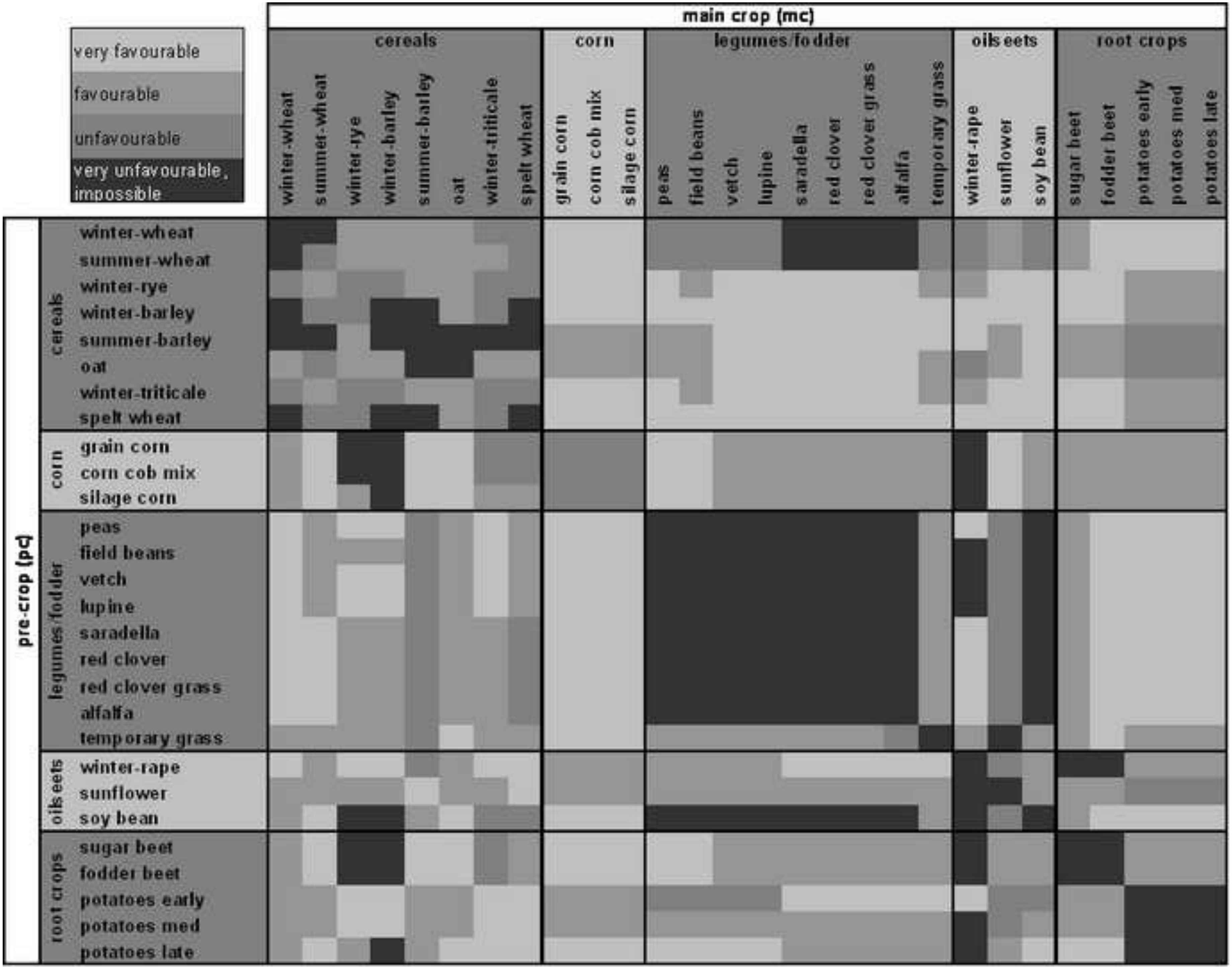

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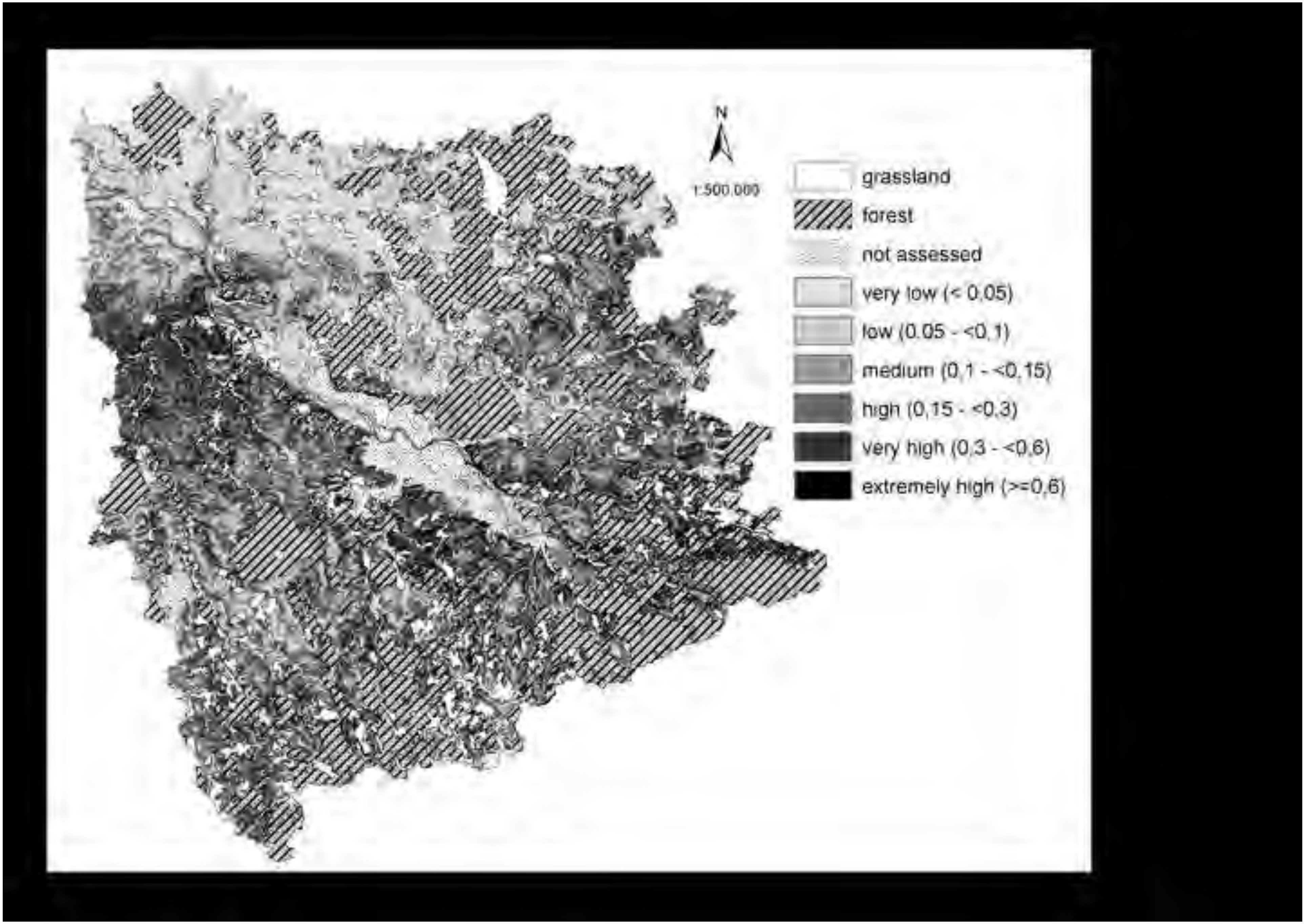

Figure6

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classification of agricultural management systems

soil: 1. sandy soils | 2. loess soils | 3. weathered soils

farm type: A. cash crop farms | B. mixed farms | C. organic farming | (D. incl. energy crops)

