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Integrating ecosystem services into spatial planning—A spatial decision support tool

Adrienne Grêt-Regamey[a,*], Jürg Altwegg[b], Elina A. Sirén[a], Maarten J. van Strien[a], Bettina Weibel[a]

[a] Planning of Landscape and Urban Systems, Swiss Federal Institute of Technology (ETH), Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland
[b] Office for Spatial Development, Baudirektion Kanton Zürich, Stampfenbachstrasse 12, 8090 Zurich, Switzerland

HIGHLIGHTS

- Ecosystem services were not considered when planning building zones in Switzerland.
- Considering ecosystem services in planning can alter urban development patterns.
- A web-based tool integrating ecosystem services fosters transdisciplinarity.
- Integrating ecosystem services in spatial planning is most effective in urban peripheries for securing fertile soils.

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ABSTRACT

Urbanization is viewed as endangering more critical habitats of global value and is more ubiquitous than any other human activity affecting biodiversity, climate, water and nutrient cycles at multiple scales. Spatial and landscape planning can help create alternative urban patterns protecting ecosystems and thus supporting the provision of needed services they provide. While many approaches exist to make the values of nature explicit, new tools are needed to interpret the vast quantity of information in an integrated assessment to support planning. In this study, we present a new spatial decision support tool PALM ("Potential Allocation of urban development areas for sustainable Land Management") aimed at supporting the allocation of urban development zones. A GIS-based MCDA approach was integrated into a web-based platform that allows distributing a requested amount of urban development areas within a selected perimeter based on ecosystem services and locational factors. The short running time of different user-defined scenarios allows exploring consequences and tradeoffs between decisions in an interactive way, thus making it a useful tool to support discussions in participatory planning processes. The results of the application of PALM in a case study region in Switzerland show that integrating ecosystem services when distributing urban development areas is particularly effective in urban peripheries, where building zones are shifted towards urban centers securing the productive soils located around cities. This shift of building zones from the urban peripheries to the urban centers when considering ecosystem services is less pronounced in rural areas, as they provide fewer ecosystem services. However, the results also show that integrating ecosystem services in spatial planning needs to be embedded in the right policy context: Ecosystem services can only be traded-off for locational factors if the perimeter of the case study ranges across municipalities. Whereas this transparent and flexible platform offers a suitable tool at the beginning of a planning process, we also discuss further development needs.

1. Introduction

Today more people live in urban than in rural areas (United Nations, 2014): in Northern America and Western Europe, early industrialized areas showed an accelerated increase of urbanization in the 19th century (Antrop, 2004), and today about 75% of Europeans live in cities (EEA, 2015, chap. 2). Urban expansion rates

* Corresponding author.
E-mail addresses: gret@ethz.ch (A. Grêt-Regamey), juerg.altwegg@bd.zh.ch (J. Altwegg), esiren@ethz.ch (E.A. Sirén), vanstrien@ethz.ch (M.J. van Strien), bweibel@ethz.ch (B. Weibel).

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exceed population growth rates (Seto, Fragkias, Güneralp, & Reilly, 2011), and under current trends a tripling of the urban area by 2030 is assumed (Seto, Güneralp, & Hutyra, 2012). The impacts of these growing urban areas on the environment are complex and cover both social and ecological aspects at different scales, ranging from changes in social structures to the loss of ecosystem functions and the provision of their services (Grimm et al., 2008). In general, land use is becoming independent from local ecological conditions and increasingly driven by large scale processes, which results in a loss of traditional landscapes (Antrop, 2004). Although land use policies have been used for decades to drive the expansion of settlement areas and transport infrastructure, spatial planning has only recently started focusing on the design of alternative urban patterns that secure the provision of essential ecosystem services (ES; Wissen Hayek, Teich, Klein, & Grêt-Regamey, 2015).

Different patterns of urban expansion can be related to factors such as capital flows, transportation costs or land use policy (Seto et al., 2011). In Switzerland, urbanization is highly decentralized resulting in a network of relatively small cities with strongest population growth in urban peripheries (Schmid, 2014). Due to topography, settlements are mainly located in the lower areas between the Jura Mountains and the Alps (i.e. Swiss Plateau). The population has increased from 4.7 million inhabitants in 1950 to 8 million in 2013, of which 6 million live in urban areas (FSO, 2013). Between 1985 and 2009 urban areas have increased by over 23% mostly at the expense of agricultural land (mainly grassland). The average land consumption in Switzerland is 407 m^2 per person with large differences across the country (FSO, 2015). In line with the global trend of expanding urban areas, the required space for living in Switzerland has increased two and a half times as fast as the population, which is related to a tendency towards smaller households in combination with higher living space requirements per person (FSO, 2015). A variety of new regulations attempts to limit urban sprawl in urban peripheries in Switzerland, such as (1) the revision of the Swiss national spatial planning regulation in 2013, which prescribes the reduction of building zone reserves in the next years, (2) an initiative from 2012 limiting the amount of second homes to 20% per municipality, or (3) initiatives at the cantonal level to protect cultivated land, which were accepted in 2012 in the canton of Zurich and 2014 in the canton of Berne. Furthermore, the Swiss Biodiversity Strategy requires the conservation of biodiversity within urban areas under Target 6, Action III (FOEN, 2012a). Due to a the Swiss direct democratic policy process requiring consensus, the implementation of these new regulations can be challenging, particularly when municipalities are mandated to unzone valuable building land under the revised national spatial planning law. As several authors have shown (e.g. Pacione, 2003; Scholz, 2011), increasing the acceptance of more sustainable and socially acceptable land use change can be supported by inter- and transdisciplinary collaboration processes. However, tools that support such processes and that facilitate balancing ecological considerations and social aspects of urbanization are rare and have not been implemented in practice in Switzerland.

Integrating ES into spatial planning might be a promising approach towards sustainable development because it supports making such services explicit, and thereby fosters the discussions about tradeoffs between ecological and socio-economic aspects when developing new urban areas. Examples of the use of ES for informing real-world decisions can be found in Ruckelshaus, McKenzie, Tallis, Guerry, Daily and Kareiva (2015) who evaluated the successful applications of ES information in ten spatial planning contexts. Other such examples include, for example, Schaefer et al. (2015), who provided examples of incorporating ES in land use planning in the United States, Arkema et al. (2015), who reported on a ground-breaking effort to use ES values and models within a coastal planning process, or Li et al. (2015), who presented the Relocation and Settlement Program of Southern Shaanxi Province – an ecosystem service protection and human development policy. However, as Rosenthal et al. (2014) state in their five enabling factors of decision-making, providing a set of ES maps alone will probably not change the course of action. Pertinent data need to be combined and applied appropriately in an iterative science-policy process, where decisions are repeatedly revisited. Integrating ES into spatial planning calls thus for transdisciplinary tools and approaches that allow integrating the ES information into decision-making processes.

Efforts are made to develop decision support tools integrating ES, for example, under the umbrella of the EU FP7 projects OPERAs (http://www.operas-project.eu/) and OpenNESS (http://www.openness-project.eu/), but the choice of the appropriate tool remains difficult because they differ in their complexity, transferability, time and data requirements. Reviewing seventeen decision support tools, Bagstad et al. (2013) found that the tools vary highly in their applicability to different locations and decision contexts, and many tools were considered to be too cost and time consuming to be widely applicable. These authors identified a large tradeoff between complex, resource intensive tools with high accuracies and simple but more transparent approaches. In general, the availability and accessibility of data were identified as major challenges (Bagstad, Semmens, Waage, & Winthrop, 2013). In order to determine the suitability of land for a certain use, multi-criteria decision analysis (MCDA) approaches have been identified as highly useful, as they allow integrating different aspects of decision-making and preferences while maintaining high transparency (Malczewski, 2006). Although MCDA approaches are potentially time consuming, technically complex and dependent on the willingness of stakeholders to participate, they facilitate structuring the decision process and making tradeoffs explicit (Gamper & Turcanu, 2007). The possibility to integrate stakeholder preferences by individual selections of criteria and weights, facilitates consensus finding, makes planning processes more efficient and the options more realizable, as they are likely to become more widely accepted (Boroushaki & Malczewski, 2010). This promotes stakeholder involvement especially for decisions about the allocation of scarce resources, which bear a high conflict potential due to conflicting interests between involved stakeholders and tradeoffs between economic, ecological and social aspects (Gamper & Turcanu, 2007). Ianni and Geneletti (2010) for example show how participatory workshops and expert panels can help reduce costs of integrating more criteria and better manage bias. ES were, for example, integrated as criteria in MCDA approaches to evaluate renewable energy sites (Grêt-Regamey & Wissen Hayek, 2012) or to study the effects of land use change on ES provision (Fontana et al., 2013). Geneletti (2010) and Geneletti and van Duren (2008) used a set of nature's services to rank landfill sites and to evaluate protected area zoning, respectively. Also for strategic urban planning, ecosystem functions were integrated into a MCDA-based spatial decision support tool (Schetke, Haase, & Kötter, 2012). Focusing on forest management, Uhde et al. (2015) provide a recent review on how ES can be integrated into MCDA methods.

