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Valuing post-mining landscapes using an ecosystem services approach—An example from Germany

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ABSTRACT

Open cut mining heavily affects landscapes and is largely irreversible. Post-mining landscapes often differ dramatically from pre-mining ones. One of the largest open cut lignite mining areas in Europe is in Eastern Germany, south of Leipzig. This paper uses an ecosystem services approach to assess the impacts of mining activity over a 100-year period, spanning pre- and post-mining states. We recorded historical land use data from maps and outlined three future potential land use scenarios based on current planning documents. Our results indicate that maps showing the potentials to provide ecosystem services support the prioritization of preference areas in regional planning. For example, forested and heterogeneous habitats are predicted to enhance future urban development and mitigation of future climate change – a goal of the Saxon government. In contrast, if future development priorities are on local food production and bio-energy use, more arable and grassland areas should be pursued. The use of freely and publicly available data and the simple methods of the approach presented here can be used to inform and improve regional landscape planning.

1. Introduction

Coal production continues to increase worldwide, particularly in India, China, Australia and South Africa. In Europe, existing reservoirs are being explored and will be expanded (fr-online.de; 10.11.2011 and sueddeutsche.de; 13.07.2011 and Deutschlandradio Hintergrundpolitik; 06.2008). Most recently, the desire to reduce reliance on nuclear power following the worst-case scenario in Fukushima, Japan, has renewed worldwide interest in coal mining along with renewable energy sources (Costanza et al., 2011). Open cut mining is one of the most landscape-altering activities of human history, producing largely irreversible changes to landscapes (Slonecker and Benger, 2001).

Post-mining landscapes often differ dramatically from pre-mining ones in terms of surface structure, resource availability and settlement structure (Haase and Rosenberg, 2003). They consist of allochthonous and loosely accumulated sediments and experience disturbed water regimes; pre-mining villages are mostly removed. Surface mining always involves a twofold change in land use: (i) from a pre-mining landscape to a mining landscape and (ii) from a mining landscape to a post-mining landscape.

Assessments or valuations of this type of large-scale landscape change either focus only on the environmental impacts of this activity on energy and matter fluxes, treating the human element as yet another form of energy or environmental flow, or concentrate solely on social and economic issues, such as attitudes or perceptions towards landscape change (Linke and Schiffer, 2002) or economically motivated cost-benefit analyses (Lienhoop and Messner, 2009). Cost-benefit assessments also dominate the discussion about post-mining landscapes and respective land use patterns. Because areas affected by mining continue to increase, a more integrated assessment of mining landscapes is urgently needed to achieve more sustainable post-mining development. Mining devastates landscapes, and restoration efforts often focus only on landscape aesthetics. In this paper, we present an integrated and functional assessment of landscape and land-use changes caused by open-cut mining. This methodology is promising, as there is of yet no state-of-the-art or blue print instrument/indicator set for both open-cast-mining impact assessment and post-mining landscape (e)valuation.

The concept of ecosystem services (ES) and associated indicators (Millenium Ecosystem Assessment [MA], 2005; TEEB urban, 2011), is of current interest because of its potential to integrate the social, economic and ecological aspects of landscapes (e.g., Termorshuizen and Opdam, 2009). We apply the ES concept to assess the pre-mining rural landscape, prevailing restoration activities and three different future scenarios for the modified landscape to develop a

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Fig. 1. Study area of the open cut mining area south of Leipzig, Germany.

feasible ex-ante impact assessment planning instrument. The concept of ES makes explicit the benefits humans obtain from nature (MA based on basic work by Costanza et al., 1997; De Groot, 1992; De Groot et al., 2002). Different land use patterns provide a specific range of ecosystem services according to the intensity of use and the proportion of virgin landscapes. In this context, ES are assumed to serve as landscape assessments, evaluating the individual parts (e.g., field plots, landscape elements or compartments) and functions (e.g., production, retention or information) demarcated by different users (Haase and Haase, 2002). Both the concepts of landscape assessment and ES are similar in that a wide range of criteria are considered within the assessment procedure or model (see a.o. Brandt, 2000), which is especially true for anthropogenically affected and modified landscapes, such as mining and post-mining landscapes.