→ each with 10 specific regional crop rotations

tillage system: a. ploughing | b. conservation tillage | c. no till

Figure7

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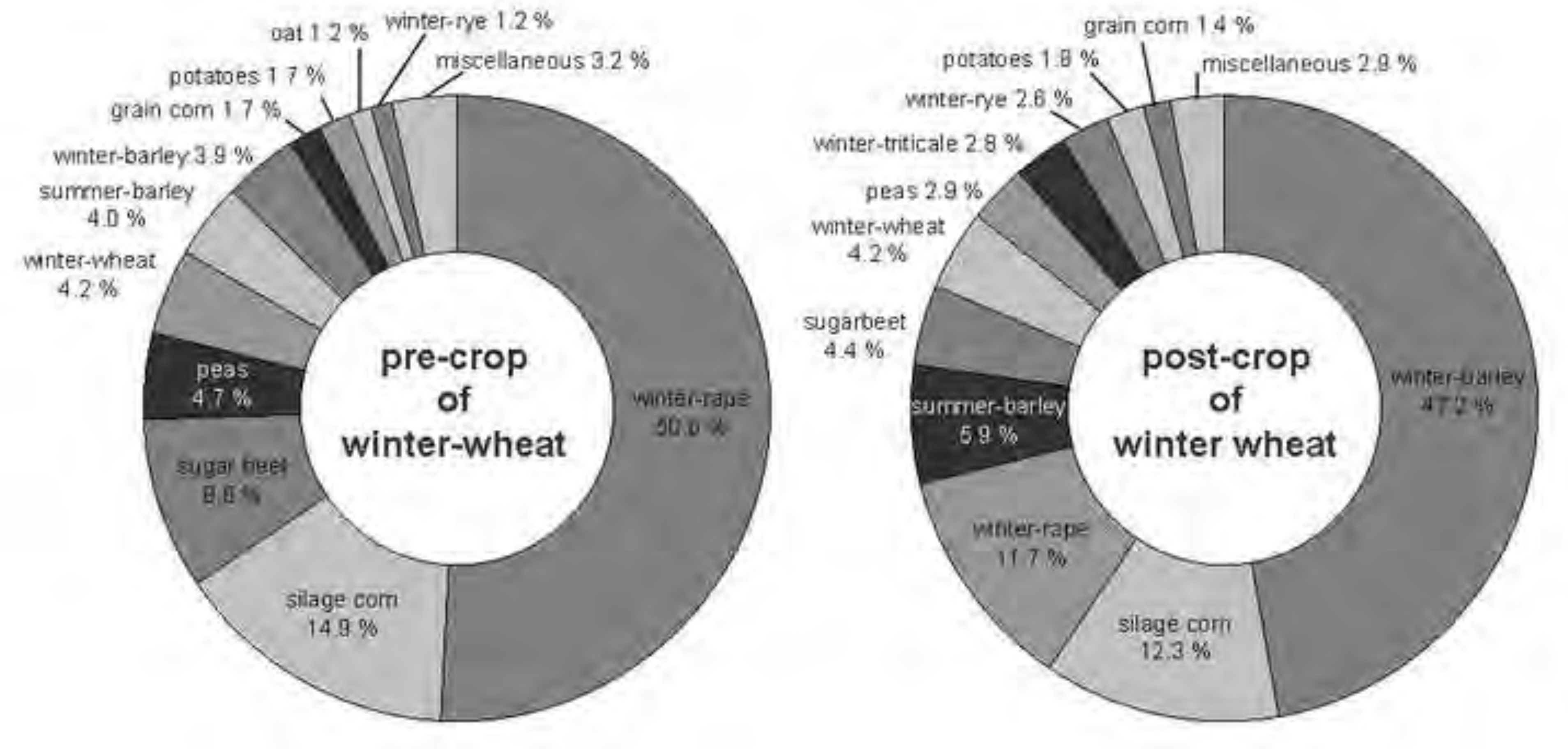

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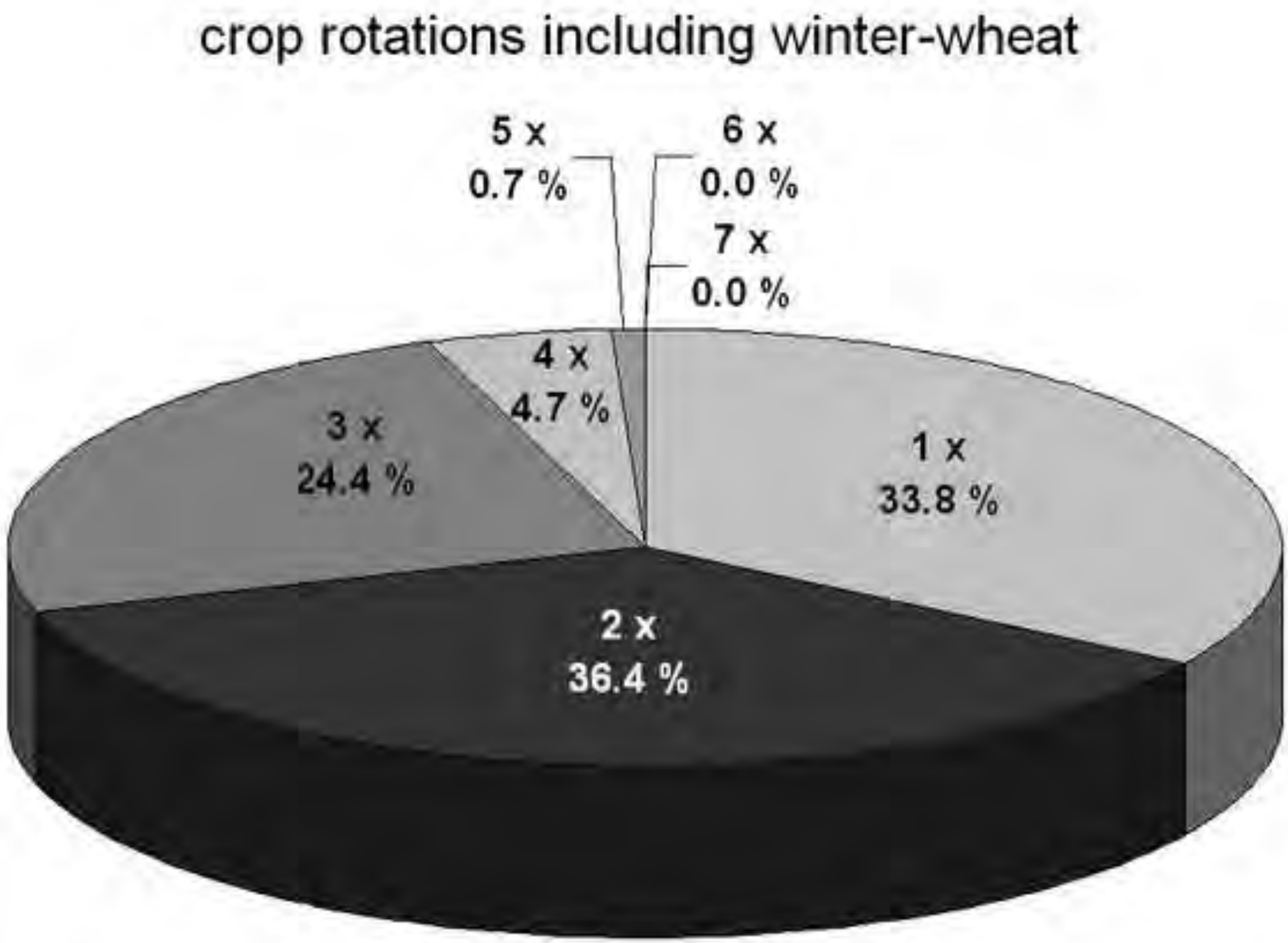