In this article, we present a new spatial decision support tool aimed at supporting the allocation of urban development zones. An MCDA approach was integrated into a web-based platform that allows distributing a requested amount of urban development areas within a selected perimeter. The MCDA integrates both ES and locational factors. Locational factors are assumed to determine suitable locations for buildings and are often used in standard urban economic models to determine land price (e.g. Alonso, 1964). After describing the development of the new tool called PALM ("Potential Allocation of urban development areas for sustainable Land Management"), we present how PALM was tested in an interactive workshop with a regional development planning group in the

frame of a regional planning process. We then assess and compare tradeoffs in ES and locational factors between urban centers, their periphery, and the rural land surrounding the urbanized areas to support the formulation of sustainable planning approaches in fast growing Swiss urban peripheries. Finally, we investigate the sensitivity of the tool to stakeholders' weighting of the ES and locational factors. PALM is currently being used in Switzerland to support the debate about and planning of a suitable allocation of building zone reserves. Its generic set-up can, however, also be further developed to inform various broader debates about the tradeoffs between environmental, social and economic aspects of land use allocation. We conclude with a discussion of possible applications of PALM and an outlook on further development of the presented tool.

2. Methods

We developed an MCDA approach to support the allocation of urban development areas with regard to ES and locational factors, and implemented it on a web-based spatial decision support platform. PALM aims at supporting the involvement of various stakeholders in decision processes related to the revised Swiss spatial planning regulation. In the following, we describe how the MCDA was set-up, implemented into the web-based platform and applied to a case study in Switzerland.

2.1. Set-up of the PALM web-tool

The PALM web-tool was developed in eight steps (Fig. 1): (1) we defined the main goals for sustainable development in the case study area. (2) These main goals were then operationalized into fifteen evaluation criteria including seven ES and eight locational factors. Nine constraint layers demarcated areas not suitable for development, which were a priori excluded from the analysis. (3) The criteria were transformed to comparable units (standardization) using a Delphi approach (Linstone & Turoff, 1975): a group facilitation technique seeking to obtain consensus on the opinions of experts through a series of structured questionnaires. (4) Decision-maker preferences for the various criteria and goals were assessed in a workshop with stakeholders. (5) Using a simple additive weighting approach as decision rule, weighted criteria were aggregated, generating suitability maps for urban development. This analysis was performed for the categories urban centers, their periphery, and the rural land surrounding the urbanized areas in the case study region of Thun to evaluate trade-offs in ecosystem services. (6) A sensitivity analysis was conducted to test the sensitivity of the distribution of the building zones to the stakeholder weightings. More information about the MCDA approach is given in Altwegg (2014). (7) The MCDA was then integrated into a web-based spatial decision support platform to be useable by the public. (8) Finally, the PALM tool was used in a workshop in the frame of a regional planning process with stakeholders from the case study area. The individual steps are described in more details in the following sections. The project was carried out over a period of three years from 2010 to 2013 in a transdisciplinary process accompanied by a group of experts described in Appendix A in the Supplementary files.

2.1.1. Definition of main goals for sustainable development

As Keeney and Raiffa (1976) describe, MCDA problems are not "given", they are "decisions that matter". In a first meeting with the expert group accompanying the project, main goals of sustainable development in the case study area were collected in a "post-it" session. Contemporary Swiss spatial planning mainly considers economic criteria, while ecological and social aspects are usually not included in locational choices. The two main goals defined by the experts to follow in the MCDA were to (i) minimize impacts on ES and (ii) maximize the potential for economic development.

2.1.2. Criteria and constraint maps

A comprehensive set of criteria to operationalize the two goals defined in step 1 was defined. The selection was based on the following six principles: criteria needed to be representative, global and measureable, coherent and independent, cohesive, and available in the whole study area. The selection of criteria was validated by the expert group in a second workshop. Each criterion and constraint factor was then mapped using the datasets and analyses described in Table 1 in a 1 ha raster.

2.1.3. Standardization of the criteria and constraint maps

For standardization, the criteria maps were transformed to values between 0 and 1000 using value functions (Keeney & Raiffa, 1976). Using a Delphi approach, we asked three to five anonymous experts for each criterion to complete structured questionnaires for transforming the raw criterion values into standardized scores. A series of two questionnaires was set up asking the experts to relate the criteria values to a scale, which reflected their opinion regarding the suitability of a certain criterion value for urban development. For this the mid-point value method was used (Farquhar, 1984). The responses from the first questionnaire were fed back in summarized form to the same experts for a second round, in which they were given the opportunity to adjust their first evaluation if considered necessary. The averages of the final value functions provided by the experts were used to standardize the raw criterion data. The value of the least-desirable outcome was set to 0 and 1000 was set to be the most-desirable score. A catalogue of all standardized criteria and constraint maps with their value function is available in Appendix B in the Supplementary files. All the georeferenced maps are also available electronically in the PALM tool under www.palm.ethz.ch (requires user registration).

2.1.4. Decision-makers' weighting preferences

Decision-makers can assign a weight to an evaluation criterion to indicate its importance relative to the other criteria under consideration. We used a simple rating method, in which decision-makers were asked to weigh individual criteria with a percentage score in such a way that the total percentage summed to 100% for all criteria. Values of 0% were allowed.

2.1.5. Aggregation with decision rule

Using the statistical programming software R (R Core Team, 2015), a suitability index V_k for each 1 ha raster cell (k), except for the cells included in the constraints maps, was estimated using a simple additive weighting approach as follows:

$$V_k = \sum_{i=0}^{m=8} w_i \times r_{ik} + \sum_{j=0}^{n=7} w_j \times s_{jk}$$

where w_i and w_j describe the stakeholder defined weight for each of the eight locational factors i or seven ES criteria j, respectively, and r_{ik} and s_{jk} the value of the locational factor i or ES criterion j, respectively, at raster cell k. The standardized and weighted values at each raster cell were summed up over the m locational factors and the n ES criterion to provide a suitability index, V_k. In order to avoid an overly scattered distribution of building zones, we implemented an algorithm to search for clusters of highly suitable zones. Raster cells were only selected as building zones if they were either neighboring other rasters with a high suitability or bordering to existing built areas. Thus, each selected urban development area consisted of minimally two highly suitable raster cells, unless it was neighboring existing built area.

