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Methodological and Ideological Options

Comparing land-use alternatives: Using the ecosystem services concept to define a multi-criteria decision analysis

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ABSTRACT

In landscape planning, land-use types need to be compared including the ecosystem services they provide. With multi-criteria decision analysis (MCDA), ecological economics offers a useful tool for environmental questions but mostly case-specific criteria are applied. This, however, makes it difficult to compare findings. Therefore, we present a systematic framework that includes the ecosystem services as criteria into MCDA. The ecological quantification of the provided ecosystem services is combined with the assigned importance of the single ecosystem services. In a case study from the central Alps, we compared three land-use alternatives resulting from land-use change caused by socio-economic pressures: traditional larch (*Larix decidua*) meadow, spruce forest (abandonment) and intensive meadow (intensification).

Criteria for the MCDA model were selected by experts, criteria importance was ranked by stakeholders and criteria values were assessed with qualitative and quantitative indicators. Eventually spruce forest was ranked as the best land-use alternative followed by traditional larch meadow and intensive meadow. The combined approach of MCDA using ecosystem services as criteria showed how criteria weightings and criteria indicator values influence land-use alternatives' performance. The MCDA-model visualizes the consequences of land-use change for ecosystem service provision, facilitating landscape planning by structuring environmental problems and providing data for decisions.

1. Introduction

1.1. The Multi-Criteria Decision Analysis

Multi-criteria analysis is one of the most frequently used methods in ecological economics (Huang et al., 2011). Due to the option to combine economic, ecologic and social criteria it is well suited to address interdisciplinary and complex environmental questions (Khalili and Duecker, 2013; Mendoza and Prabhu, 2003). If a discrete number of alternatives is given, multi-criteria decision analysis (MCDA) is a useful tool to structure the decision-making process (Busch et al., 2011; Hein et al., 2006). Furthermore, MCDA is considered to be one of the most flexible methods since it can be made site as well as time specific, considering qualitative and quantitative attributes simultaneously (Garfi et al., 2011). Up to now, multi-criteria analysis has been mainly applied for case studies with specific focus, e.g. forest management (Ananda and Herath, 2009), river alteration projects (Oikonomou et al., 2011), or bioenergy solutions (Buchholz et al., 2009). Most of those studies apply case-specific criteria, so that the solutions to the environmental problems addressed are hardly comparable or transferable to similar cases. A standardized framework of criteria would help to derive more general solutions for environmental or nature conservation questions. Surprisingly, different land-use options, or land-use changes as omnipresent phenomenon have rarely been the focus of MCDA studies, even if 287 publications in the Web of Science carried 'land use change' in the title only in the year 2012.

1.2. The Ecosystem Service Concept

The ecosystem service concept has become more and more popular since the United Nations' Millennium Ecosystem Assessment 2005 (further referred to as MEA, 2005). It defines ecosystem services as the benefits which humans obtain from ecosystem functions and resources. These benefits can be divided into market and non-market ecosystem goods or services and classified in multiple ways (Costanza

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et al., 2008), e.g. provisioning services, regulating services, habitat or supporting services and cultural services (The Economics of Ecosystems and Biodiversity, further referred to as TEEB, 2010). Common frameworks such as TEEB facilitate scientific work when dealing with the complexity of landscapes (de Groot et al., 2010) but so far it is little known and applied by regional, administrative authorities. Likewise, the concept of ecosystem services (TEEB, 2010) could be used as general framework where criteria for multi-criteria analyses are selected from.

Several studies have applied the ecosystem service concept to asses land-use change including its consequences for biodiversity loss and provision of ecosystem services to the society (e.g. Carreno et al., 2012; Hao et al., 2012; Mendoza-Gonzalez et al., 2012). However, the local demand or importance of the single ecosystem services has only recently been included in those studies (Burkhard et al., 2012). Moreover the way in which the changes in ecosystem service provision, caused by land-use change, are summarized differs among these studies or is lacking completely. The MCDA may be an appropriate tool to assess the importance of the ecosystem services and to consequently compare land-use types regarding their ecosystem service provision. In that way, even regional studies could provide generalizable results and solutions by absorbing the established ecosystem service framework (MEA, 2005; TEEB, 2010) on MCDA criteria.