Figure9

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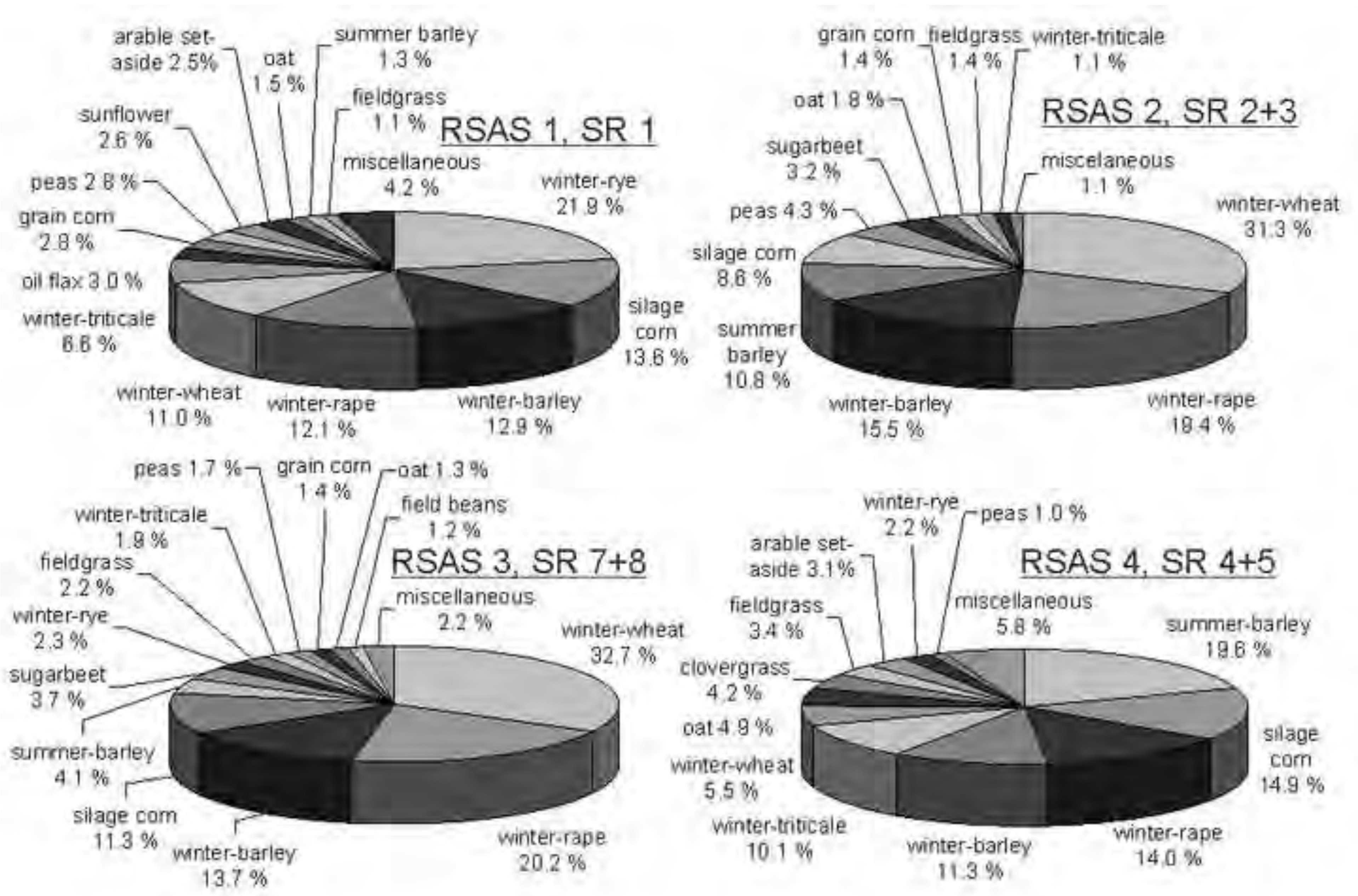

Figure10
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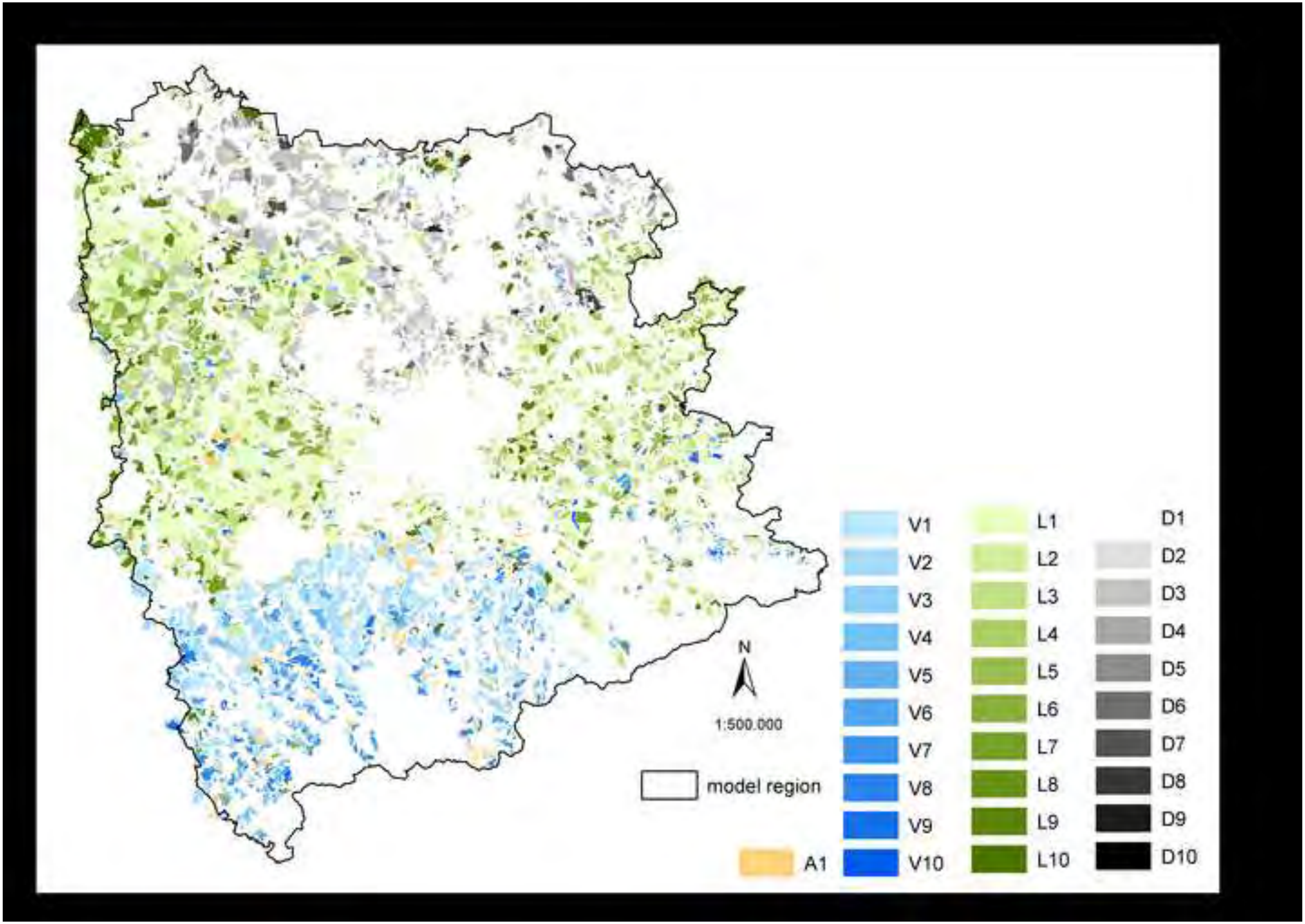

Figure11
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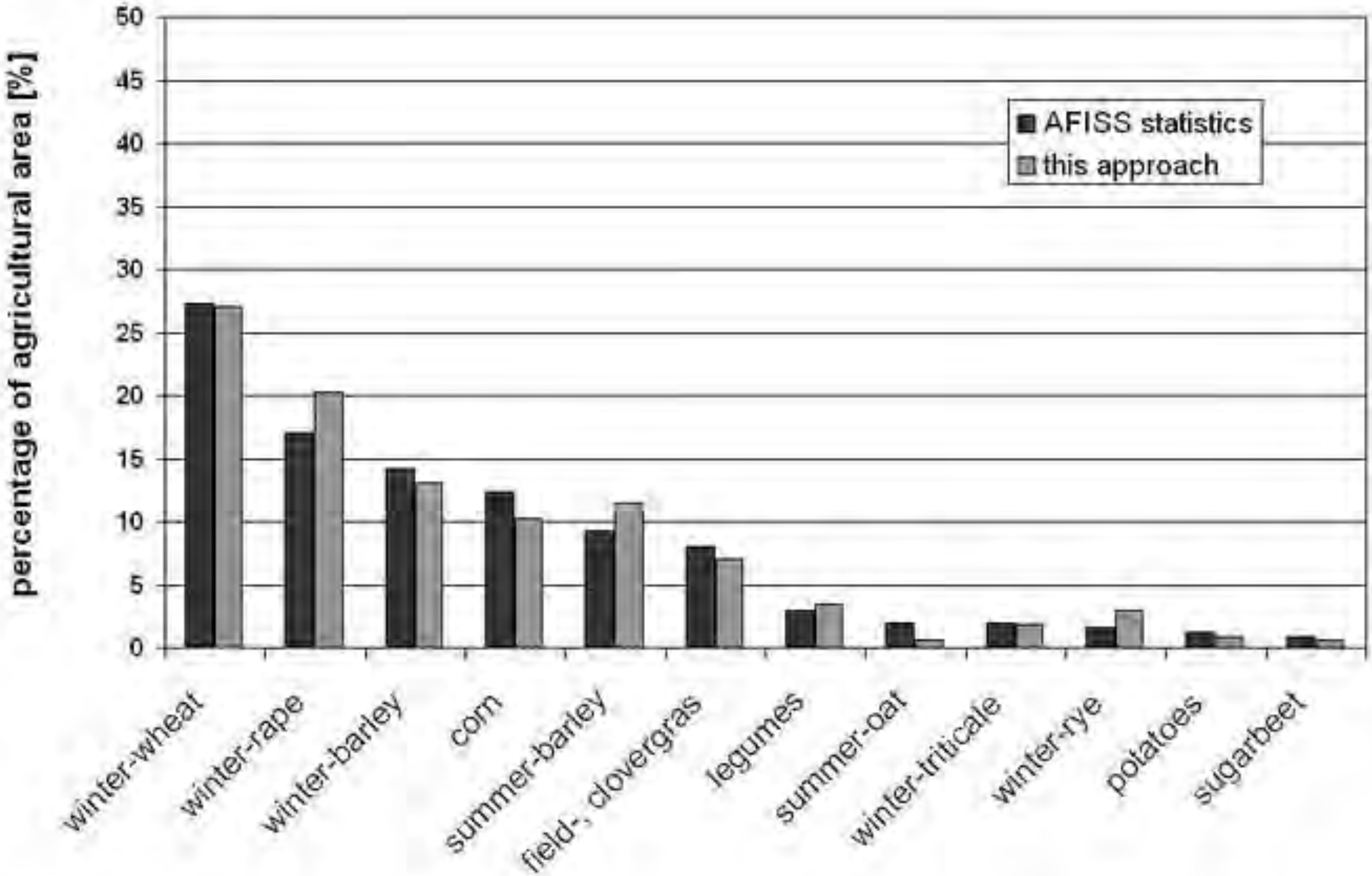