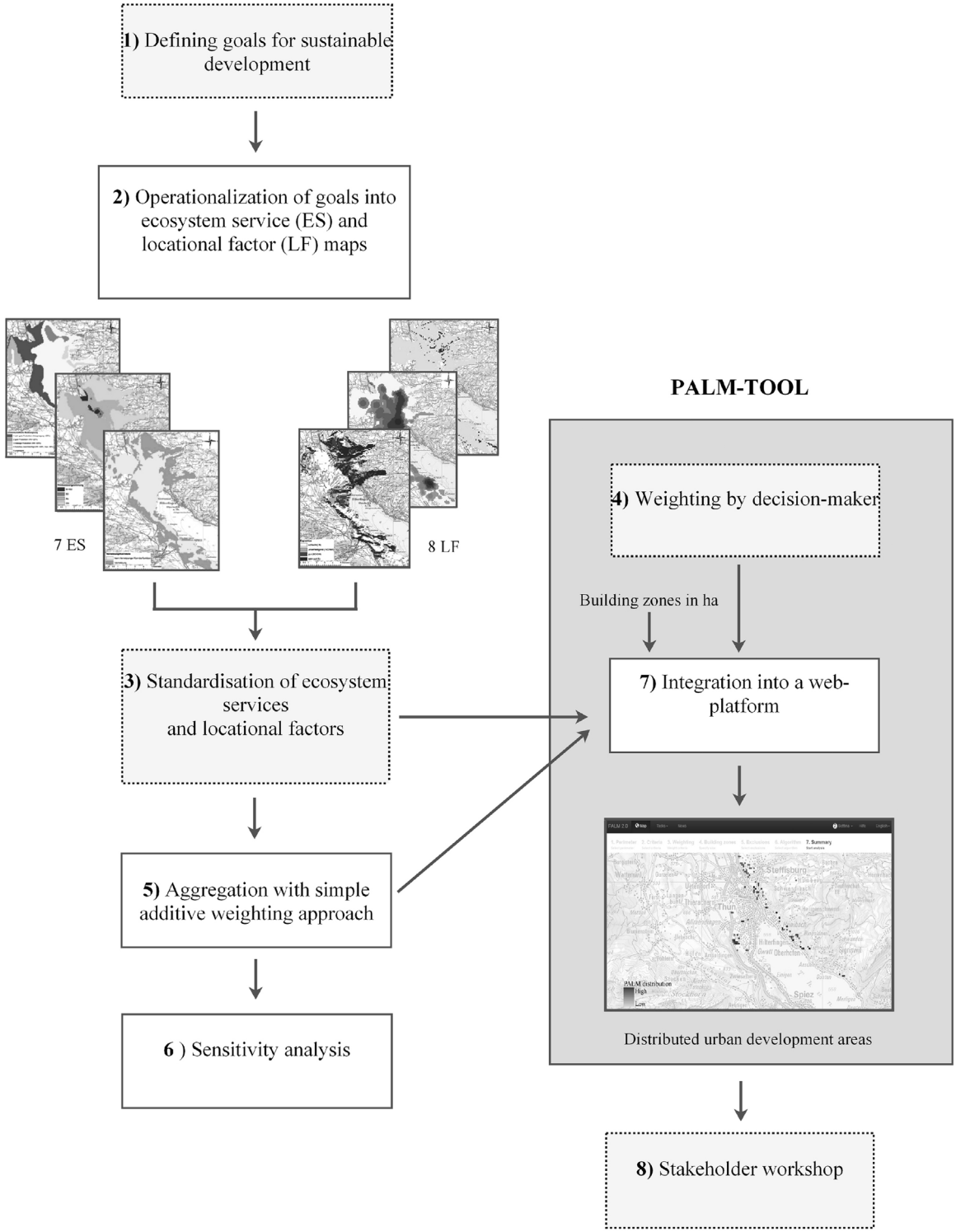

Fig. 1. Workflow for setting-up the GIS-based MCDA web-tool PALM for supporting sustainable spatial development.

2.1.6. Sensitivity analysis

We explored the effect of a step-wise increase of the weight of a single criterion by 5% on the change in suitability for urban development, while all other criteria were weighted equally and all weights summed to 100%. We analyzed the sensitivity of the prioritization of a set of eleven designated development sites to the criteria and weights. In order to efficiently iterate through the different weighting values, the sensitivity analysis was performed with a version of PALM that ran completely in R (opposed to using the web-based PALM platform, see below).

2.1.7. Development of the web-based spatial decision support tool PALM

We integrated the described MCDA approach into a web-based spatial decision support platform. The resulting PALM tool is available on the web under www.palm.ethz.ch and is thus accessible to various stakeholders independent of a specific software or of

Table 1
List of criteria identified and mapped as inputs for the MCDA. ES = ecosystem service, LF = locational factor, CF = constraint factor.

Criterion	Type	Description	Indicator
Food production	ES	Soil suitability for food production	Soil suitability map (FSO, 2000)
Groundwater recharge	ES	Rate of groundwater recharge (regulation and filtering in the soil)	Estimated monthly recharge values 1981–2000 based on model PREVAH (Zappa, 2002; Viviroli, Zappa, Gurtz, & Weingartner, 2009)
Drinking water production	ES	Groundwater protection areas in drinking water catchments	Groundwater protection areas (FOEN, 2015)
Ecological connectivity	ES	Areas of high ecological connectivity	Protected sites (REN) (FOEN, 2011) and wildlife corridor maps (FOEN, 2013)
Public recreation spaces	ES	Recreation areas within settlements – 400 m buffer (reachable within 15 min by foot)	Land Use Statistics (FSO, 2009)
Quiet recreation areas	ES	Areas without noise that would disturb recreation	Noise database sonBASE (FOEN, 2009)
Quiet residential areas	ES	Areas with noise level below threshold for living	Noise database sonBASE (FOEN, 2009)
Exposition	LF	South facing slopes are preferred for living	DEM Swisstopo (Swisstopo, 2007)
Natural hazards	LF	The higher the natural hazard risk the less suitable for development	Natural hazard maps – available at each cantonal administration
Infrastructure for public transport	LF	According to public transportation accessibility categories	Infoplan (Period 2012–2013) (FOSD, 2012a)
Accessibility by private transportation	LF	Distance to next highway exit	TLM Swisstopo (Swisstopo, 2013)
Distance to settlement	LF	Short distances are preferred for concentrated development	TLM Swisstopo (Swisstopo, 2013)
Distance to utility services	LF	Distance to services such as shopping centers and public infrastructure	Business Census (FSO, 2008)
Building costs	LF	Costs for development depending on slope gradient	DEM Swisstopo (Swisstopo, 2007)
Visibility	LF	Locations with nice views are preferred for living	Visibility Map© HSR (Lienhard & Binna, 2013)
Drinking water protection	CF	Groundwater protection areas	Groundwater protection areas (FOEN, 2015)
Biodiversity	CF	Protected Areas	Federal Inventory of Landscapes and Natural Monuments of National Importance (FOEN, 2006)
Agricultural production potential	CF	Protected areas of high agricultural production potential	Inventory of Agricultural Production Potential – property of cantons
Forest area	CF	Forest areas are excluded from development	Land Use Statistics (FSO, 2009)
Natural hazards (considerable)	CF	Areas of considerable natural hazard risk are excluded from development	Natural hazard maps – available at each cantonal administration
Recreation areas and green spaces	CF	Recreation areas and public green spaces within settlements including public parks, sport facilities and graveyards	Land Use Statistics (FSO, 2009)
Traffic areas	CF	Traffic infrastructure is excluded from development	Land Use Statistics (FSO, 2009)
Water bodies	CF	Water bodies are excluded from development	Land Use Statistics (FSO, 2009)
Elevation (>2000 m asl)	CF	Areas above 2000 m als are excluded from development	DEM Swisstopo (Swisstopo, 2007)

expert knowledge (see Appendix C in the Supplementary files for a screenshot of the PALM tool). PALM is basically a web application that runs an MCDA with geographic data. The MCDA is written in R, and the web-platform runs the script using criteria and constraint factor maps stored in a PostgreSQL spatial database. PostGIS is used to add support for geographic objects allowing location queries to be run in SQL.