Here, we use the ES approach to assess the ecosystem functions and services of different post-mining land use scenarios, relative to the pre-mining and mining landscapes. Our objectives are as follows:

- Assess the pre-mining, mining and post-mining landscapes with respect to function and sustainability. We seek a quantitative pragmatic assessment.
- Apply the ES approach to this assessment.
- Evaluate the applicability of the ES concept to mining impact assessment and post-mining landscape patterns.

Our results may be used to inform land use and landscape planning in the study region (Fig. 1).

2. Study area

One of the largest opencast lignite mining areas in Europe is in Eastern Germany, south of Leipzig (Fig. 2). The area covers 250 km^2 and includes three large, inactive lignite open-cast mines within 10 km of 2040 active mines (in the municipalities of Markkleeberg, Großpösna, Espenhain, Rötha, Böhlen, Zwenkau and a small part of the city of Leipzig; http://de.wikipedia.org/wiki/Mitteldeutsche_Braunkohlengesellschaft). Affected land in the region includes large parts of arable land and remnants of the floodplain forests of the Pleiße and Weiße Elster rivers. Small settlements lie along a central road. Much of the region consists of former open-cast mines under recultivation.

When the construction of the opencast mines began in 1921, the original floodplain landscape, which included more than 70 villages, became devastated; some 24,000 people were displaced. Between 1926 and 1989, eight large open-cast mines, sixteen briquette production sites and six large power stations were in operation. After the political transition in 1990, three inactive mines were subject to restoration efforts by both the international energy and mining company Vattenfall and the regional planning authority (Wiegand et al., 2003). As the first mining activities date back to the 1920s, the overall impact of open-cut mining spans a period of approximately 100 years. The extensive and dynamic landscape changes in the study area are comparable to many open-cut mining landscapes across the globe (Kabisch and Linke, 2002).

The post-mining landscapes south of Leipzig currently exhibit novel ecological, economic and social features, with new lakes (36.62 km^2) in Pleistocene landscapes formerly devoid of lakes (Krüger et al., 2002; Hüttl and Gerwin, 2004). In addition to the loss of the floodplains and large recreational areas for the city of Leipzig, settlement and population development in the mining area have been disturbed since 1925. From an economic point of view, a mono-centric development of coal-based energy and chemical production dominated from 1930 to 1990 (Kabisch, 2004; Kabisch and Linke, 2002).

Along with other areas in the world with a history of open-cast mining, such as the USA, Australia, Germany, India, Poland, Greece and Kazakhstan, where a considerable proportion of coal production results from surface mining (Thomas, 2002) the pre- and post-mining landscapes of the study area also face large problems with water acidification, poor soil quality and disturbed ecosystems. For example, in the USA, approximately 83% of all coal production occurs in surface mines (calculation based on data in Szwilski et al., 2001). Many open-cast mining sites in other parts of the world are comparable to those of Leipzig; the results of the present study will be relevant to other regions as well.

After the political transition of 1990, the post-socialist restoration process initiated discussions about future development paths and land use scenarios and encouraged the involvement of planning institutions, municipalities and other stakeholders (part of the democratisation process within the former GDR). Thus, restoration became a multi-dimensional, multi-actor and multi-criteria process and represents an ideal case for integrated assessment (IA) procedures and tools (McIntosh et al., 2011).

This paper evaluates whether ES indicators can illuminate the impacts of mining on the landscape in Saxony and makes recommendations for future planning and development of the post-mining landscape at the regional scale.

3. Methods

3.1. Modelling ecosystem services

The Millennium Ecosystem Assessment (2005) formally defined 24 types of ES. Since then, several studies of landscape planning and land use policy have referred to this concept (e.g., Cowling et al., 2008; Grêt-Regamey et al., 2008; Termorshuizen and Opdam, 2009; others). However, the “flows of ecosystem services remain poorly characterised at the local-to-regional scale” (Chan et al., 2006). The ES concept forces people to “view our landscapes holistically rather than looking at individual components in isolation from one another” (Ecosystem Services Project, 2001: 4). Therefore, it seems appropriate to apply the ES concept in developing IAs of anticipated change in highly dynamic landscapes, such as mining regions. The ES considered in this study were chosen on the basis of their relevance to the study area and the availability of data. All appear in the majority of ES studies worldwide (Seppelt et al., 2011).