Table 1: Aggregation of 12 sub-regions to 5 regions of similar agricultural structure

12 sub-regions (SR)	**5 regions of similar agricultural structure (RSAS)**
1, 10, 11	I Sächsisches Heidegebiete, Rieser-Torgauer Elbtal
2, 3	II Oberlausitz, Sächsische Schweiz
7, 8, 9	III Mittelsächsisches Lößgebiet
4, 6, 6a	IV Erzgebirgsvorland, Vogtland, Elsterbergland
5	V Erzgebirgskamm

Table2

Table 1: Characteristics of the main agricultural soil type regions (STR) in the study area (according to LfULG (2009), Bernhofer et al. (2009), Mirschel et al. (2010))

agricultural region	1. Sandy soils	2. Loess soils	3. Deeply weathered bed-rock soils
RSAS / SR	RSAS 1 / SR 1	RSAS 2 + 3 / SR 2, 3, 7, 8	RSAS 4 / SR 4 + 5
soil	mainly diluvial sandy soils with lower soil qualities and yields in comparison to the loess soils	mainly loess soils with different depths and high agricultural soil qualities	mainly shallow weathered soils, ranging from loamy weathered gneiss soils in the eastern part to sandy loam soils with granite and slate origins in the western part of the low mountain 'Erzgebirge'
relief	moderately inclined terrain	partly strong inclined terrain	typical is a heavily moving topography and an undulating hilly terrain
climate	partly dry regions with decreasing negative climatic water balance Ø temperature: 9-10°C Ø precipitation: ~ 600 mm/y	decreasing negative climatic water balance Ø temperature: 7-9°C Ø precipitation:650-750 mm/y	low mountain climate Ø temperature: 5-7°C Ø precipitation: 750-1000 mm/y
risk of…			
… soil erosion	low - medium	high - very high (inclined terrain, loess layer)	medium - high
… draught stress	high (decreasing negative climatic water balance, low usable field capacity)	low (high buffer capacity of loess soils, decreasing negative climatic water balance, but high usable field capacity)	low (positive climatic water balance, low to medium usable field capacity)
… nutrient leaching	high in wet years	low - medium	medium - high
… yield depressions	high in dry years, especially for water-intensive crops like corn, potatoes, sugar beets or grasses	low	moderate increase of yields especially for winter crops and crops with high temperature demands, e.g. corn
crop cultivation	in general, higher yield variations	best soil qualities for agricultural production, high yields	the prevailing weathered soils are partly suitable to only a limited extend for the cultivation of more demanding crops (low mountain climate, e.g. short vegetation period) High share of grassland areas and farms with animal feed production and mixed farms with a high share of forage crops
impact of climate change	climate change conditions will have a high impact in this region in future	climate change conditions will have a rather low impact on yield stability in this region in future	rather positive impact on yields in this region in future; usually well-balanced water supply and an extended vegetation period in future

Table3

Table 1: crop rotations and corresponding indicators of soil erosion (C-factors), (w: winter, s: summer)

	sites	**C-factors (USLE)**		
code	**crop rotation**	**plough-ing**	**conservation tillage**	**no-till**
A1	clovergrass - clovergrass - clovergrass - clovergrass	0.036	0.006	0.003
	Sandy soils			
D1	w-rape - w-wheat - w-barley	0.065	0.019	0.013
D2	w-rape - w-wheat - silage corn - s-barley	0.123	0.024	0.014
D3	w-rape - w-barley - w-rye - grain corn - w-triticale	0.102	0.020	0.013
D4	w-rape - w-triticale - s-barley - clovergrass - w-rape - w-rye - w-barley	0.071	0.019	0.013
D5	w-rye - silage corn - s-barley - sunflower	0.138	0.026	0.018
D6	peas - w-wheat - w-rye - oat	0.073	0.017	0.013
D7	clovergrass - w-wheat - potatoes - peas - w-rye - sunflower	0.106	0.053	0.032
D8	alfalfa - alfalfa - w-rye - silage corn - lupine - w-triticale	0.112	0.021	0.014
D9	s-barley$_{wps}$ - silage corn - w-triticale$_{wps}$ - w-wheat	0.116	0.020	0.013
D10	s-triticale$_{wps}$ - sunflower - hemp - w-rye	0.080	0.022	0.020
	Loess soils			
L1	w-rape - w-wheat - w-barley	0.051	0.017	0.013
L2	w-rape - w-wheat - w-barley - w-wheat	0.058	0.018	0.012
L3	w-rape - w-wheat - silage corn - s-barley	0.107	0.021	0.013
L4	sugar beet - w-wheat - silage corn - s-barley - w-wheat - w-barley	0.090	0.022	0.017
L5	sugar beet - w-wheat - w-wheat	0.076	0.024	0.017
L6	peas - w-wheat - w-barley - potatoes - s-barley	0.065	0.023	0.017
L7	clovergrass - w-wheat - silage corn - field beans - w-rye	0.107	0.020	0.012
L8	alfalfa - w-wheat - potatoes - w-rye - field beans - w-triticale	0.065	0.019	0.015
L9	oat - mixed grain$_{wps}$ - w-rape - w-wheat	0.054	0.018	0.012
L10	silage corn - silage corn - silage corn - w-wheat	0.232	0.030	0.016
	Deeply weathered bed-rock soils			
V1	w-rape - w-wheat - w-barley	0.053	0.018	0.012
V2	w-rape - w-wheat - silage corn - s-barley	0.138	0.024	0.013
V3	peas - w-wheat - silage corn - s-barley	0.156	0.024	0.013
V4	w-rape - w-triticale - s-barley - clovergrass - w-rape - w-triticale - w-barley - lupine	0.067	0.017	0.012
V5	fieldgrass - silage corn - w-triticale - s-barley	0.151	0.021	0.013
V6	w-barley - clovergrass - w-rye - silage corn -oat	0.128	0.022	0.013
V7	clovergrass - w-wheat - peas - w-rape - w-rye - s-barley	0.087	0.018	0.012
V8	clovergrass - clovergrass - oat - w-rye - peas - s-barley	0.093	0.017	0.012
V9	s-barley$_{wps}$ - silage corn - w-triticale$_{wps}$ - w-rye	0.125	0.019	0.012
V10	s-barley$_{wps}$ - alfalfa - alfalfa - w-wheat	0.103	0.019	0.012

Table4

Table 1: Mean soil erosion [t/(ha*y)] of the regional crop rotations in the selected sub-study-area