The user can register on the web-platform to create an account where all the personal analyses are archived and where additional data, such as other criteria maps, can be uploaded to a personal workspace. Different types of account (i.e. roles) provide a range of accesses to the tool: "anonymous" users can only view the criteria maps but cannot perform analyses, "users" can additionally perform analyses for a requested perimeter and "editors" are also allowed to upload own datasets to their workspace. Role changes as well as access to certain communities or cantons can be requested on the platform. A short help page as well as the option to report bugs is available. The different steps of the analysis described above are also provided in a summarized form in the tool and shown on the top of the page to guide the user. The first step includes the selection of the perimeter of the analysis, where municipalities or whole cantons can be selected interactively on a map. In the next step, a set of standardized criteria can be selected, which are displayed on a map of Switzerland and are accompanied by a description on how the criterion was mapped and how its value function was generated. This information can be turned on or off interactively. Subsequently, the user can assign weights to the criteria and define the amount of urban development area (in hectares) to be distributed (either for the whole canton/perimeter or for each individual municipality). Finally, the user can select constraint factors presented in a similar manner as the other criteria. Existing built areas are automatically excluded from the potential building zones. The input settings (criteria, constraints, weighting, and development area) are summarized before the user can decide to run the analysis; it is possible to go back and forth between the different steps to make changes to the input settings. Results are displayed on an interactive map and can be integrated into standard GIS programs via Web Map Services WMS. The MCDA analysis takes up to a few seconds to run (depending on the size of the specified perimeter), which allows running several scenarios within several minutes. A message queue system avoids blocking the system when multiple MCDA are requested at the same time.

2.1.8. *Test of the interactive PALM web-tool in a workshop*

The PALM web-tool was used in the frame of a regional planning process aimed at defining a structural regional plan. A 2.5 h stakeholder workshop was run with interested members of the association Development Area Thun (DAT), which is an organization that supports the development and awareness of the region and represents the municipalities in supra-municipal planning and development issues (DAT, 2014). The workshop was initiated by the DAT that was interested in how ecological aspects could be considered in the regional planning process and the prioritization of their development sites, and how the PALM tool could support such a process. During the workshop, participants were first introduced to the new spatial planning requirements as defined in the revised Swiss spatial planning regulation as well as in the national biodiversity strategy currently being outlined. The functionalities of the tool were illustrated and important results generated by the PALM tool for the case study region were presented. After the partici-

pants were familiarized with the ES criteria and locational factors included in PALM and the principle of weighing these criteria to calculate a suitability map, these principles were applied to a spatial planning issue that was particularly relevant for the DAT members. For a selection of industrial sites that were designated to be restructured for working and living, the DAT members were interested to determine the ranking of these sites with respect to ES and locational factors. The values of the ES criteria and the locational factors that are also used in PALM were extracted for each of these industrial sites. After a coffee break that provided the possibility for an informal exchange, the PALM tool was tested interactively in three groups, each accompanied by a researcher. The participants discussed the weighting of the criteria and assessed the suitability for development of the designated restructuring sites located in the main urban center of the case study area.

2.2. Case study area

2.2.1. Spatial planning context

The spatial planning process in Switzerland is organized across three spatial scales. At the *national level* instruments, concepts and sectoral plans for aspects of national interest are defined (Fig. 2). *The 26 cantons* are then responsible for the implementation of the spatial planning regulation including the design of a structural plan for their canton, which gives them a high autonomy and provides possibilities for locally adapted solutions while maintaining a harmonization and coordination at the national level. According to revised spatial regulation of 2013, structural plans need to be updated and revised every 10 years or earlier if necessary. All structural plans are made available to the public and need to be accepted by the cantonal government before final acceptance by the national government. At the smallest scale, *municipalities* develop land-use plans that define the use in different zones (usually building, agriculture and conservation zones) in a binding manner for landowners. Revisions of these land-use plans have to be accepted in a public vote in the municipality or the municipal parliament and approved by the canton. Recently, the Swiss Office of Agriculture requested that this multi-scale participatory land allocation process should be supported by a tool that considers ES in a comprehensive manner, makes nature's services explicit and allows analyzing potential impacts of the land use plans on ES. Such a tool also supports one of the main principles of the Federal Constitution of the Swiss Confederation; to "achieve a balanced and sustainable relationship between nature and its capacity to renew itself" (Art. 73 Swiss Constitution, Sustainable development). The request led to the development of the here presented PALM tool.

2.2.2. The region of Thun, Switzerland

The region of Thun is located about 30 km south-east of the Swiss capital Berne at the head of the lake Thun close to the Swiss Alps Jungfrau-Aletsch UNESCO World Heritage site (Fig. 3). The study area covers 18,023 ha, and is home to 106,483 inhabitants (Canton of Berne, 2013). The area encompasses thirteen municipalities around the lake Thun, which are part of the DAT. About 40% of the land is used for agriculture, 30% for settlement and 25% for forest with considerable differences between the municipalities (DAT, 2012).

In the strategic national planning development concept "Raumkonzept Schweiz" (FOSD, 2012b), the region is described as part of the metropolitan region of Berne with four urban centers (Heimberg, Thun, Spiez, Steffisburg), five urban peripheries (Seftigen, Uttigen, Uetendorf, Hilterfingen, Oberhofen) and four rural areas near centers (Wattenwil, Thierachern, Wimmis, Sigriswil) (Canton of Berne, 2014). According to this development concept, urban areas such as the city of Thun should be densified with high quality development areas, whereas further sprawl should be limited in urban peripheries such as those in the surroundings of Thun.

Over the last decades, population has increased by about 10%, fostering a high demand for urban development areas. Based on a procedure suggested in the structural plan of the canton of Berne currently in revision (Canton of Berne, 2014), a business-as-usual scenario of a further population growth of 10.5% until 2038 would lead to a theoretical need for building zones of 158 ha for the case study region. For each municipality type, the structural plan provides target densification values (88 p/ha in urban centers, 43 p/ha for urban peripheries and 37 p/ha for rural areas near centers) as well as estimated population growth. By combining this data the theoretical need for new building areas can be calculated (Table 2). Considering that the region currently has 113 ha of available building zone reserves, an additional 45 ha of new building zones would have to be allocated in the next 20 years. Urban centers have in general the largest theoretical need for new building zones. The center of Thun will need an area of 36 ha by 2038 to accommodate the expected population growth, while Heimberg and Spiez have to reduce their building reserves (Table 2). For municipalities with a densification value below the target value, the structural plan proposes that the actual demand for building zones is reduced by 1/3. As Heimberg, Spiez and Steffisburg do currently not reach these target values, their demand will additionally be reduced by a third to foster densification. Urban peripheries are expected to grow considerably in the next decades, thus most of the municipalities in these areas need new building zones, except in Uttigen; a small municipality in the north of the region. In contrast, most of the rural areas need to reduce their building zone reserves according to the structural plan of the canton of Berne as these municipalities are expected to have a negative population growth.

3. Results

We compared the actual distribution of 113 ha of available building zone reserves with the distribution of 113 ha modeled with PALM when selecting all ES and locational factors and weighing the fifteen criteria equally (each by 100/15) (Fig. 4). We observe that the current building zone reserves are distributed across all municipalities in a scattered pattern. However, a distribution minimizing the impact on ES while maximising locational factors would concentrate the building zones in six of the thirteen municipalities including Steffisburg, Thun and Spiez as well as along the eastern shore of the lake Thun. The PALM distribution is more compact and shows little overlap with the current distribution. High suitability values for development are found in every municipality, and tend to correspond to highly accessible areas close to city centers at lower elevations.

In the above analysis all ES criteria and locational factors were considered in the PALM analysis. If only equally weighted ES criteria are considered in PALM, building zone reserves are shifted from the urban peripheries and the rural areas to the urban centers (Fig. 5). In contrast, when solely considering locational factors, only those building zone reserves located in rural areas are shifted to the urban centers.