1.3. Study Case Larch Meadows

To test the integration of the ecosystem service concept into multi-criteria decision making on the example of a land-use change question, we used a traditional land-use system of the central Alps, which is currently under pressure by two contrasting trends: intensification and abandonment. So-called larch meadows are semi-open grasslands that are mown or pastured and scattered with larch trees (*Larix decidua* Mill.). They provide both hay and timber, but mowing around the trees and collecting the fallen branches are awkward and time-consuming. Therefore, they are often either abandoned so that succession into forest begins, or the larches are cut and the ground is leveled so that they can be managed more intensively. These two trends are very typical for extensive land-use systems in Europe (Hunziker, 1995; Tasser et al., 2007), which have co-evolved with human use for hundreds of years (Ellenberg and Leuschner, 2010). In fact, very few European ecosystems can be considered 'natural' today; instead most of them have been altered by humans (Grabherr et al., 1994). Within this cultural landscape, extensive agricultural systems exhibit biodiversity hot spots (European Habitat Directive, 1992; Zerbe and Wiegleb, 2009). In particular, traditional wood-pasture systems, which are named differently and made up by different species depending on the geographic region, are of high nature conservation value (Bergmeier et al., 2010). High biodiversity, in turn, is generally connected with many ecosystem services such as climate regulation, water purification, and recreation (MEA, 2005). For that reason, the European Union as well as local authorities are spending a lot of money to support this kind of traditional land-use systems (Institute for European Environmental Policy, 2007; Marini et al., 2011). To test if those subsidies entail a surplus of ecosystem services, we compared three competing land-use types regarding their provision of ecosystem services.

In this case study from the Central Alps, we present a multi-criteria decision analysis which combines normative values with the ecological quantification of ecosystem services. The importance of ecosystem services in the regional landscape is indicated by stakeholder interviews and the provision of those ecosystem services is assessed with qualitative and quantitative indicators. In this way we demonstrated the use of MCDA with an ecosystem service framework and developed four systematic, discrete steps to compare different land-use types regarding their ecosystem service provision. At the end of the paper, the suitability of this method to help the decision-making process in practice is discussed.

2. Methods

2.1. Study Area

South Tyrol is the northern-most province of Italy covering an area of 7400 km^2 located in the south of the Eastern Alps. According to the definitions of the European Union, 94% of the total area of South Tyrol belongs to mountain territory (Autonome Provinz Bozen-Südtirol, 2009). Larch meadows, the objects of our study, are an ancient man-made land-use system which is found mainly on dry south-exposed slopes around the alpine main ridge at 1000–2000 m a.s.l. Beside South Tyrol, which is one of the main distribution areas of the remaining larch meadows, they are also present in adjacent countries. Results of fossil pollen analysis in nearby Switzerland show a high accumulation of pasture and culture indicator species together with macro-residuals of *L. decidua* between 2100 and 1900 B.C. (Gobet et al., 2004). This warm and dry climate period is known as an intensive culture phase in the Alps (Tinner et al., 2003) where a lot of forests were cleared and the origin of larch meadows is assumed (Ammann, 2001b). Over the centuries, larch meadows were preserved as a double functional land use, and particularly in times of poverty single larches were cut and sold. However, larch meadows need a lot of human care. Depending on weather, fallen branches have to be removed at least once a year, the area around the trees can be mown only by hand and the tree shade increases drying time for the hay. Furthermore the areas are often steep or difficult to reach. Consequently larch meadows lost far more than half of their former areal proportions since the 1980ies and nowadays they play only a small part in South-Tyrolean agriculture. Nevertheless larch meadows are beautiful landscape elements which are used by tourists and locals for recreational activities. Due to this scenic beauty and the high biodiversity they harbor, larch meadows are regarded as an important ecosystem. Therefore they are supported with European and national subsidies.

2.2. Multi-criteria Decision Analysis

Among the different methods of multi-criteria analysis we chose the multi-attribute decision making (MCDA) because a discrete and finite number of alternatives (meadow, larch meadow, and forest) is given. MCDA solutions are more likely to achieve realizable results because of its transparency and traceability (Linkov et al., 2006). The multi-criteria decision analysis to compare the three land-use alternatives regarding their ecosystem service provision entailed four steps (Fig. 1).

2.2.1. Problem Definition

The problem in the study region is that traditional larch meadows are disappearing due to two contrasting trends: abandonment and intensification. Hence three land-use types representing the alternatives required for a MCDA are given (Table 1). The alternative forest is the result of succession taking place on abandoned larch meadows and the alternative meadow follows from removing the larches and converting the area into a permanent meadow often leveling the ground to facilitate machine use. With the changing land use, also the amount of provided ecosystem services can change. To structure this problem we formulated three questions (step 1, Fig. 1). First we asked which alternative provides the most ecosystem services, second we wanted to know which points make larch meadows strong or weak and third we asked if larch meadows can compete with the other two alternatives.

2.2.2. Expert Selection and Criteria Elicitation

To perform a MCDA, a number of five to seven criteria describing the alternatives are ideal (Buchholz et al., 2007). To select criteria for this MCDA from ecosystem goods and services, we hold an expert discussion. Based on their knowledge and familiarity with larch meadows, we invited 30 local private and official experts of agriculture, forestry, nature conservation, research, and tourism. In the end, ten