	B. mean soil erosion [t/(ha y)]			**C. relative reduction [%] compared to ploughing**		
A. crop rotation	plough ing	conservation tillage	no-till	plough-ing	conservation tillage	no-till
V1: w-rape - w-wheat - w-barley	0.445	0.151	0.101	-	66.0	77.4
V2: w-rape - w-wheat - silage corn - s-barley	1.159	0.202	0.109	-	82.6	90.6
V3: peas - w-wheat - silage corn - s-barley	1.310	0.202	0.109	-	84.6	91.7
V4: w-rape - w-triticale - s-barley - clovergrass - w-rape - w-triticale - w-barley - lupine	0.563	0.143	0.101	-	74.6	82.1
V5: fieldgrass - silage corn - w-triticale - s-barley	1.268	0.176	0.109	-	86.1	91.4
V6: w-barley - clovergrass - w-rye - silage corn - oat	1.075	0.185	0.109	-	82.8	89.8
V7: clovergrass - w-wheat - peas - w-rape - w-rye - s-barley	0.731	0.151	0.101	-	79.3	86.2
V8: clovergrass - clovergrass - oat - w-rye - peas - s-barley	0.781	0.143	0.101	-	81.7	87.1
V9: s-barley$_{wps}$ - silage corn - w-triticale$_{wps}$ - w-rye	1.050	0.160	0.101	-	84.8	90.4
V10: s-barley$_{wps}$ - alfalfa - alfalfa - w-wheat	0.865	0.160	0.101	-	81.6	88.3
min.	0.445	0.143	0.101	**mean**	**80.4**	**87.5**
max.	1.310	0.202	0.109	**min.**	**66.0**	**77.4**
% difference max.-min.	**66.0**	**29.2**	**7.7**	**max.**	**86.1**	**91.7**

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Regionalisation of Climate Change sensitive forest development types for potential afforestation areas

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ABSTRACT

This paper describes how to use sectoral planning information from forestry to predict and up-scale information on Climate Change sensitive forest development types for potential afforestation areas. The method was developed and applied in the frame of the project RegioPower with focus on the case study region 'Oberes Elbtal–Osterzgebirge'. The data for our study was taken from forest management planning at level of the Federal State of Saxony, Germany. Here, a silvicultural system is implemented, which describes best practices to develop our actual forests into Climate Change adapted forest development types. That includes the selection of drought resistant tree species, a broad range of tree species mixtures per eligible forest development type and the tending, harvesting and regeneration strategies to be applied. This information however, exists only for forest areas and not for areas which could be potentially afforested. The eligibility of the forest development types within the actual forest areas depends on site information, such as nutrient potential, exposition and hydrological soil parameters. The regionalisation of the forest development types to landscape scale had to be based on topographical parameters from the digital elevation model and hydrological soil parameters from soil mapping. In result, we could provide maps for regional planning and decision making with spatially explicit information on the eligible forest development types based on forest management planning information. These maps form a valuable input for testing and optimising afforestation areas with regard to improving the ability of our case study region to mitigate Climate Change effects such as water erosion or drought.

1. Introduction

Forests are one of the key land use systems providing regulating, supporting, provisioning and cultural ecosystem services. The increasing demand of timber and the major role forests play in local and global Climate Change mitigation and regulation has already influenced policy decisions (cf. the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD)) (FAO, 2007; FAO and UNEP, 2008). Policies that account for this important role of forests target therefore to increase the forest areas. In Europe, this increase is however low with a rate of about 0.4% per year. This small success underlines the need to develop strategies how to identify appropriate afforestation areas and to ensure that optimally adapted forests are established on them.

Another request mainly coming from the expected Climate Change impact on our land use systems is the necessity to adapt land use systems and especially our actual forest types with their long history of anthropogenic management to future conditions (see e.g. D'Amato et al., 2011; Millar et al., 2007). Forest conversion as a means of adapting forests to Climate Change aims to reduce mainly the impact of pest calamities whose frequency and intensity is expected to increase if no countermeasures are taken (Spiecker et al., 2003; Vasechko, 1983). Thereby, conversion focuses mainly on introducing or increasing the share of tree species that are resistant to more frequent warm periods and altered patterns of precipitation (Norby et al., 2001; Wullschleger et al., 2001). Furthermore, the consequences of increasing extreme weather conditions, such as drought and storms, need to be considered (Milad et al., 2011).

Forest management planning information on how better adapted forest ecosystems should look like in the future should be made strategically available as regional planning basis. The importance of the integration of forest planning in regional planning becomes obvious when looking at essential regional risk

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mitigation aspects such as flood protection. Forests in the right spatial position would be the best means to buffer water regarding the high water holding capacity of forest soils compared to other land uses (Badoux et al., 2006; Wahren et al., 2007). Due to the observed increase of heavy precipitation events, floods are expected more frequently and stronger with increasing floodplain areas (IPCC, 2000). In result, we should identify criteria to get spatially explicit afforestation areas of highest regional impact for flood protection or ecosystem services provision and enhance the accessibility of decision criteria on the site suitability and choice of tree species or forest stand types (Fürst et al., 2011, 2012). Furthermore, spatial variation in precipitation might provoke in the future also a higher spatial variation of the profitability within agricultural areas and therefore support the identification of potential afforestation areas, where the economic interest of the land owner allows for alternatives such as forests or short rotation coppices (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge (Hg.), 2009). These areas are expected to be easier available for afforestation compared to the actual poor situation, where new forests are often the rejected decision alternative when rethinking land-use opportunities (Nelson et al., 2009; Parry et al., 2004).

The objective of our paper is to introduce a methodological approach for upscaling of forest management planning information. The realisation was done with the corresponding forest management planning data at the level of the Federal State of Saxony, Germany (Eisenhauer and Sonnemann, 2008, 2009). By developing this approach, we intended to provide information on Climate Change adapted tree species and forest development types, which provide a framework for silvicultural action in forest planning units with the objective of planning afforestation areas by means of these information. This is intended to ensure a better consideration of forest management specific knowledge in regional planning and improve the basis for assessing the impact of afforestation on the provision of ecosystem services at regional scale in the frame of the project RegioPower (see www.eli-web.com/RegioPower/; Fürst et al., 2011, 2012). Our aim within the RegioPower focus region 'Oberes Elbtal/Osterzgebirge' (Fig. 1) is to develop (a) opportunities in land use including forest land use for regional Climate Change adaptation and (b) integrated strategies comprising selected forest and agricultural opportunities at the scale of the focus region. Our approach took into account that forest management specific site classification is not fully compatible to soil and topographical information available at landscape scale (Fürst et al., 2011). Therefore, we translated forest site classification which is relevant for the tree species choice into hydrological and topographic proxies which can be taken from soil mapping and a digital elevation model (DEM). The paper introduces (i) the case study region in Saxony, North-Eastern Germany and the available environmental data, (ii) the Saxon silvicultural strategy as a basis for spatial transfer of the tree species eligibility and (iii) the hereon based regionalisation approach and its outcomes. (iv) We discuss the applicability of our approach and (v) give some ideas on its transferability to other regions and how to develop it further.

2. Materials and methods

2.1. Study area 'Oberes Elbtal/Osterzgebirge'

The study region covers an area of 3434 km^2 in Central Saxony, North-Eastern Germany and stretches from the plains and hill country at the border to Brandenburg in the north to the montane zone at the border to the Czech Republic in the south (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge (Hg.), 2009). The region is divided into different climate zones and soil regions: first, the Elbe valley with fluviatile sediments and mild climate, in comparison to the whole model region. The Elbe valley is mainly dominated by settlements, viticulture and horticulture crossing our model region from South-East to North-West. Second, the loess-belt crossing the model region from East to West characterised by a dry lowland climate and mainly dominated by agriculture. Third, the area in the north-east of the region with diluvial sandy soils on which forestry is primarily practiced. And finally, the Ore Mountains, dominated by deeply weathered bed-rocks and a cold and humid mountain climate which results – depending on the altitude – in large pasture or forest areas.

The two main forest species in the study area, which occur commonly in Central Europe are deciduous tree species common beech (*Fagus sylvatica* L.) and common oak (*Quercus robur* L.) (Ellenberg and Leuschner, 2010). On diluvial soils in the NE of the study area primarily scots pine (*Pinus sylvestris* L.) is found. Norway spruce (*Picea abies* L.) and silver fir (*Abies alba* Mill.) are found on weathered soils in the middle and higher altitudes of the Ore Mountains.

2.2. Available data sets

For the spatial transfer of forest management data, three GIS-data sets were identified as suitable and applicable. The first and most important one is provided by forest management planning at the level of the Federal State of Saxony, Germany. The data set is scaled to 1:10,000 and contains the forest site classification (Kopp and Schwanecke, 2003), information from state forest inventory (tree species, forest stand types) and information on the silvicultural management planning targets (see 2.3.). Second, the so-called mesoscale soil map 'BKkonz' generated by the Saxon State Office for the Environment, Agriculture and Geology (LfULG, 2006) was applied. This data set scaled to 1:25,000 contains, among others, information on the soil type and available field water capacity and is a synthesis product from the above-mentioned forest site mapping and mesoscale agricultural soil mapping (GeoSN, 1980).