We also compared the average value of the individual ES criteria between the current building zone reserves and the building zone reserves when they are redistributed with PALM only considering equally weighted ES (Fig. 6). We found that especially food production, quiet recreational areas, public recreational spaces and ecological connectivity can be fostered in urban centers, urban peripheries and rural areas when building zones would be distributed based on maximising ES provision. When building zone reserves are redistributed with PALM only considering ES, urban peripheries can particularly foster food production by preventing

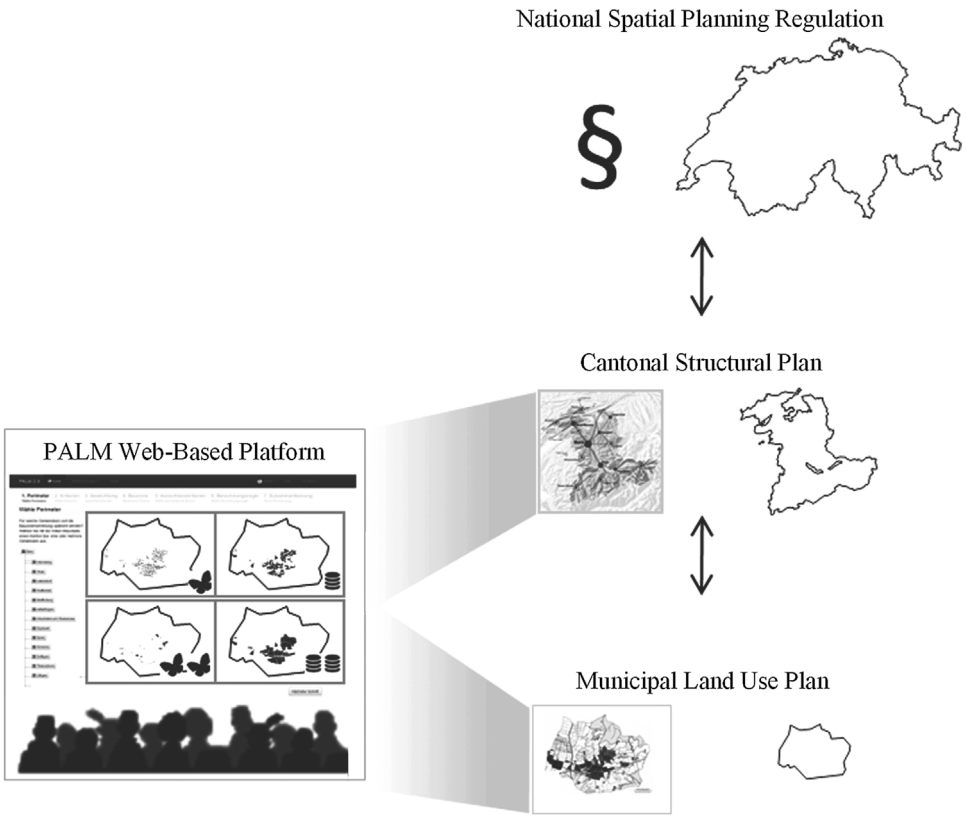

Fig. 2. Multi-scale spatial planning process in Switzerland. The MCDA-based PALM tool is particularly suitable to support the participatory land allocation process at the cantonal and municipal level.

Table 2
Need for new building zones for the thirteen municipalities of the region of Thun. The theoretical need is based on the expected population growth and a density threshold, the current reserve accounts for all building zones that are outside current settlement areas and are accessible.

Regional classification	Municipality	Theoretical Demand [ha]	Current Reserve [ha]	Actual Demand [ha]
Urban centers (density threshold of 88 persons/ha)	Heimberg	9.1	14.5	−5.4
	Spiez	16.6	16.9	−0.3
	Steffisburg	21.7	15.6	6.1
	Thun	68.8	33.0	35.8
Urban peripheries (density threshold of 43 persons/ha)	Uetendorf	9.9	3.8	6.1
	Uttigen	3.6	4.1	−0.5
	Hilterfingen	8.3	5.9	2.4
	Oberhofen am Thunersee	4.7	3.3	1.4
	Seftigen	3.9	2.1	1.8
Rural areas near centers (density threshold of 37 persons/ha)	Wattenwil	2.4	2.8	−0.4
	Wimmis	2.5	3.8	−1.3
	Thierachern	2.4	1.2	1.2
	Sigriswil	3.7	5.7	−2.0

good soils to be sealed (Fig. 6). Ground water recharge, ecological connectivity, and quiet recreational areas are also fostered in the urban peripheries and the rural areas when ES are considered. In the urban centers and rural areas, the suitability values of the building zones with regard to public green spaces increase.

Whereas we redistributed building zone reserves with PALM considering various criteria in the first part of the results, the potential for densification is a key issue in the case study region. The main question leading the stakeholders through the workshop was to evaluate the potential of various sites for restructuring in the urban center of Thun. Therefore, we selected 11 sites in Thun that mainly consist of industrial areas planned to be restructured for living and working. Using the interactive PALM web-tool, the participants discussed first the selected criteria and their weights to better understand the effect of the different factors on the distribution of building zones in the region of Thun. During more than one hour, participants then avidly exchanged opinions regarding appropriate criteria and weights to reach an agreement on the site to be restructured first. Main questions raised by the participants included the given data format (raster) and how easily other formats such as shapefiles or tables could be implemented as well as the resolution (1 ha) of the outputs which are a relevant information regarding accuracy and precision. Other requests for further development of the tool included the option to allocate different types of urban development areas, the possibility to display 3D visualizations of densification scenarios and the integration of policy regulations such as the restriction of second homes or development goals. Fig. 7 shows that the suitability values for the restructuring sites differ considerably between an evaluation based on locational factors and ES. Area 2 was, however, always among the least suitable ones,

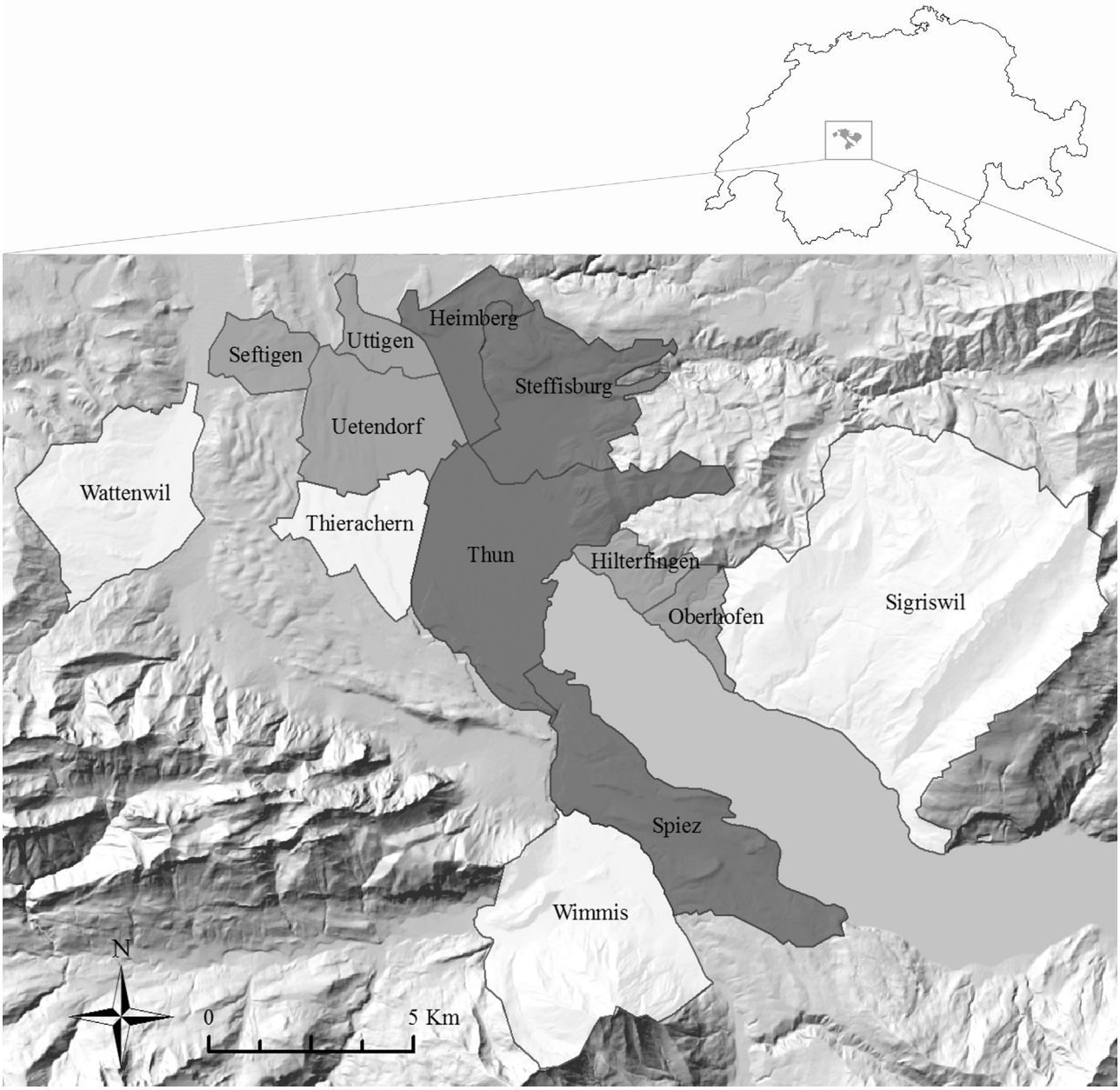

Fig. 3. Overview of the thirteen municipalities of the study area around the lake Thun, Switzerland (Swisstopo, 2007, 2014). Municipalities which are categorised as urban centers are represented in dark grey, urban peripheries in light grey, and rural areas near centers in white (Canton of Berne, 2014).