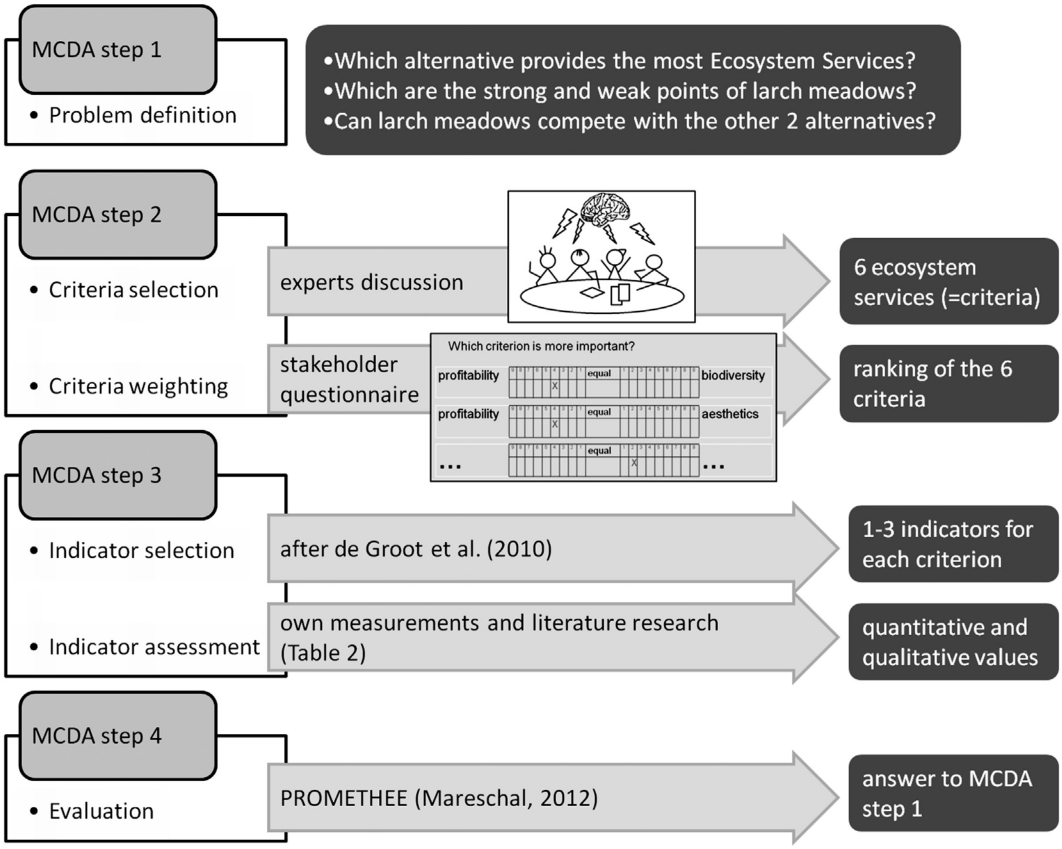


Fig. 1. The MCDA framework comprises four discrete steps and includes ecosystem services as criteria.

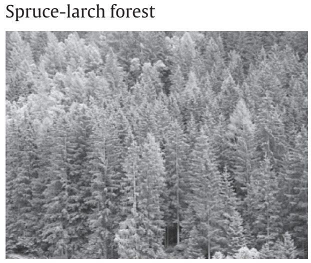
experts (head official forestry planning, head official hunt and fishery, responsible organizer subsidy landscape conservation, spokesperson farmers, spokesperson tourism, head official mountain agronomy, curator nature museum South-Tyrol, responsible organizer EU agronomic subsidies, carbon cycling scientist, vegetation scientist) attended to the discussion in August 2011 so that each discipline was covered. At the beginning of the 90-minute event each expert had 5 min to think about benefits deriving from larch meadows. Then, these benefits were written on a flipchart by the coordinators of the discussion. In an open discussion together with the experts, analogous benefits were merged, and at the end of the event the experts jointly decided upon the six most important benefits provided by larch meadows.

The experts were not asked in advance to mention explicitly ecosystem services defined through either TEEB (2010) or MEA (2005), because of differences among experts in familiarity with this scientific concept. We reformulated the six elicited criteria into TEEB (2010) categories later on (Table 2) to maintain the common scientific terminology.

2.2.3. Criteria Weighting

Given the multitude of different decision makers involved in land-use management decisions (Koschke et al., 2012), we applied codified weighting taken from the analytic hierarchy process (AHP; Saaty, 1988). The weighting was derived by a questionnaire comparing each criterion pair wise, a popular method in MCDAs (Fig. 1; Steele et al.,

Table 1
Characteristics of the three land-use alternatives under consideration.

Alternative	Spruce-larch forest	Extensive larch meadow	Intensive meadow
			
Process	<--------ABANDONMENT------		--------INTENSIFICATION---->
Description	Late-succession stage of an abandoned larch meadow	Traditionally used larch meadow	Intensively used meadow
Mowing	None	Once per year	Twice per year
Fertilization	None	Once per year (max. 3 Mg ha^{-1} stall manure per year)	Twice per year (max. 10 Mg ha^{-1} stall manure per year)
Tree density	500 trees ha^{-1}	126 trees ha^{-1}	Without trees

2009). In order to determine the weights of the six criteria, questionnaire respondents answered the question: "How much more important is criterion A than criterion B in the South-Tyrolean landscape?" on a nine-point scale where 1 represents equal importance, and 9 represents complete dominance of one of the criteria. The questionnaire was answered by 20 stakeholders distributed among the categories agriculture, forestry, nature conservation, and tourism representing the main interest groups of larch meadows. These individual judgments of each stakeholder were aggregated into a single representative judgment for the entire group (Fig. 2). For that we used the geometric mean as in AHP we aim to aggregate individual priorities in order to obtain a group that acts together as separate individuals (stakeholders) and not in concert as a new individual (Escobar et al., 2004; Forman and Peniwati, 1998; Grošelj and Zadnik Stirn, 2012).