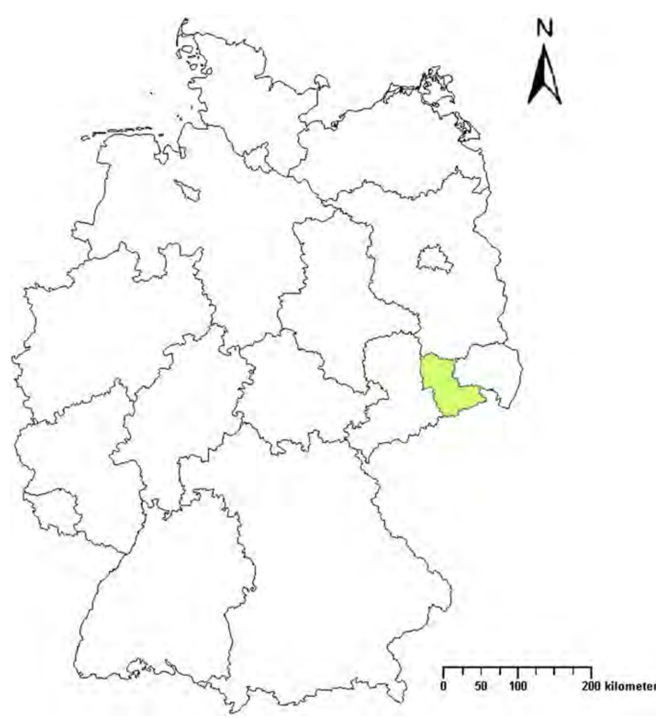

Fig. 1. Location of the case study area "Oberes Elbtal–Osterzgebirge", Saxony, Germany.

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The third geodata set, scaled to 1:25,000 is the digital elevation model (ATKIS DEM 25) of Saxony (GeoSN, 2010).

2.3. Silvicultural concept of Saxony

In Saxony, the silvicultural concept of so called forest development types is applied as a basis for forest management planning (Eisenhauer and Sonnemann, 2008, 2009; Schlutow and Gemballa, 2008). This concept assumes that the actual forest stand types, which are recorded in forest inventory, are not well adapted to Climate Change. It describes a strategy how to develop the actual forest stand types into types, which are well adapted to a moderate Climate Change scenario (A1/B) (IPCC, 2000). It further includes concepts regarding how to correspond to uncertainties in the real climate development by a combination of drought resistant dominating tree species and a broad range of tree species mixtures per forest development type. The eligibility of tree species is based on forest site mapping (topographical, hydrological and pedochemical parameters) and regionalised data for the Climate Change scenario A1/B. The silvicultural guidelines describe further the tending, harvesting and regeneration measures (a) for evolving the forest development types from the actual forest stand types and (b) for further treatment of the forest stands in the case the targeted forest development types are once set up (Eisenhauer and Sonnemann, 2009).

Information on forest development types is available for the current forest areas, while information on the suitability of the forest development types beyond existing forests can only be made available by regionalisation of site and climate information. This information is bundled into so-called ecograms, from which forest development types may be derived (Eisenhauer et al., 2005; Gemballa, 2005). Such ecograms can be described as a kind of multidimensional decision matrix (see Fig. 2) including information on the water and nutrient availability, climate zone and altitude. Considering the climate zones, these are elements of the Saxon forest site classification, and describe larger areas with homogeneous characteristics of the macro- meso- and microclimate (humidity, average temperature/annual temperature variation, exposition, vegetation types, see also chapter 2.4.1.) (Kopp and Schwanecke, 2003).

Fig. 2 presents as an example a matrix for terrestrial sites under humid and temperate-cool climate and for middle altitudes. The first decision factor (I) in our ecogram is soil moisture reflecting mainly landform classes. In combination with factor II (exposition) it can be subdivided into three moisture levels depending on the landform classes crests and sunny slopes (terrestrial dry), flats (terrestrial) and depressions and shady slopes (terrestrial humid). Factor (III) is the nutrient status and differentiates between rich, intermediate, rather poor and poor sites, whereas these classes can be further subdivided into categories of substrate humidity (factor IV), which were generated by the available water holding capacity.

As written before, a problem consists in the availability of the requested information beyond forest areas. Information on the forest stand type as a starting point for the selection of a suitable forest ecosystem type can only be involved by considering neighboured forest stands as proxy information. Information on hydrological or topographical parameters can be obtained from soil mapping and the DEM. Missing, however, is information on the nutrition status of non-forest sites since, for instance, the pedochemical and physical characteristics of agricultural sites are greatly impacted by soil management. Therefore, we assumed that the nutrition status of agricultural sites is generally to be assessed as "rich" according to the forest site classification.

Table 1 provides an overview of the 20 terrestrial forest development types which are relevant for our case study region and gives information about the dominating and tree species mixtures. It should be noted that a dominating tree species has a share of 50–80%, while the additional tree species are divided into tree species which have a share of >10% and such with a share of <10% in the forest area.

2.4. Regionalisation of the forest development types

Regionalisation of our forest development types was done with ArcGIS 9.2. from ESRI. All topographic attributes except the elevation percentile were calculated using Spatial Analyst functions in ArcGIS. The calculation of the elevation percentile was done using a Visual Basic script in ArcGIS, written by Sven Lautenbach from the Centre of Environmental Research (UFZ), Leipzig, Germany.

The calculated map with the obtained forest development types was integrated as a layer into the web-based software platform GISCAME. This software is an assistant tool for simulating changes in land-use pattern and evaluating the effects of these changes within the scope of environmental planning (Fürst et al., 2010a, 2010b).

In order to scale up information on forest development types it was necessary to simplify the structure of our decision matrix in Fig. 2 and to concentrate on the available topographical and soil

<table>
<tr><td colspan="3"></td><td colspan="6">climate zone II and middle altitudes</td></tr>
<tr><td colspan="3">(I) soil moisture due to the terrain situation</td><td colspan="2">terrestrial humid</td><td colspan="2">terrestrial</td><td colspan="2">terrestrial dry</td></tr>
<tr><td colspan="3">(II) exposition</td><td>+</td><td>-</td><td>+</td><td>-</td><td>+</td><td>-</td></tr>
<tr><td rowspan="10">(III) nutrient status and (IV) substrate humidity</td><td>rich</td><td></td><td colspan="6"></td></tr>
<tr><td rowspan="3">intermediate</td><td>humid substrate</td><td colspan="2" rowspan="9">spruce-beech</td><td rowspan="2">beech-spruce</td><td colspan="3" rowspan="6">beech-fir</td></tr>
<tr><td>moderate dry substrate</td></tr>
<tr><td>strong dry substrate</td><td></td></tr>
<tr><td rowspan="3">rather poor</td><td>humid substrate</td><td rowspan="3">beech-spruce</td></tr>
<tr><td>moderate dry substrate</td></tr>
<tr><td>strong dry substrate</td></tr>
<tr><td rowspan="2">poor</td><td>moderate dry substrate</td><td colspan="4" rowspan="2">extensive coniferous mixed forest</td></tr>
<tr><td>strong dry substrate</td></tr>
</table>

Fig. 2. Decision matrix for terrestrial sites with the example of the ecogram adapted to climate zone II and middle altitudes (the Roman numerals represent the factors, which structure the ecogram).

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Table 1
Specification of forest development types.