whereas the ranking of the most favorable site shows little overlap between ES and locational factors. An integrated assessment including both ES and locational factors indicated suitable sites in Steffisburg and Thun with low values for the biggest area (0 ESP Thun Nord) due to low values for public green spaces, accessibility by public and private transportation, distance to utility services, exposition and visibility.

To give an impression of sensitivity changing the weights of the ES criteria and locational factors for the 11 restructuring sites in Thun, we assessed the overall suitability for development for incrementally changing weights of individual criteria (weights for the other criteria being equal; Fig. 8). The average suitability value across all sites and criteria is 649 when the 15 criteria are each weighted equally. For all of the ES criteria, there is a linear increase of suitability values with increasing weight, meaning that the more weight is assigned to a certain ES, the higher is the suitability of the sites for development. Increasing the weight of a criterion with a relatively low suitability for building results in a declining trend and one with a relatively high suitability for building in an increasing trend. The rate of suitability increase with weight increase is highest for drinking water production and ecological connectivity. Many of the restructuring sites, which are located within urban areas, only provide few ES (giving them all a relatively high suitability for development). The locational factors show a different pattern with increasing weights: For the location factor "distance to settlement" and "natural hazards" the suitability values increase with increasing weight, while for the other factors the suitability values decrease with increasing weight. This decrease is most accentuated for the locational factors "distance to utility services" and the "visibility" due to very low provision of these factors across all sites. The suitability of the other decreasing factors is low but tends to show a higher variability between sites.

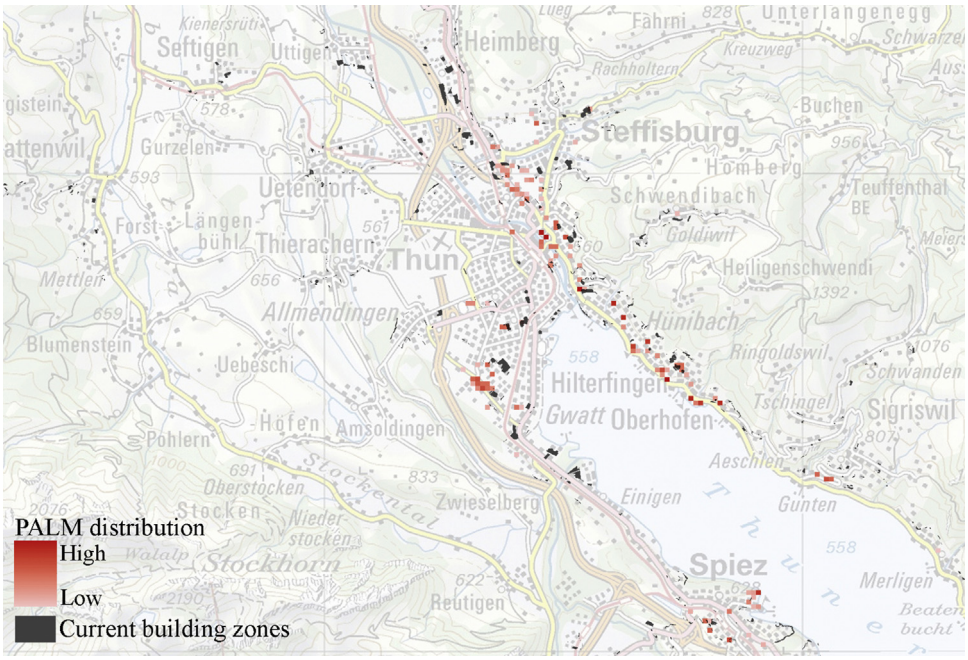

Fig. 4. Spatial overlay of the current distribution of 113 ha of building zone reserves (gray) with the distribution calculated with PALM when selecting all fifteen criteria and weighing them equally (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

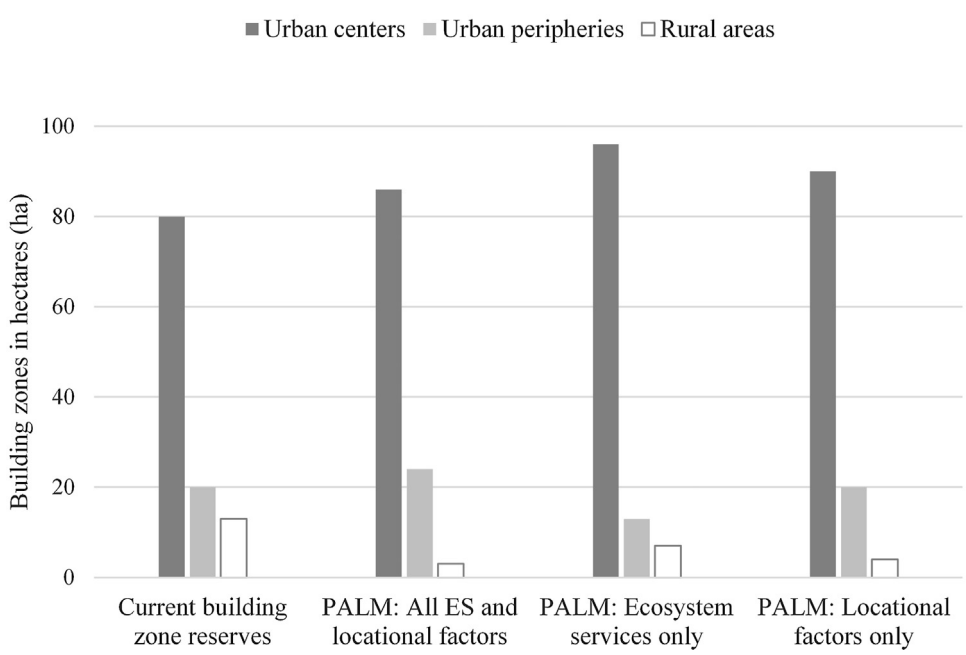

Fig. 5. PALM calculated distribution of current building zone reserves (113 ha) considering locational factors and ES, together respectively separately.

4. Discussion

Limiting urban sprawl to halter the loss of valuable land and restrict negative impacts on the environment, while still enabling economic growth and acknowledging local development pathways, is a challenging spatial planning task. Clearly, there is a need to better balance economic, ecological and social aspects in planning processes. In this study, we showed how a GIS-based MCDA approach allows integrating various criteria including ES and locational factors to guide land use allocation and evaluate tradeoffs between different urban development options. The implementation of the MCDA approach into the web-based spatial decision support tool PALM makes it widely accessible, facilitating participation of stakeholders. The interactive PALM tool provides two main contributions required to adapt planning processes to current challenges: (1) raising awareness about nature's limited resources and (2) integrating stakeholder preferences by individual selections of criteria and weights. These contributions are discussed in more detail in the next paragraphs.