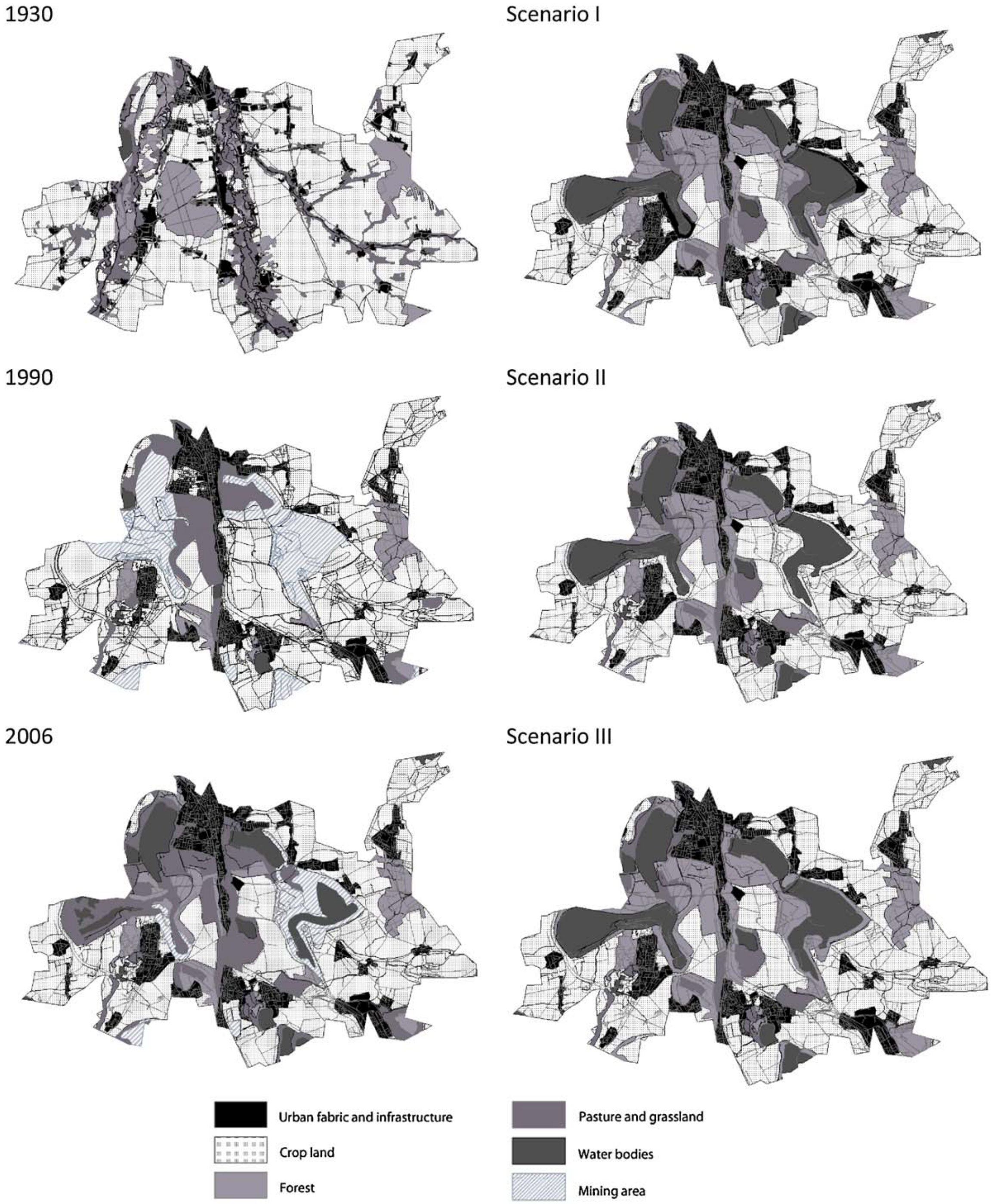

Fig. 2. Land use patterns of the pre-mining state of 1930, the mining state of 1990, the current post-mining state of 2006 and the three scenarios.