	Dominant tree species (50–80%)	Additional tree species I (>10%)	Additional tree species II (<10%)
Pine–birch mixed forest	*Pinus sylvestris* L.	*Betula pendula* Roth.	*Quercus rubra* L.
Pine–oak mixed forest	*Pinus sylvestris* L.	*Quercus robur* L., *Quercus petraea* (Matt.) Liebl., *Carpinus betulus* L, *Tilia cordata* Mill.	*Betula pendula* Roth., *Quercus rubra* L.
Pine mixed forest	*Pinus sylvestris* L.	*Fagus sylvatica* L., *Abies alba* Mill., *Larix decidua* Mill., *Quercus petraea* (Matt.) Liebl.	*Betula pendula* Roth., *Picea abies* L., *Pseudotsuga menziesii* Mirb.
Oak-pine mixed forest	*Quercus robur* L., *Quercus petraea* (Matt.) Liebl.	*Pinus sylvestris* L., *Carpinus betulus* L, *Quercus rubra* L.	*Betula pendula* Roth., *Acer platanoides* L.
Oak–beech mixed forest	*Quercus robur* L., *Quercus petraea* (Matt.) Liebl.	*Carpinus betulus* L, *Tilia cordata* Mill., *Quercus rubra* L., *Fagus sylvatica* L.	*Betula pendula* Roth., *Cerasus avium* L.
Hydromorph oak deciduous mixed forest	*Quercus robur* L.	*Carpinus betulus* L, *Tilia cordata* Mill., *Quercus rubra* L., *Pinus sylvestris* L.	*Betula pendula* Roth., *Cerasus avium* L.
Oak deciduous mixed forest	*Quercus robur* L., *Quercus petraea* (Matt.) Liebl.	*Carpinus betulus* L, *Acer platanoides* L., *Acer pseudoplatanus* L., *Fraxinus excelsior* L.	*Betula pendula* Roth., *Cerasus avium* L.
Beech–oak mixed forest	*Fagus sylvatica* L.	*Quercus robur* L., *Quercus petraea* (Matt.) Liebl., *Tilia cordata* Mill., *Pseudotsuga menziesii* Mirb.	*Betula pendula* Roth., *Cerasus avium* L., *Abies alba* Mill.
Beech–fir mixed forest	*Fagus sylvatica* L.	*Abies alba* Mill., *Pseudotsuga menziesii* Mirb., *Fraxinus excelsior* L.	*Larix decidua* Mill., *Betula pendula* Roth.
	Dominant tree species (50–80%)	Additional tree species I (>10%)	Additional tree species II (<10%)
Beech–spruce mixed forest	*Fagus sylvatica* L.	*Picea abies* L., *Pseudotsuga menziesii* Mirb., *Abies alba* Mill., *Acer pseudoplatanus* L.	*Betula pendula* Roth., *Sorbus aucuparia* L., *Larix decidua* Mill.
Beech deciduous mixed forest	*Fagus sylvatica* L.	*Acer pseudoplatanus* L., *Fraxinus excelsior* L., *Ulmus glabra* Huds.	*Betula pendula* Roth.
Spruce mountain forest	*Picea abies* L.	*Sorbus aucuparia* L., *Fagus sylvatica* L., *Abies alba* Mill.	*Betula pendula* Roth., *Acer pseudoplatanus* L., *Fraxinus excelsior* L.
Spruce–fir mixed forest	*Picea abies* L.	*Abies alba* Mill., *Fraxinus excelsior* L., *Acer pseudoplatanus* L.	*Sorbus aucuparia* L.
Spruce–beech mixed forest	*Picea abies* L.	*Fagus sylvatica* L., *Abies alba* Mill., *Fraxinus excelsior* L.	*Betula pendula* Roth., *Sorbus aucuparia* L.
Extensive coniferous mixed forest		*Pinus sylvestris* L., *Picea abies* L., *Fagus sylvatica* L.	*Betula pendula* Roth.
Peat forest		*Pinus sylvestris* L., *Betula pubescens* Ehrn., *Picea abies* L., *Sorbus aucuparia* L.	
Forest in small stream valleys	*Alnus glutinosa* L., *Fraxinus excelsior* L.	*Acer pseudoplatanus* L., *Ulmus glabra* Huds., *Ulmus laevis* Pall., *Quercus robur* L.	
Floodplain forest	*Quercus robur* L.	*Alnus glutinosa* L., *Fraxinus excelsior* L., *Ulmus laevis* Pall., *Acer pseudoplatanus* L.	*Cerasus avium* L.
Red oaks mixed forest	*Quercus rubra* L.		
Douglas fir mixed forest	*Pseudotsuga menziesii* Mirb.		

data. Information on hydrological features taken from the soil map and on exposition was bundled into one criterion ‘soil moisture’. Information on altitude and climate zone was adopted from the DEM and forest management planning (‘silvicultural regions’; Eisenhauer and Sonnemann, 2008, 2009).

Fig. 3 presents a flowchart which outlines the up-scaling process described in the following four steps:

2.4.1. *Intersection of dynamic climate zones and altitude zones*

In the first step the dynamic climate zones were up-scaled based upon the information from forest site mapping (Kopp and Schwanecke, 2003). Saxonian forests are divided into six dynamic climate zones of which the following zones occur in our model region: (I) humid with cold winters, (II) humid and temperate-cool climate, (V) temperate-dry to temperate-humid with warm

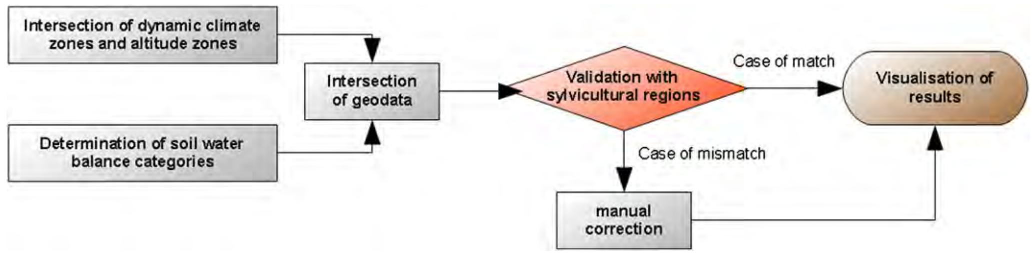

Fig. 3. Flowchart of the upscaling process for the forest development types.

summers to temperate-cool climate and (VI) dry with warm summers to temperate-cool climate. Climate zone 'II' was subdivided into areas of middle (450–650 m a.s.l.) and higher (>650 m a.s.l.) altitudes, because of the large-scale appearance of the humid and temperate-cool climate in Saxony and the various silvicultural demands which are influenced by different snow depths and different durations of the frost periods in middle and higher altitudes. Subdivision was done on the basis of the DEM.

2.4.2. Determination of soil water balance categories

To determine the soil water balance for areas beyond existing forests, information about soil type and landform elements were used on the basis of the mesoscale soil map (BKkonz) as well as the DEM was applied. Four of seven soil water balance categories applied in forest site mapping, namely peatlands, floodplains, hydromorph soils and semi-hydromorph soils were directly conveyed from the attribute soil type from the BKkonz. Peatland soils are characterised by a mass percentage of organic matter of at least 30%. The deposition of Holocene sediments in river valleys is typical for floodplain soils. Soils classified as gley types were summarised as hydromorph soils and pseudogley and stagnogley soil types were assigned to semi-hydromorph soils.

The spatial allocation of terrestrial humid, terrestrial and terrestrial dry sites was directly modelled on the basis of relief attributes provided by the DEM. Therefore, the relief was divided into four landform classes based on the definitions of Speight (1974) and the landforms were assigned to our humidity classes (see chapter 2.3.).

After having generated in a first step the topographic attributes slope, elevation range, elevation percentile as well as plan and profile curvature, the landform elements were calculated using thresholds, which were determined by Speight (1974), Coops et al. (1998) and Klingseisen et al. (2008). According to these, crests are areas with positive and therefore convex plan or profile curvature or both as well as an elevation percentile larger than 0.65 and an elevation range larger than 5.0. Areas of depressions have either an elevation percentile less than 0.4 or a plan curvature smaller than −0.5. Furthermore, flats have a slope gradient, which should be smaller than 3% or 1.35°. All other areas not classified as crests, depressions or flats are assigned to be slopes.

Additionally, the aspect was calculated on the basis of the DEM to differentiate between shady and sunny slopes. All slope cells having an aspect value between 112.5° and 292.5° were classified as sunny slopes, which comply with an E–SE to W–NW orientation. Slope cells with an aspect value between 292.5° and 360° as well as 0° and 112.5° were assigned to shady slopes, which conform to a W–NW to E–SE orientation.

2.4.3. Intersection of the geo-data referred to under 2.4.1. and 2.4.2.

In a next step the combined map of climate and altitude zones were intersected with the map of the obtained soil water balance categories within ArcGIS (see Fig. 3).

2.4.4. Validation with silvicultural regions in Saxony

Finally, the map with the forest development types was validated based on a map with so called silvicultural regions in Saxony (Eisenhauer and Sonnemann, 2008, 2009). These silvicultural regions are a means to regionalise the forest development type concept in existing forest areas for practical forest management planning based on stratification into areas with similar site conditions (pedochemical/topographical and modelled climate zones for the scenario A1/B). Since suitable forest development types are defined for each of the silvicultural regions, we could test the matching of our preliminary forest development types map with the current silvicultural planning bases. In the case of mismatch, the forest development type was manually corrected.

The prediction quality of the regionalised map with forest development types was determined by spatial intersection with forest development types in existing forest areas received from forest management planning at the level of the Federal State of Saxony. We expressed it (i) by the accordance [in %] of our results with the mapped forest development types in the forest management plan and (ii) by the root-mean-square error (RMSE) as the average difference between estimated and measured value. To calculate the RMSE the most common forest development types in the study area were ranked from 1 to 11 according to their increasing water balance categories and dynamic climate zones. The impact of water balance and the combined climate and altitude information on the prediction quality of forest development types was determined by calculating the correlation coefficient for both parameters.