Making a set of criteria including ES available in a spatial planning process raises awareness about nature's limited resources, which might otherwise not be recognized by stakeholders. The results of the application of PALM in a case study region in Switzerland show that considering ES when redistributing building

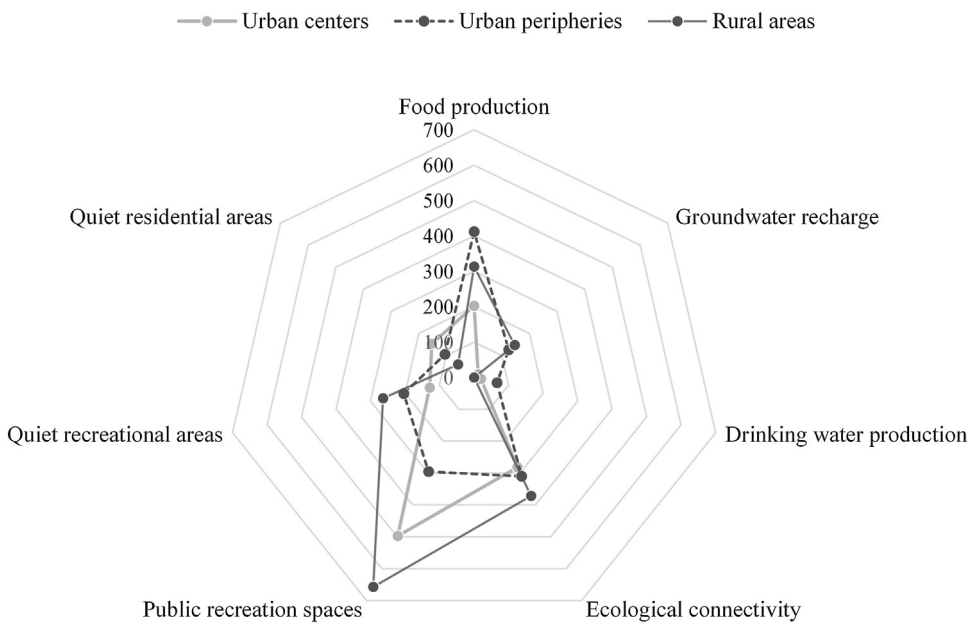

Fig. 6. Trade-offs in ES when considering ecosystem services in redistributing building zone reserves in the case study region with PALM. The values show the differences between the ES values averaged over the current building zone reserves and the mean ES values of the PALM-distributed building zone reserves (considering all ES criteria and weighing them equally). Here we assume that ES are lost as soon as the area is used for urban development.

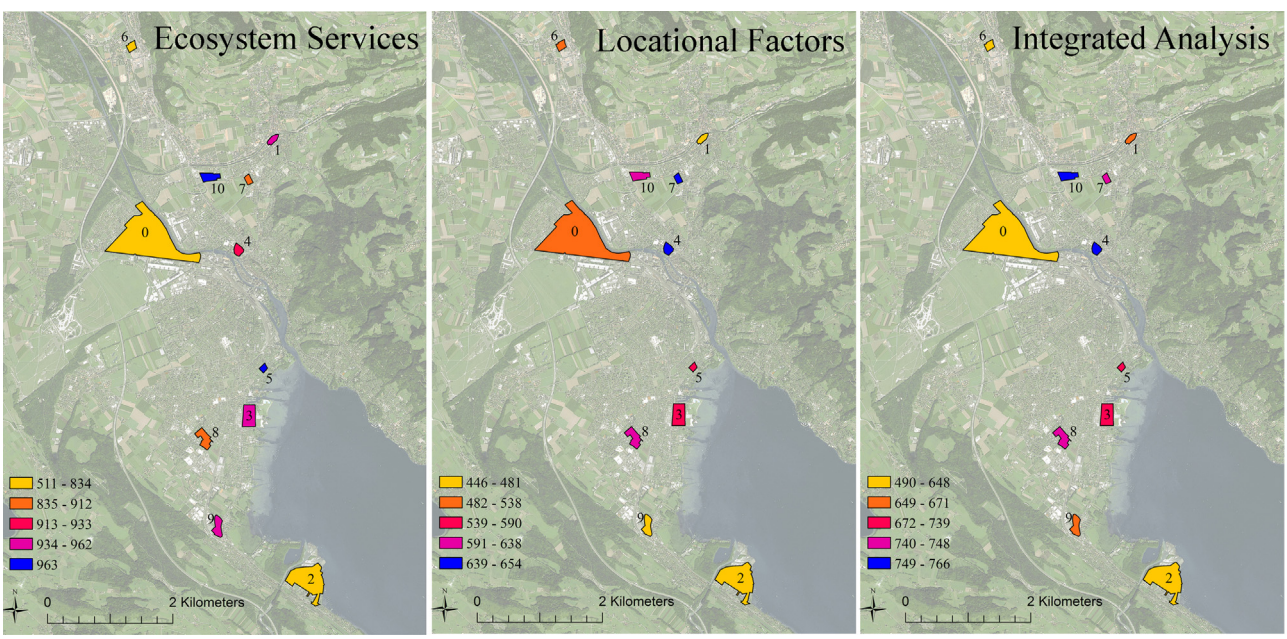

Fig. 7. Suitability values of restructuring sites in the urban center of Thun calculated by taking the average from all of the ES criteria per site (left), the average of the locational factors per site (middle) and the average of both ES and locational factors per site (right). The suitability values are classified according to quantiles. 0–ESP Thun Nord, 1–Dükerweg, 2–Kandergrien, 3–Areal Lachen, 4–Grabengut, 5–Gymermatte, 6–ZPP Nr. 7, 7–Hodelmatte, 8–Bostudenzelg, 9–Rösslimatte, 10–Bahnhofstrasse.

zones is particularly effective in urban peripheries, which are characterized by flat and productive soils supplying crucial ES for the inhabitants of urban centers. By integrating ES into PALM, building zones located in urban peripheries are shifted towards urban centers securing the productive soils located around cities. This effect will even be more pronounced in the future as demand for both ES and building zones in urban peripheries is likely to increase with the expected population growth (Verburg, Eickhout, & van Meijl, 2008) – a trend, which is readily observable in our case study region. This shift of building zones from the urban peripheries to the urban centers when considering ES is less pronounced in rural areas, as they provide fewer ES. However, while the use of PALM shows the importance of considering ES for steering spatial planning decisions, the implementation of such a tool in practice needs be embedded in the right policy context. PALM demonstrates that ES can only be traded-off for locational factors if the perimeter of the case study ranges across municipalities. Planning across administrative boundaries is currently required under the revised spatial planning regulation in Switzerland, but is still difficult to implement. The application of PALM in other case studies not presented here has, however, shown that the platform can indeed support such a planning process over administrative boundaries.