2.2.4. Criteria Assessment

To assess the criteria in a comprehensive way, a set of indicators was selected for each criterion following the suggestions of de Groot et al. (2010). Seven indicators were assessed by own measurements or calculations in a quantitative way and the other five by literature analysis in a qualitative way (Table 2). Five of the indicators measured by ourselves were based on vegetation samplings (labeled with * in Table 2). 38 representative relevées were used for each alternative. The relevées on larch meadows were collected by ourselves, those of the intensive meadows are unpublished data from Niedrist et al., and those relevées of the larch–spruce forest are from Peer (1980). All vegetation samplings and the emerging indicator assessments refer to south-east to south-west exposed larch meadows, meadows or spruce–larch-forests in South Tyrol between 1400 and 1800 a.s.l. with a mean slope between 6 and 22°.

2.2.4.1. Criterion 1: Biodiversity. This criterion was assessed with three quantitative indicators describing vascular plant diversity only. Effective species richness was selected because it focuses on the number of equally common species and was calculated based on the Shannon index (Beck and Schwanghart, 2010; Jost, 2006). To consider also rare species and species considered in nature conservation questions the number of red-list species was derived from the list of Wilhalm and Hilpold (2006). Mean species richness corresponds to the mean number of species and shows the concrete diversity of the single alternative.

2.2.4.2. Criterion 2: Profitability. Net productivity of the three alternatives was calculated by including primary production of hay or timber and subtracting labor costs and mechanization costs (fertilization was not included). The financial support of public subsidies was also considered but included only direct subsidies for the management of the areas. Additional subsidies or payments which farmers receive e.g. for fuel, machines, or buildings were not considered in the profitability calculations.

2.2.4.3. Criterion 3: Regulation Capability. This criterion with three indicators was qualitatively assessed using a 3-point scale based on existing literature on ecological patterns. The first indicator 'climate regulation' was derived from carbon-sequestration literature. In the long term, grasslands are considered to have a neutral carbon balance, despite their inter-annual variability (Gilmanov et al., 2007; Wohlfahrt et al., 2008) and managed forests are most often carbon sinks (Etzold et al., 2011; Valentini et al., 2000). The carbon balance of larch meadows has not yet been investigated why we assumed it to be intermediate. The second indicator 'air quality regulation' was assessed using the leaf-area index (LAI) because of the ability of leaves to remove gaseous and particulate air pollutants from the atmosphere (de Groot et al., 2010; Fowler, 2002). Since meadows have lower LAI values than forests (Gilmanov et al., 2007; Valentini et al., 2000) and the LAI of larch meadows should be intermediate, we deduced the aerosol extraction capacity to be low in meadows, medium in larch meadows and high in forests. As a third indicator we chose 'water retention capacity' which depends on interception, infiltration and evapotranspiration of a certain land use. Interception correlates with LAI (Bormann et al., 2007) and infiltration with root penetration, but the relatively deep and porous soils of the studied systems exhibit excellent infiltration characteristics anyway (Frehner et al., 2005). Evapotranspiration

Table 2
Criteria elicited in the stakeholders' discussion, corresponding ecosystem services, and indicators as suggested by de Groot et al. (2010) and their performance among the three land-use alternatives under consideration. NEE — net ecosystem exchange; LAI — leaf area index. Indicators labeled with * are based on 38 vegetation samplings per land-use alternative.

Criterion	Ecosystem service category (TEEB, 2010)	Indicator	Meadow	Larch meadow	Forest	Assessment
Biodiversity	*Habitat or supporting services*[1]					
	Habitat	Effective species richness*	15	22	5	Measured
	Habitat	Number of red list species*	0	10	0	Measured
	Habitat	Mean species richness*	24	47	21	Measured
Profitability	*Provisioning services*[2]					
	Hay & timber	Net productivity [€ ha^{-1}] (including hay and timber revenues)	−426	−97	252	Measured
Regulation capability	*Regulating services*[3]					
	Climate regulation	Carbon sequestration (NEE)	Low	Medium	High	Literature
	Air quality regulation	Aerosol extraction (LAI)	Low	Medium	High	Literature
	Water regulation	Interception (LAI), root penetration, evapotranspiration	Medium	High	High	Literature
Protection potential	*Regulating services*[4]					
	Natural hazard mitigation	Protection against avalanches, landslides and rock fall	Low	Low	High	Literature
Aesthetics	*Cultural services*[5]					
	Recreation, tourism	Scenic beauty	Good	Very good	Good	Literature
	Aesthetic inspiration	Variety of flowering plants*	Medium	High	Low	Measured
Culture-historical value	*Cultural services*[6]					
	Local identity, tradition	Number of healing plants*	24	55	26	Measured
	Sense of place	Rareness (% of area in the study area)	7.9	0.135	9.1	Measured