3. Results

We assumed that up-scaling information on suitable forest development types which integrate regional Climate Change scenarios provides a valuable decision support for forest and

	I	II + higher altitudes	II + middle altitudes	V + lower altitudes and hill country	VI + lowlands
peatlands	peat forest				
floodplains	floodplain forest				
hydromorph	spruce-fir			hydromorph oak deciduous forest	
semi hydromorph					
terrestrial humid	spruce	spruce-beech	spruce-beech	beech-fir	beech-oak
terrestrial			beech-fir	beech-oak	oak-beech
terrestrial dry		beech-spruce		oak-beech	pine-oak

Fig. 4. Modified decision matrix for the choice of forest development types.

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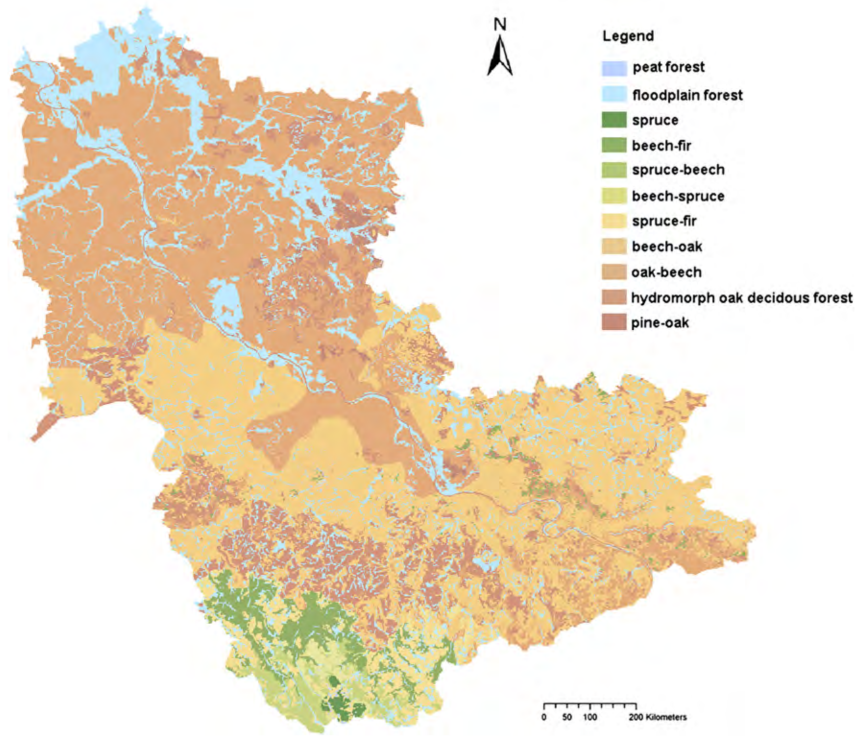

Fig. 5. Map of all forest development types in the study area.

regional planners (Fürst et al., 2012). Our regionalisation approach provided two main outcomes. The first result is a decision matrix for the choice of the eligible forest development types based on the matrix presented in Fig. 2. The combination of dynamic climate zones and altitude zones and soil water balance classes resulted in the suitable forest development type read from Fig. 4.

As a second outcome, a map with the allocation of our eligible forest development types as a recommendation for action in regional planning was provided (see Fig. 5). The resulting information basis should not be misunderstood as an afforestation map, but rather as a recommendation to ensure a better integration of forest management planning knowledge in regional planning processes.

The validation of our preliminary forest development type map with the silvicultural regions resulted in most cases in a spatial consistency of the forest ecosystem types in both maps. However, some small-scaled inaccuracies appeared in the border areas between different altitudes or between different climate zones.

The prediction quality of the regionalisation map determined by spatial intersection of forest development types in existing forests and its regionalised results provides an accordance of 48% within the regional forest area. The root-mean-square error amounts to 2.81 with a range of 1–11 referring to the number of forest development types. Furthermore, the correlation coefficients amounted to 0.92 for the dynamic climate zone and to 0.60 for water balance. This implies that especially the dynamic climate zone which addresses already some aspects of the water balance can be used as a suitable predictor for a spatial allocation of the forest development types.

Of the originally eligible 20 forest development types, only 11 types remained to be applicable as a decision basis in afforestation areas. At 61% of the study area, the classes "beech–oak" and "oak–beech" would be eligible. This value is nearly consistent (59%) with the corresponding information on eligible forest development types in existing forest areas received from forest management planning at the level of the Federal State of Saxony. Table 2 shows the total share of each forest development type in our case study area.

Table 2
Total distribution of each forest development type in the study area.

Forest development type	Total distribution in the study area [%]
Beech–oak	34
Oak–beech	27
Floodplain forest	15
Hydromorph oak deciduous forest	12
Beech–fir	5
Spruce–beech	3
Spruce–fir	2
Pine–oak	1
Beech–spruce	<1
Spruce	<1
Peat forest	<1

4. Discussion and conclusions

To assess our approach, the following strengths and weaknesses have been identified;

Our regionalisation exercise was dedicated to delivering an improved information basis for regional planning by aggregating and up-scaling forest management planning information. Spatial coincidence between our regionalised forest development type map and information on eligible forest development types regionalised by so called silvicultural regions was sufficient within existing forest areas, and only a few corrections had to be made in border areas between different altitude or climate zones. These were mainly generated by aggregation algorithms when intersecting climate and altitude zones. Finally, we were able to provide a digital layer to be implemented as part of the map material within the regional plan (Regionaler Planungsverband Oberes Elbtal/Osterzgebirge (Hg.), 2009) and which is now used for a more detailed assessment of potential afforestation areas considering their optimal impact on the provision of ecosystem services, depending on their spatial location and the impact of the single forest development types (Frank et al., 2011; Fürst et al., 2012).

In comparison to other regionalisation approaches, dealing with forest management and site information (see e.g. Jansen et al., 2002; Zirlewagen et al., 2007; Zirlewagen and von Wilpert, 2004) our method presented here was conceived as matrix-based regionalisation technique because an application of multiple linear regression analyses or geostatistic interpolation techniques, such as co-kriging methods failed to the fact that our target variable forest development type is not of numeric, but more of descriptive character depending on thresholds and semi-qualitative decision criteria which can only partially estimated based on biophysical information. Fuzzy logic approaches as shown for instance by Salski (1999) and Burrough (1989) would enable dealing with qualitative information in regionalisation methods. In our case, the focus of the regionalisation was however to provide information for regional planning in form of maps, where the question of uncertainty (fuzziness) of the provided information does not play a role.

Our approach and its outcomes can be improved considering two major aspects. First, the soil map, which is a synthesis product from approximately 20-year-old agricultural and silvicultural site mapping, can be replaced by a current, but to date not-yet-digitally-available, site mapping generated by the Saxon State Office for the Environment, Agriculture and Geology (LfULG). This would especially support an improvement in the quality of the soil moisture classes derived from soil type, which is based on homogeneous site mapping independent from land use (LfULG, 2010). Second, a division of the slope into lower, mid and upper slopes can facilitate a more precise classification of terrestrial humid, terrestrial and terrestrial dry sites, see e.g. Klingseisen et al. (2008). Based upon the calculated landform classes and the DEM, slope profiles can be constructed that include information on the direction of the steepest slope. The obtained slope profile should then further be divided into slope classes at breakpoints, where significant changes occur in the slope, see e.g. Giles and Franklin (1998). Depending on the number of breakpoints (n) a slope can be divided into a) simple slope ($n = 0$); b) upper slope and lower slope ($n = 1$), or c) upper slope, lower slope and one ($n = 2$) or more ($n > 2$) mid slopes. This slope classification would enable an allocation of sunny mid slopes to terrestrial dry sites, shady mid- and upper-slopes to terrestrial sites and shady lower slopes to terrestrial humid sites, which finally would help to improve the accuracy for spatial transfer of our forest development types.

Specific information taken from forest site mapping is normally considered to be not well compatible to other soil or site classification systems (Kopp and Schwanecke, 2003). In our paper we were able to demonstrate that an iterative aggregation or even disregard (nutrient status) of decision criteria relevant for the eligibility of forest development types can be successfully applied to scale up sectoral planning information from forestry to landscape scale. Thereby, a sufficient spatial matching in comparison to forest management planning information in existing forest areas was determined. Our example provides therefore an approach also for other case study regions and other silvicultural systems, which are based on comparable decision criteria for the eligibility of tree species or forest stand types.

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