The ES considered in this study were chosen in consideration of their importance for the landscape in the study region. Despite data limitations, the services and respective indicators listed in Table 1 are considered to be most important when assessing the impact of mining on a landscape (Krüger et al., 2002): soil, soil functions, and water are ecosystem components most affected by mining through removing and elimination. Therefore, food and fibre production are good indicators of the extent to which landscape functionality has changed during mining and the post-mining potential of landscapes. As well, all indicators and services related to water resources i.e., fresh water supply and climate regulation are good indicators for the overall mining impact. For any region close to a large city, the service of recreation is important (Schetke et al., 2010). As biodiversity conservation is a goal of the Saxon Government (Freistaat Sachsen, 2003a,b) and as species data were not available for all six time steps, we used landscape metric indicators to assess habitat quality.

Model-based analysis of ecosystem services assessments currently lacks support in policy-adequate model development (Seppelt et al., 2009). Many approaches at the regional scale over the last 15 years incorporated highly complex models requiring a high degree of parameterisation (see Seppelt et al., 2011) for which data are lacking. Alternatively, we propose the use of simple algorithms and models. The benefits of this approach include the

Table 1
Indicators and methods for the ecosystem services quantified (non-cited methods were developed by the authors).

Service	Indicators	Method
Food production	Agricultural productivity A_p	A_p = Area[$ha_{agricultual\ area}$]crop yield potential
Fibre production	Forest productivity A_f	A_f = Area[$ha_{forest\ area}$]crop yield potential
Fresh water provision[a]	Groundwater recharge G	$G = 1 + \frac{N-312.5-(ET_{class} \times 25)}{A/A_u \times 50}$ (according to Dörhöfer and Josopait, 1980)
Climate regulation	Above-ground carbon storage	Above-ground carbon storage linked to land use [MgC/ha] according to Strohbach and Haase (2012)
	Potential evapotranspiration (ET_p)	ET class (according to Dörhöfer and Josopait, 1980)
Flood regulation	Settlements in floodplains	Settlements in natural floodplains [ha]
Primary production	Net primary production	Net primary production linked to land use [$g/m^2/a$] according to the literature: Larcher (1994), Sitte et al. (1999), Ciais et al. (2010) and Luyssaert et al. (2010)
Recreation	Recreational areas	Recreational areas ≤300 m from settlements (Handley et al., 2003)
Biodiversity	Shore development SD	$SD = \frac{length_{shore}}{2\sqrt{\pi \times area_{lake}}}$
	Landscape Metrics (Fragstats; http://www.umass.edu/landeco/research/fragstats/fragstats.html)	Mean patch size = MPS = A/NP Edge density $= ED = \frac{\sum_{k=1}^{m} e_{ik}}{A} \times 10,000$ Number of patches = NP = N

[a] The amount of water extracted is difficult to measure, as freshwater from the Harz Mountains and the Mulde basin is added to the water in the study area due to the ongoing mining activities. Thus, it is difficult to use, for example, the indicator of "water amount extracted" as a "autochthone and landscape-bond" indicator.

availability of digital data, simplicity and feasibility during planning, applicability to other regions/impacts and transparency in stakeholder discussions. Table 1 lists the algorithms and models used in this study, including the indicators and equations for their calculation. All listed models use publicly and freely available data. The models vary from look-up tables, which help to transfer results from prevailing studies to each region of interest, to empirical models adapted to the study region.

In our method, all algorithms and models have been displayed in a Geographical Information System (ArcGIS). We followed an analogue quantification scheme for all time steps and respective land use patterns: the pre-mining state of 1930, the mining state of 1990, the post-mining recultivation state of 2006 and three land use scenarios for 2050.

All quantitative data were normalised to values between 1 and 10 (Han et al., 2011; Al Shalabi et al., 2006) with the following algorithm:

$$v = (n' - \min) \times \frac{\max(\text{norm}) - \min(\text{norm})}{\max - \min} + \min(\text{norm}) \quad (1)$$

3.2. Land use change mapping

The historic land use of 1930, representing the pre-mining state, was reconstructed using the ArcGIS editor from a scanned, georeferenced historical map (German topographic map series *Messtischblätter*). Future land use changes were constructed from present-day planning maps and documents developed by state authorities (Freistaat Sachsen, 2003a,b, 2004). The number, shape and structure of predicted changed land parcels were estimated on the basis of the pre-mining land use status recorded by the authors and the statistical trends of land use change on the edge of urban agglomerations in Eastern Germany (Kroll and Haase, 2010). Therefore, within each scenario, the number of cells/patches per category of land use was subject to change, as was the structure of land use (when considering the cell/patch neighbourhood).