[1] Each ecosystem stands for a different biological diversity on the species and gene level. The provision of living spaces for plants and animals is a supporting service which acts as the base for most of the other services. The criterion takes into account only vascular plant species diversity.
[2] The criterion profitability consists of several market goods such as timber and hay although working time and subsidies also must be taken into account.
[3] This criterion comprises different regulating functions or services that the ecosystem provides.
[4] Ecosystems consisting of trees often play an important role in the protection of people and their living places from avalanches, erosion or falling rocks.
[5] Through the aesthetic qualities the natural environment provides many opportunities for recreational activities, such as walking, hiking, horse riding, hunting or cross country skiing. Humans benefit from aesthetics not only directly, enjoying the beauty of the environment, but also indirectly, by the high number of tourists and visitors.
[6] The different alternatives contribute in different ways to the sense of place of local people. Traditional land uses have a unique cultural evolution behind them, which formed several human perceptions and regional developments over time.

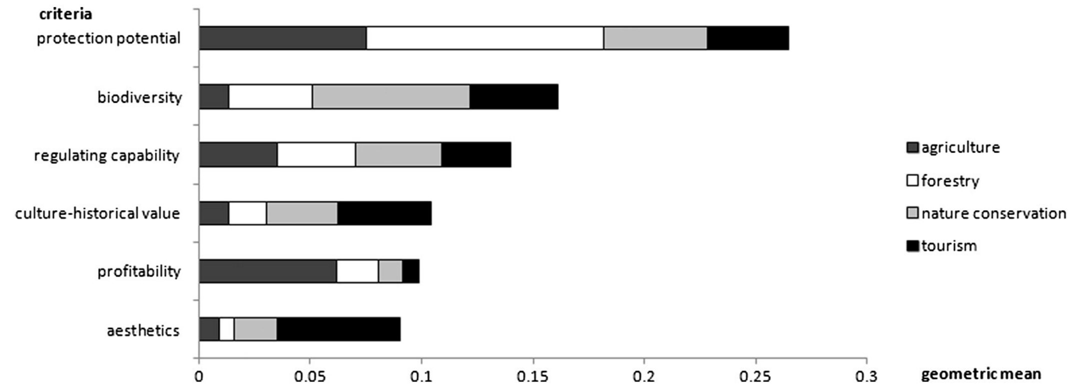


Fig. 2. Criteria weighting assessed by questioning 20 stakeholder.

is higher in coniferous forests than in grasslands (Dirnböck and Grabherr, 2000). Therefore we assumed water regulation to be medium on intensive meadow and high on larch meadow and forest.

2.2.4.4. Criterion 4: Protection Potential. Based on the literature this criterion was assessed qualitatively: primarily forested landscapes can considerably mitigate natural hazards such as avalanches, rock fall, and landslides because trees act as an obstacle to mass movements that might harm infrastructure or cultivated land (Brang et al., 2006). However, using the example of avalanches, the protection potential of such a landscape largely depends on canopy density, gaps in the tree-layer and the ground-surface structure (Margreth, 2004; Perzl, 2005). Snow gliding increases rapidly towards cleared stands and small gaps facilitate the formation of avalanches (Höller, 2001). In the case of rock fall, dense forest areas reduce the speed and the rebound heights of falling rocks or even stop single stones (Dorren et al., 2007). The high root penetration in forest areas stabilizes the ground and prevents landslides and erosion better than in open areas (Rickli et al., 2002). Thus, meadows and larch meadows provide little to no protection against natural hazards why we assessed their protection potential as low and only that of the forest as high.

2.2.4.5. Criterion 5: Aesthetics. The aesthetic value was assessed with the help of two indicators: scenic beauty and variety of flowering plants. Scenic beauty was valued qualitatively through a literature review. As we did not find any study explicitly comparing forest, meadow with single trees and intensive meadow, we relied on the following studies which revealed that semi-open landscapes scattered with trees are preferred over the investigated forest or cultural landscapes: Schroeder (1986); Kenner and McCool (1985); Gundersen and Frivold (2008); Hunziker (1995); Kaltenborn and Bjerke (2002); Hunziker and Kienast (1999); and Perrenoud et al. (2003). Kellert and Wilson (1993) confirmed the "biophilia hypothesis", i.e. park or savanna-like landscapes are preferred by people of various cultures.

The second indicator 'variety of flowering plants' is the biodiversity index of Shannon calculated from the vegetation samplings and converted into a qualitative scale. Biodiversity is a good aesthetic indicator as the attractiveness of mountain grasslands to humans was found to enhance in a linear way with increasing plant biodiversity (Lindemann-Matthies et al., 2010a, 2010b).