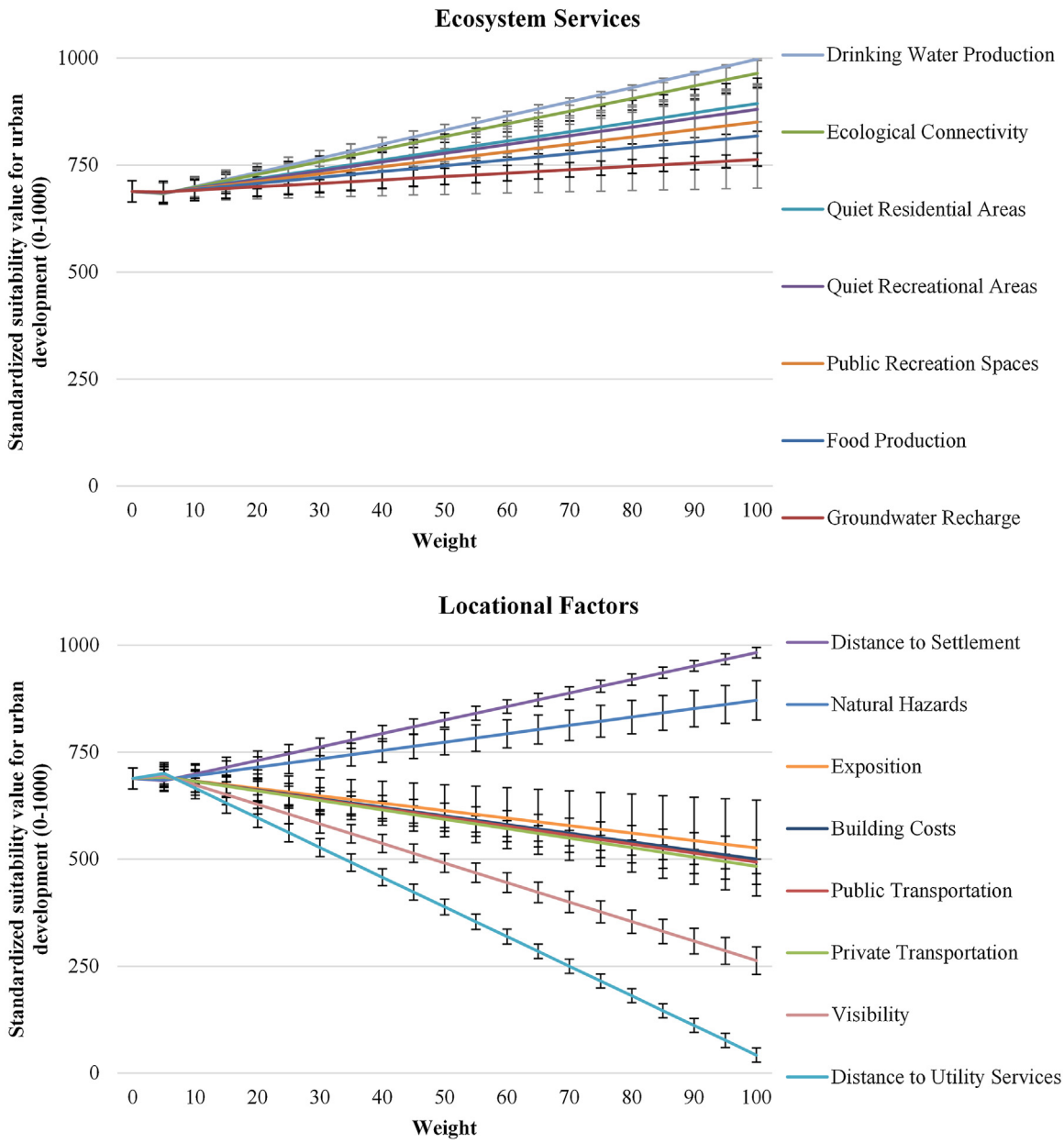

Fig. 8. Sensitivity of the suitability values for urban development to a step-wise increase of the weighting of ecosystem services (top) and locational factors (bottom). Variability between the restructuring sites (Fig. 7) is indicated by standard error bars.

For planning processes in Switzerland, widely acceptable solutions are needed to pass the public vote. While one of the main objectives of an MCDA is to integrate various aspects into an analysis and explicitly quantify tradeoffs, many MCDAs have dealt with tradeoffs in the form of the weights expressed by stakeholders (e.g. Brown, Tompkins, & Adger, 2001; van Huylenbroeck, 1997). Furthermore, there is usually a limited understanding of the implications of the tradeoffs for different groups of beneficiaries. Sanon et al. (2012) demonstrated how to explicitly include stakeholder objectives in an MCDA in a case study region, and Neuenschwander et al. (2014) showed how development targets defined by various stakeholders can be identified and operationalized within a GIS-based MCDA using a linear goal-programming algorithm – two different approaches, which could be implemented in PALM. Though this would require the involvement of various stakeholders in the aggregation of the criteria used in the tradeoff analysis, it would certainly increase the validity of the findings and foster participation in the planning process.

One of the main issues for applying PALM in practice is the resolution of its output – a topic also raised during the validation process with stakeholders. Several authors have combined MCDA with spatial planning (e.g. Geneletti, 2008; Sharma, Kanga, Nathawat, Sinha, & Pandey, 2012; Zhang et al., 2013; Uribe, Geneletti, del Castillo, & Orsi, 2014) usually generating raster-based output maps. Zoning is however mostly done at a parcel level. Raster outputs are thus often difficult to translate into detailed plans, particularly when discussing land ownership issues. Furthermore, the information provided at the raster cell might convey another message than if considered at a landscape scale: ES supplied in a given area may, for example, not be used in the perimeter, but by people outside the area. The importance of considering scale effects when mapping ES has been mentioned by many authors (e.g. de Groot, Alkemade, Braat, Hein, & Willemen, 2010; Anton et al., 2010;

Seppelt, Lautenbach, & Volk, 2013). Hein et al. (2006) even investigated the effect of stakeholders and the scales of their associated institutions on the value of ES, and Konarska et al. (2002) and Grêt-Regamey et al. (2014) found large changes in ES values depending on the applied resolution. Geneletti (2011) showed the importance of scales in strategic environmental assessments, where benefits can be delivered at one scale, while costs fall at another scale. Currently all criteria in PALM are available at a national scale, but using additional or higher resolution criteria could improve its use, particularly also to communicate tradeoffs in criteria over the scales. A particular effort should also be made to integrate the spatial inaccuracies and the uncertainties in the datasets (Wolfslehner & Seidl, 2010), as not only the resulting raster outputs, but also the spatial pattern of the distribution of the building zone reserves might change substantially when considering uncertainties (Grêt-Regamey, Brunner, Altwegg, & Bebi, 2013). The here conducted sensitivity analysis is only one step to address this challenge. Fuzzy set theory, for example, seem to be an interesting way to direct uncertainties in decision-making processes (e.g. Kaya and Kahraman, 2011; Triantakonstantis, Kalivas, & Kollias, 2013).

It is known that the set of criteria as well as the aggregation methods have a great impact on the outputs of a MCDA (Keeney & Raiffa, 1993). In this case study, we selected seven ES and eight locational factors based on the goals defined by experts, but nevertheless this selection was quite arbitrary. The PALM tool allows including new criteria, yet a great amount of effort should be invested to define goals and the datasets needed to operationalize these goals. Furthermore, the tool has been developed to allow integrating various MCDA rules and it would be useful to use multiple methods or hybrid approaches as demonstrated by Kangas and Kangas (2005) and reviewed in Uhde et al. (2015). Though PALM ensures a transparent and fast processing, spatial relations between criteria as well as their spatial pattern can strongly influence mapping outputs (e.g. Qi and Wu, 1996; Grêt-Regamey et al., 2014) and should be considered for a better evaluation of tradeoffs. Ignoring these spatial relations can lead to a strong scattering of the model outputs, which would not reflect the current political efforts conducted in Switzerland to cluster building zones in a polycentric manner to reduce sprawling effects (Schwick, Jaeger, Bertiller, & Kienast, 2012). Additionally, feedback loops between the urban development patterns and the criteria values should be addressed (Verburg, Schot, Dijst, & Veldkamp, 2004). However, such extensions have the disadvantage that they tend to reduce the transparency of the analyses, making it difficult for decision makers to understand how their preferences affect the results. Lastly, a further development of PALM could be the link to a 3D visualization platform, allowing stakeholders to better experience changes in the landscape. Better spatially explicit visualizations are known to facilitate collaboration processes (Wissen, Schroth, Lange, & Schmid, 2008; Stock & Bishop, 2005; Sheppard & Meitner, 2005; Salter, Campbell, Journeay, & Sheppard, 2009; Schroth, Wissen Hayek, Lange, Sheppard, & Schmid, 2011; Wissen Hayek, Teich, Klein, & Grêt-Regamey, 2015).

5. Conclusions

Integrating ES into a MCDA approach provides a suitable approach to better balance ecological and socio-economic aspects of land use change related to the continuing expansion of settlement. The operationalization of the MCDA into a web-based spatial decisions support tool PALM has further facilitated stakeholder involvement. It provides a tool that supports discussions about tradeoffs of various criteria relevant for defining new urban development areas, whereby supporting consensus finding for selecting more widely accepted solutions. Compared to urban centers and rural areas, this is particularly important in urban peripheries, where development pressure is relatively high, which generates conflict of interests between developers, farmers aiming at securing their fertile land, and urban dwellers requiring various ES in the vicinity of urban centers.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2016.05.003.

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