Using the ArcGIS 9.3 and 10.0 software packages, land use change scenarios were constructed as follows: on the basis of Corine Landcover data (CLC; 2006) and land use classes, each scenario is represented by a number of rules that change land use A (in CLC 2006) to land use B (in one of the scenarios). The rules are given in Table 2 with respect to each land use class. Land use change occurs only in areas that are directly influenced by mining activities.

Scenario I is characterised by a focus on tourism as the dominant form of future land use. In this scenario, the pit lakes are completely flooded (as in the remaining scenarios, according to the current goals of land use planning in Saxony and the natural processes of groundwater rise that occur after mine closure) and new housing estates line the shorelines within a 1 km buffer-zone from prevailing settlements. Flooding entails the enlargement of cells/patches of water up to the top of the relief depression, whereas shore development involves a structural change determined by the location of existing settlement areas and proximity to the new lake shoreline. Natural recreation areas for tourism occur along lake shorelines in remote areas. Forests formerly characteristic of the area now only appear as transitional woodland-shrub. Scenario II is characterised by a maximum agricultural production. Most restored land is used for agriculture; forests remain in some peripheral parts. The pit lakes are also completely flooded. Scenario III is characterised by maximum reforestation. The pit lakes are completely flooded, and no new settlement or commercial areas occur within the restoration area.

4. Results

The historical pre-mining landscape is characterised by a high patchiness of the agricultural land and alluvial forests along the Pleiße and Weiße Elster rivers (Fig. 2). Settlements are arranged within and along the flood plains and waterways. The 1930 landscape is widely occupied by agricultural areas and is virtually lake free. Broad, continuous forested areas occur only in the central part of the study area.

By 1990, the loss of landscape due to mining greatly decreased the amount of arable land (Fig. 2). The open-cut-mines of Cospuden (northwest), Zwenkau (southwest) and Espenhain (east) strongly characterise the 1990 landscape. The majority of forest areas are distinguished by transitional forests and woodland-shrub. The open landscape adjacent to mining areas is sparsely vegetated.

In contrast to the pre-mining and the 1990 landscapes, land use patterns in 2006 were strongly influenced by recultivation and renaturation processes (Fig. 2). In the 2006 landscape, the pit lakes are flooded and up to 10% of new forest (compared with the total forest stand of the area) occurs in former mining areas, primarily dump grounds. Compared with the pre-mining state, the settlement structure is more compact, and the area available for

Table 2
Land use classes (in % of total study area) and transformation procedures for the three scenarios of 2050, based on Corine Land Cover data from 2006. Procedures were developed from present-day planning documents developed for the region by state authorities (Freistaat Sachsen, 2003a,b, 2004). The number and shape of changed land parcels is based on the pre-mining land use status recorded by the authors and statistical trends of land use change on the edge of urban areas in Eastern Germany (Kroll and Haase, 2010).

Land use	CLC 2006	Scenario I	Scenario II	Scenario III	Procedure
Urban fabric	9.7	11	9.7	9.7	Buffers around existing settlements and new lakes
Extraction sites	6	0	0	0	Set to zero
Arable land	45	46	50	46	Depends on scenario description
Greenland and pastures	2.9	3.8	2.9	2.9	Depends on scenario description
Forest	8.1	17	15	19	Transitional woodland change for forest in dependence on scenario description
Transitional woodland-shrub	7.2	0	0	0	Set to zero
Sparsely vegetated areas	3.1	0	0	0	Set to zero
Water bodies	9	14	14	14	Mining lake area after successful flooding

agricultural production is much smaller. However, the entire landscape is characterised by existing open-cut mines.

None of the three scenarios presents land use patterns comparable to the pre-mining state. The strong and dynamic impact of mining on landscapes is heavily reflected in the values of the services the ecosystem provides. This impact is apparent for all values quantified in this analysis (Fig. 3).

The pre-mining state of 1930 is characterised by a balanced combination of different ecosystem services, especially with regard to food supply, recreation, primary production and biodiversity. The high value of food production reflects the widespread presence of agricultural areas. High biodiversity values reflect the heterogeneous landscape and types of land use. The distribution of settlements along forest edges and waterways explains the high indicator value for recreation. High values for primary production stem from the widespread agriculture and large expanses of forest along the rivers.