2.2.4.6. Criterion 6: Culture-historical Value. This criterion was assessed with two quantitative indicators. A good indicator for cultural heritage can be the number of culturally important species or the area of culturally important landscape features (de Groot et al., 2010). We considered healing plants to be culturally important species and excerpted the regionally relevant ones (Mayr and Plaikner, 1995) from the vegetation samplings (as used for the criterion biodiversity). For the second indicator 'area of culturally important landscape features' (called 'rareness') we used the area of larch meadows (as well as the area of the alternatives), being themselves the important landscape features. Forest area is based on the map of the 'potential natural vegetation' (Autonome Provinz Bozen-Südtirol, 2010) which corresponds to the natural distribution of montane spruce forest. The areas of 'intensive meadow' and 'larch meadow' were withdrawn from the land use database of the province (Autonome Provinz Bozen-Südtirol, 2011).

2.2.5. MCDA Evaluation

From the various MCDA methods and the different software applications available, we used PROMETHEE II, which applies the outranking method and provides a complete ranking of a discrete set of possible alternatives, from the best to the worst, using the net flow (Brans and Vincke, 1985; Macharis, 2004). PROMETHEE requires (i) a matrix of criteria performance over the different alternatives (Table 2), (ii) the weights of the criteria assigned by the stakeholders (Fig. 2) and (iii) the specific preference function for each of these criteria (Brans and Mareschal, 2005; Brans et al., 1986). Hence a MCDA model is built, wherein if required, weights can be easily changed or indicator values and alternatives added. The calculation was conducted with Visual PROMETHEE, Version 1.1 (Mareschal, 2013), which includes several graphical outputs to visualize the results.

3. Results

The six criteria were defined and allocated into the TEEB categories in Table 2. The experts insisted on the separation between protection potential and other regulating services such as carbon sequestration, air quality and water retention, summarized in the criterion regulation capability. Being in a mountainous region, protection against natural hazards such as avalanches, landslides or rock fall is a big topic and awareness is high. Furthermore, the experts saw a clear difference between the aesthetic aspect of the landscape and its cultural-historic value.

The criteria weighting attributed by stakeholders ranked protection potential highest, followed by biodiversity, regulation capability, and culture-historical value (Fig. 2). Profitability and aesthetics were ranked lowest. While looking at the group rankings, singular preferences differ notably. As expected, the group of stakeholders representing agriculture gave the highest importance to the criterion profitability and the group of stakeholders representing tourism gave the highest importance to the criterion aesthetics.

The results of criteria assessment are summarized in Table 2. Details about the calculation of the criterion profitability are shown in Table A1 in the Appendix A. The performance of the single alternatives together with the amount of each provided ecosystem service per alternative is visualized in the rainbow chart of Visual PROMETHEE. Forest is ranked at the first place followed by larch meadow and then meadow (Fig. 3). Hence forests provide a greater amount of ecosystem services to people than larch meadows and meadows. However, only three of the criteria contributed positively to the performance of the forest alternative, while four criteria contributed positively to the performance of the larch meadow alternative. For the alternative meadow all criteria had lower indicator values than the other two alternatives (Fig. 3).

4. Discussion

In this case study, forest resulted as the best land-use alternative regarding the provision of ecosystem services, followed by larch meadow and then intensive meadow. Primarily responsible for this ranking is that the alternative forest has the best indicator value in the criterion protection potential which at the same time has by far the highest weight. In comparison to the alternatives forest and larch meadow, the alternative intensive meadow has the lowest values for almost every indicator, resulting in the worst alternative performance. Larch meadow has the highest indicator values in four criteria which contribute positively to its performance, but it was ranked only on the second place, mainly because of the low weights attributed to those criteria. Hence, the best alternative depends not only on the ecosystem services it provides but also on the importance that is given to the single ecosystem services.

The presented method allows the comparison of different land-use types by building a MCDA model composed of four easy-to-follow steps. It helps to structure land-use problems such as current land-use change and the decision making process.

4.1. Criteria Selection and Criteria Weighting

At the beginning, it is essential to invite representatives of each interest/beneficiary group to the discussion to get a complete list of criteria. For that, it is important to select cooperative and experienced experts for the criteria elicitation to obtain a balanced and productive discussion (Glicken, 2000; Reed, 2008).

Criteria weights are a crucial and controversial point within MCDAs because they allow scientists and practitioners to understand different priorities of different interest/beneficiary groups (Herat and Prato, 2006; Munda, 2008). However which services are considered most important will always depend on who you ask, and for the final ranking of the alternatives the weight of one criterion is at least as important as the single indicator value. In the pair-wise comparison of the ecosystem services some stakeholders expressed difficulties to distinguish their personal point of view from the point of view of the organization/field they were representing. Others had difficulties to state if one ecosystem is more important than another especially if the services were similar. Those difficulties may influence the final weighting. Likewise, the degree of familiarity of the stakeholder with a certain service or the awareness of a service in society should be considered. In the mountainous region of the study area, where natural hazards like avalanches or rockfall are an omnipresent topic, it is not surprising that the highest weight was attributed to protection potential. In this context, the weights attributed from stakeholder to the ecosystem services can be interpreted as the local demand for ecosystem services. Despite the fact, that the demand for ecosystem services is difficult to measure, people have to be aware of an ecosystem service to be able to appreciate and request it (Costanza, 2001; Sen, 1995).

4.2. Criteria Assessment Through Indicators

Selecting indicators for each criterion (corresponding to an ecosystem service) was facilitated by the progress which has been recently made in ecosystem service research and application (de Groot et al., 2010). In contrast, the subsequent indicator assessment was more challenging due to three main reasons: (a) little data is available for specific land-use types (e.g. carbon sequestration of one land-use type differs under different environmental conditions), (b) cultural ecosystem service indicators are difficult to assess and have gotten into the scientific focus relatively recently so that precise data is scarce and (c) provisioning services (usually market goods) are difficult to assess with cost and benefit analyses, because e.g. the net return of the hay a farmer can gain from a meadow, cannot prescind from the return he gains from the milk he produces with the hay. Nevertheless, the knowledge regarding the difficulties (a) and (b) is growing very quickly, making the use of these indicators easier. An advantage of MCDA is the neglectability of the indicator units, which allows mixing qualitative and quantitative indicator values. This fact

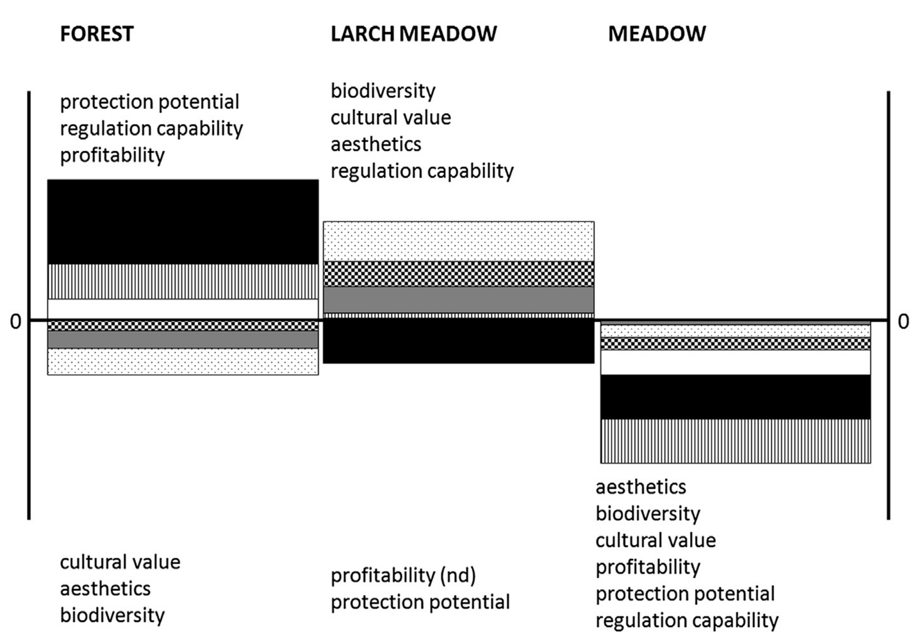


Fig. 3. Visual PROMETHEE's rainbow chart combines criteria's indicator values (Table 2) with criteria's weighting (Fig. 2). Criteria mentioned above the 0-line contribute positively to alternatives' performance and criteria below the 0-line negatively. The length of the bars reveals the amount of single criteria contribution. (nd) not displayed - because the bar is too small.

enables to assess indicator values by own measurements, by literature research or also with expert guesses if required.

4.3. Practical Relevance

If the land is privately owned, as in our case larch meadows, management decisions are ultimately made by farmers themselves. Especially mountain farmers are forced to manage their properties economically efficient due to naturally challenging conditions and increasing production costs (Streifeneder et al., 2007). At this point, the problem of competing goods arises, i.e. enhancing one (private) good or service may reduce the production of another (public) good or service. The influence of the society to shape the landscape in a way that it provides ecosystem services is therefore very limited, except society recognizes its responsibility to compensate farmers for both products (Dale and Polasky, 2007). An attempt to counteract this trend is agro-environmental schemes (AESs), which pay subsidies to land-owners to preserve biodiversity by reducing the competitive pressure on traditional land-use systems. So far, AESs have been poorly linked to the provision of ecosystem services (Whittingham, 2011). De facto linking AES to ecosystem services increases the awareness of land managers and policy-makers (Isaacs and Kirk, 2010), and can thus help to justify subsidy payments in the vague future of agro-environmental schemes in Europe. The ranking of larch meadows behind forests in our case study actually questions the payment of further subsidies for larch meadows. Although larch meadows have the highest indicator values in most of the provided services, the attributed weights were rather low. This indicates that the ecosystem service concept needs more acceptance and implementation by the local, administrative authorities. With the growing understanding and popularity of the ecosystem service concept and with its improved linkage to AES, it will become easier to justify payments in the future also for the traditional larch meadows.