The extent of ES of the mining state of 1990 differs from that of the pre- and post-mining states. With the exception of the food supply remaining at the mine edges, almost all ES are absent. The high indicator value for fresh water is of limited validity: it results from bare land without surface vegetation (as characteristic of mining areas) while ignoring groundwater pumping. In 2006, patterns of ES provisioning reflect the beginning of the restoration process. The values for recreation and climate regulation increase in response to the increase in forest in former mining areas. Our results suggest that areas subjected to mining activity limit the subsequent provisioning of ES in a region; i.e., the more land is mined the fewer ES can be provided.

Scenario I describes the land use pattern most resembling present-day land use. This scenario presents the most balanced activity of ES of the three scenarios. The values for recreation, fibre and climate regulation are similar (standardised values between 2 and 3). Values for water supply, primary production and biodiversity are slightly higher (5). Scenario I comprises more protected land as a result of extensive tourism and heterogeneous land use. In Scenarios II and III, more homogeneous land uses dominate. More specific land use patterns favour certain ES at the expense of others (Fig. 3); for example, in Scenario III, high values of fibre production and climate regulation accompany low values of biodiversity and food supply. Taken together, our results provide evidence of the potential of restored landscapes to provide ecosystem services. In our assessment, we prefer to use the word "potential ecosystem services" and concur with Bastian et al. (2011) that an ecosystem function converts into a service when a demand for the function or outcome of a natural or ecosystem process arises.

Fig. 4 provides a specific example of the improvement of land use planning via ES-based assessment. It shows an analysis of the potential of ecosystem services as identified in Scenario I. Darker colours indicate higher potentials for the valued ecosystem services. Additionally, the green infrastructure concept of the state regional planning authority "Planungsverband Westsachsen" in the regional plan of 2008 is demarcated by black lines. Approximately 45% of the high potential area identified in our study is already covered by Planungsverband Westsachsen-defined green infrastructure areas. However, 20% of the designated area was identified as having low ecological potential.

5. Discussion

5.1. Explanatory power of the ES indicators

"Although a wealth of information is available on land cover change, both in the form of current vegetation maps and as scenario-based projections, few tools exist for translating this information into relevant indicators of EP [ecosystem properties] or ES [ecosystem services] provision" (Diaz et al., 2007: 20687). The ES evaluation presented in this paper uses historical and current maps as well as scenario-based projections to accommodate the dynamic changes of (post)mining landscapes. We employed a range of simple methods to quantify ES indicators. With the exception of the indicators of net primary production (NPP) and fresh water provision, all indicators were highly relevant and yielded explanatory power. It was difficult to compare NPP among the pre- and post-mining situations. Because of the succession of vegetation towards a climax community, given a set of biophysical conditions (climate, soil, relief, water balance, etc.), and because those conditions changed dramatically as a result of mining, pre-mining biophysical conditions do not apply to the post-mining landscape; therefore, NPP fails as an indicator. With respect to fresh water, in mining areas, groundwater is pumped out, and water-storing sediments are largely removed. Following mine closure, mines are converted into lakes, and water reservoirs and flows are interrupted and/or modified; therefore, comparisons of the fresh water indicator are difficult between pre- and post-mining conditions.

As illustrated by the example in Fig. 4, the approach outlined herein can foster discussion between science, policy and planning groups and encourage review of policies and policy instruments. For Scenario I, we identified areas of high ES provisioning in the southeastern part of the region, close to inactive mines; these areas should be included as part of the protected infrastructure. In contrast, the ES provisioning analysis identified large parts of the protected infrastructure with low ES potential. We recommend