5. Conclusion

Our study presents MCDA as a suitable tool to illustrate in detail the consequences of land-use change for ecosystem service provision. The advantage of the presented method is its flexibility. Actually the key point is the construction of the MCDA model according to a problem statement. After that, it is very easy within the PROMETHEE software to modify the weighting, the indicator values or the alternatives. This allows for example the simulation of singular interest group perspectives or the insertion of additional land-use types. This flexibility facilitates case-to-case applications, dynamic decision processes and spatial up and down scaling. Hence our framework can be a good instrument to structure environmental problems and provide data for decisions. It can help to maintain diverse and multifunctional landscapes which provide various ecosystem services.

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Appendix A

Table A1
Calculation of net productivity for the criterion profitability. Provision of hay and timber including labor cost, mechanization cost and financial support.

	Units	Intensive meadow		Larch meadow		Larch–spruce-forest		Source
		Values	Comments	Values	Comments	Values	Comments	
Hay productivity								
Hay production [dt/ha year]	[dt/ha year]	60.00		30.00		–		a
Reduced hay production [dt/ha year] due to tree area (=0.017 ha)	–	–		29.50		–		a
Hay price	[€/dt]	18.00		18.00		–		b
Gross yield	[€/ha year]	1080.00		531.00		–		
Required labor	[h/ha]	10.00	(Machine use)	10.00	(More by hand)	–		c
Additional time to go around the trees	[h/ha]	–		4.16	Mow by hand	–		a
Additional time to collect tree branches	[h/ha]	–		33.50	By hand + 2 h transport w/ truck and trailer	–		a,e
Sum of labor	[h/ha]	10.00		47.66		–		
Hourly wage	[€/h]	12.00		12.00	86.00	–		e
Total labor cost	[h/ha]	120.00		657.90		–		
Sum of mechanization	[h/ha]	10.00	Mow (2 h) + spin (2 h) + tracking (2 h) + collect and transport (4 h)	5.00	Mow (1 h) + spin (1 h) + tracking (1 h) + collect and transport (2 h)			e1
Mechanization cost	[€/h]	160.00	4 × 25.00 truck + 18.00 mower + 12.00 spinner + 12.00 tracker + 18.00 trailer	160.00	4 × 25.00 truck + 18.00 mower + 12.00 spinner + 12.00 tracker + 18.00 trailer			e,e1

Table A1 (*continued*)

	Units	Intensive meadow		Larch meadow		Larch–spruce-forest		Source
		Values	Comments	Values	Comments	Values	Comments	
Hay productivity								
Total mechanization	[h/ha]	1600.00		800.00				
Revenue hay = gross yield − labor cost	[€/ha year]	−640.00		−926.90		–		
Timber productivity								
Timber stock		–		126.00	n° trees of larches/ha	441.00	m^3 spruce/ha (70%)	f,g
				1.785	m^3/tree	189.00	m^3 larches/ha (30%)	f,g
	m^3/ha			224.91		630.00		f,g
Timber price	[€/m^3]	–		118.00	Larch	118.00	Larch	h
	[€/m^3]	–				94.00	Spruce	h
Harvest and transport (including labor)	[€/m^3]	–		25.00		25.00		e1
Rotation length	[years]	–		100.00		190.00		a,g
Revenue timber	[€/ha year]	–		209.16		252.66		
Total revenue	[€/ha year]	−640.00		−717.73		252.66		
Financial support	*[€/ha year]*	*214,00*		*620*		–		i,i1
Total	*[€/ha year]*	−426,00		−97.7297		252.66		

a1 — Rungger and Kuβtatscher (1995) b — Thomaseth, J., Amt für Viehzucht, Autonome Provinz Bozen, hay price remained stable during the last 5 years, personal communication, 2012; c — Ammann (2001a), Werte für Futterbau in Bergbetrieben, d — Beratungsring Südtirol, Produktionskosten 2010 personal communication e — Maschinenring Südtirol (2011) e1 — Maschinenring Südtirol, Ludwig, M., personal consultancy; f — larch meadow calculations are based on own data (n° trees = 126, dbh = 43, height = 20) calculating volume of single trees with the equation: $V = 8.8267 + 0.03426 * dbh^2 * height + 0.27518 * dbh$ (including branches > 5 cm) after ,Gasparini et al. (2006) g — forest calculations are based on information in Autonome Provinz Bozen-Südtirol (2010) h — Autonome Provinz Bozen-Südtirol (2010); Autonome Provinz Bozen-Südtirol (2003–2011). Mean wood prices for spruce and larch for the last 10 years; i Thaler F., Amt für EU-Strukturfonds in der Landwirtschaft, Autonome Provinz Bozen, weighted mean considering the last 5 years of a farmer reaching 77 difficulty points, personal communication i1 — www.provinz.bz.it/natur/themen/bestockte-wiesen-weiden.asp (accessed 21.02.2012).

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