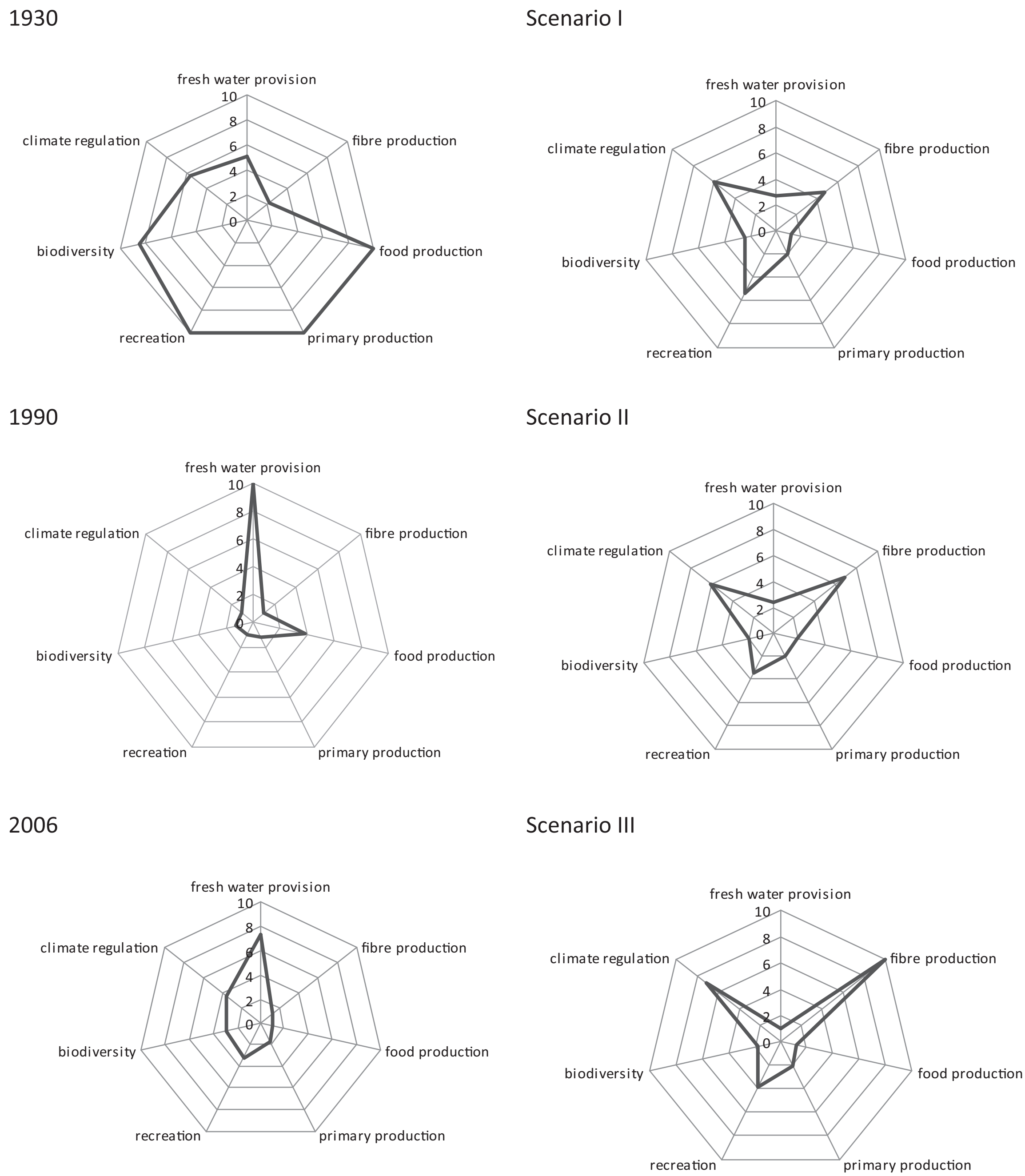

Fig. 3. Spidergrams displaying the provisioning of ES for the different land use states: values are standardised between 1 and 10, where 0 exhibits the lowest, and 10 the highest, value.

using the results of the ES assessment to align this nature protection measure with estimates of expected ES and thereby better protect the area from soil sealing. In so doing, priorities could be established by either focusing on climate change adaption or food and bioenergy production. As argued by Chan (2006: 2150), "the inclusion of ecosystem services in conservation planning has great potential to provide opportunities for biodiversity protection". Simple, ES-based models are useful in stakeholder-planning-processes, as they are easy to understand, use publicly available data and provide high transparency (as required for environmental decision support tools by McIntosh et al. (2006).

5.2. Data and model uncertainty

For the present study, the Corine Land Cover map (1:100,000) and the historical ordinance survey maps from 1930 (1:25,000) were adequate for our purposes. Simple but well-proven algorithms have been also used to assess ES provisioning in Switzerland, in accordance with Staub et al. (2011). In contrast to such simple algorithms, existing dynamic or process-based models are much more temporally and data intensive, but are more precise. To meet the demands of planning policy and to enhance participation in the planning process, assessment and (e)valuation methods must balance scientific accuracy with practical utility. Thus, limitations in accuracy must be tolerated to achieve higher usability.

5.3. Applicability to other regions

Our approach can be applied to other regions, as the selection of ES is flexible and the data are freely and publicly available. The models and algorithms used in the present study have been

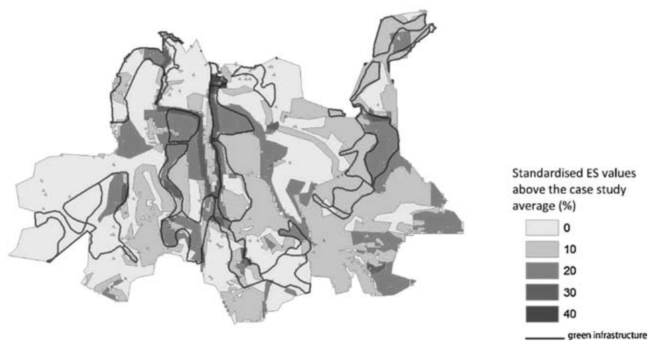

Fig. 4. Analysis of the potential of valued ecosystem services in scenario I. The darker the colour the higher the potential provisioning value above average. Black lines delineate the protected green infrastructure established by the state regional planning authority of Western Saxony (2008). Some areas of high ES value in the southeastern part of the study area, near formerly active mines, lie outside of the protected infrastructure; in contrast, some regions of low ES value in the south of the study lie within the protected region.

validated across Europe and the US, and capture a wide range of biophysical conditions. Our results are also relevant to other studies applying the ES concept to landscape planning and environmental assessment in several regions worldwide, for example, Australia (Ecosystem Services Project, 2001), China (Liu et al., 2008), the Alps (Grêt-Regamey et al., 2008) and Switzerland (Staub et al., 2011). The outcomes of these studies are comparable with respect to the range of values calculated and the resulting spatial patterns.

5.4. Applicability to regional planning

"Throughout the world, land-use decisions are seldom made on the basis of the outcomes of economic valuation studies; they usually are made by officials and politicians—many of whom are poorly informed—or, in functional democracies, by variously informed citizens" (Cowling et al., 2008: 9485). State regional (land use and environmental) planning, particularly in regions affected by mining, could benefit from ES studies like this one. In this paper, we address the scale of the regional planning represented by the Saxon Regional Planning Agency. At this scale, neither in everyday interventions and administrative business nor in steering of nature conservation or restoration projects the value of ecosystems and their functions are rarely considered during the planning process, because the monetary and non-monetary values of ES are still poorly understood (Bastian et al., 2011). Our study suggests that incorporating the ES concept into the planning process can improve assessments of project sustainability. The IA approach is readily understood by policy makers, planners and collaborating scientists and is methodologically transparent, graphical, interdisciplinary and flexible. Therefore, comparisons among different ES and land use changes are tractable.

6. Conclusions

We presented an approach for valuing the impact of mining as well post-mining restoration options. The study represents the first attempt to assess highly dynamic "man-made" landscapes using the concept of ES. As open-cut mining activities continue to increase worldwide, the problems of environmental impacts through mining on the one side as well as planning post-mining landscapes on the other remain crucial.

What did we learn? Our study suggests that it is not practical or possible to restore nature or ecosystems that existed in the pre-mining rural landscape; instead, one can identify future land use solutions that provide places to live, produce food, and supply recreational areas or that can mitigate climate change and temperature rise, a top priority of Saxon state regional planning efforts. This paper offers a comprehensible and reliable tool to assess both pre- and post-mining landscapes and land-use patterns and inform the complex planning process about what natural and ecosystem potential was gone by mining and what new potential restoration offers. We also learned that the concept of ES, combined with simple but well-proven algorithms, can be beneficially used for informing regional planning actors working in (post-)mining landscapes.

What should we do better? Of course, there are shortcomings of the approach presented here, mostly related to the choice of ES and indicators which is not complete and can be expanded. In a next study, we will focus on improving the ES calculation algorthims by finding process-based but still simple solutions for some of the ES. What is more, we will focus more on the uncertainties related to the single algorithms used.

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