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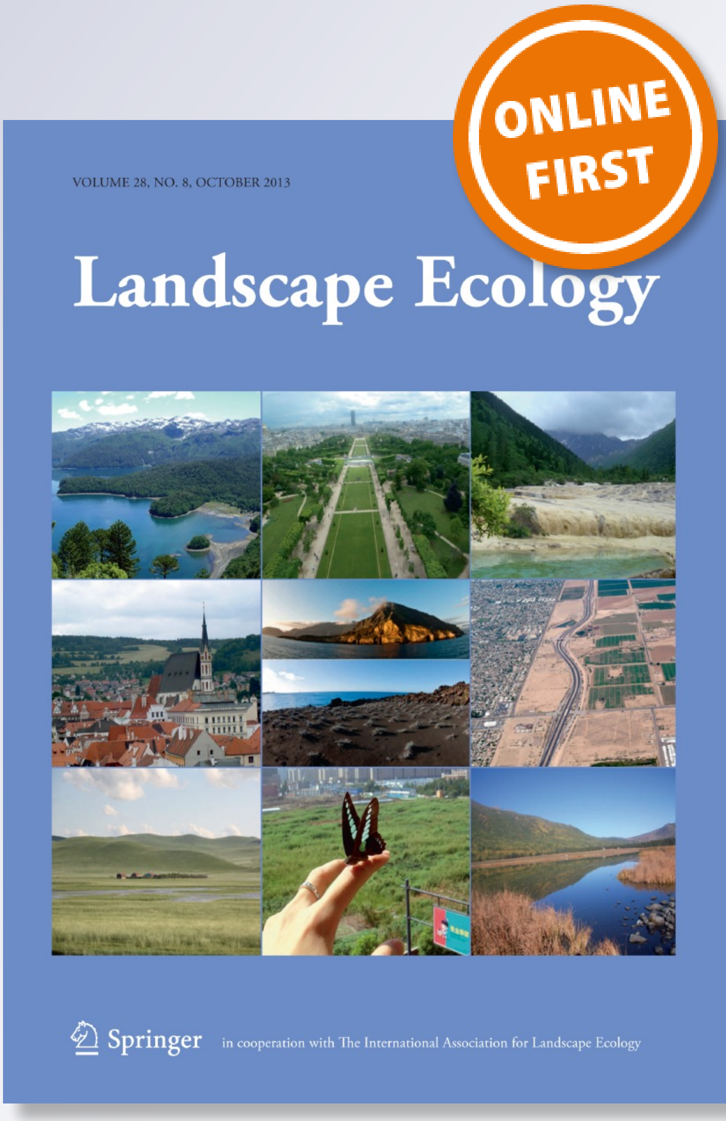

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RESEARCH ARTICLE

Concepts and methods for landscape multifunctionality and a unifying framework based on ecosystem services

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Abstract The potential of landscapes to supply multiple benefits to society beyond commodities production has received increasing research and policy attention. Linking the concept of multifunctionality with the ecosystem services (ES) approach offers a promising avenue for producing scientific evidence to inform landscape planning, e.g., about the relative utility of land-sharing and land-sparing. However, the value for decision-making of ES-based multifunctionality assessments has been constrained by a significant conceptual and methodological dispersion. To contribute towards a cohesive framework for landscape multifunctionality, we analyse case studies of joint ES supply regarding ten criteria designed to ultimately answer four aspects: (i) the multifunctionality of what (e.g., landscapes), (ii) the type of multifunctionality (e.g., based on ES synergies), (iii) the procedure of multifunctionality assessments, and (iv) the purpose of multifunctionality. We constructed a typology of methodological approaches based on scores for criteria describing the evaluation method and the level of stakeholder participation in assessments of joint ES supply. Surveyed studies and underlying types of methodological approaches (spatial, socio-spatial, functional, spatio-functional) differed in most criteria. We illustrate the influence of methodological divergence on planning recommendations by comparing two studies employing contrasting approaches (spatial and functional) to assess the joint supply of wildlife habitat and agricultural production in the Argentine Chaco. We distinguish between a pattern-based and process-based multifunctionality, where the latter can only be detected through approaches considering the ecological processes (e.g., ES complementarities) supporting the supply of multiple ES (functional and spatio-functional). Finally, we propose an integrated approach for assessing a socially-relevant process-based multifunctionality.

Keywords Landscape services · Spatial scales · Ecosystem functions · Stakeholder participation ·

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Land-sharing · Land-sparing · Landscape planning · Synergy · Ecosystem service relationships

Introduction

The widespread and intense simplification of landscapes to maximize the production of food, fibres, and biofuels has raised calls for promoting multifunctionality as a strategy for securing the delivery of multiple benefits from ecosystems and landscapes to society, and thus for increasing returns from conservation and restoration efforts (Crossman and Bryan 2009). In response, multifunctionality has become an increasingly common target in evaluations of ecosystem services (ES) supply, where multifunctionality has been conceived and assessed in practice as different expressions of the joint supply of multiple ecosystem functions and/or services and/or benefits (hereafter "joint ES supply", embracing ES "hotspots", "bundles", "synergies", and "complementarities"). The burgeoning use of the multifunctionality concept, however, has led to divergences in the definitions and methodologies for its assessment, undermining the potential utility of this concept for landscape planning. Such divergences can be summarized around four simple aspects: (i) the multifunctionality of what is assessed, (ii) the type of multifunctionality, (iii) the procedure of multifunctionality assessments, and (iv) the purpose of multifunctionality assessments.

Regarding the "of what" question, multifunctionality has been analysed as a property of different organizational levels and at distinct spatial scales. Classic conceptions of multifunctionality relate to the ecosystem level and local scale, where it is the result of synergistic interactions among organisms in diverse communities, which are usually disrupted by ecosystem simplification, leading to a view of simplified and diverse land uses as opposing ends on a multifunctionality spectrum (e.g., intensive vs. multifunctional agriculture, Altieri 2000). More recently, multifunctionality is viewed as an emergent property of the landscape level and scale, where the complex interactions among multiple land covers, land uses and stakeholders may result in positive spatial correlations among ES (i.e., ES hotspots) as well as functional complementarities among them (Chan et al. 2006; Laterra 2011; Laterra et al. 2012).

As for other multidimensional concepts (e.g., sustainability), the type of multifunctionality observed in a landscape depends on the relative importance given by researchers to its underlying dimensions: spatial, functional, and social. For example, when the focus is on the functional dimension of multifunctionality, the type of interactions among ES (i.e., antagonistic or synergistic), the strength of such interactions, and the number of interacting ES determines the type of multifunctionality. In any case, the spatial scale and socio-ecological context under evaluation strongly influences the relationships among land covers, intermediate forms of capital (human, physical, and social), and emergent land uses (Fig. 1).

Some authors that focus on joint ES supply at spatial scales from global to regional advocate for the spatial separation of intensive land uses and native undisturbed land covers as the best strategy to reduce antagonisms between them. This "land-sparing" strategy would contribute to achieving sufficient production levels, habitat protection, and other ES (Phalan et al. 2011). In contrast, other authors that

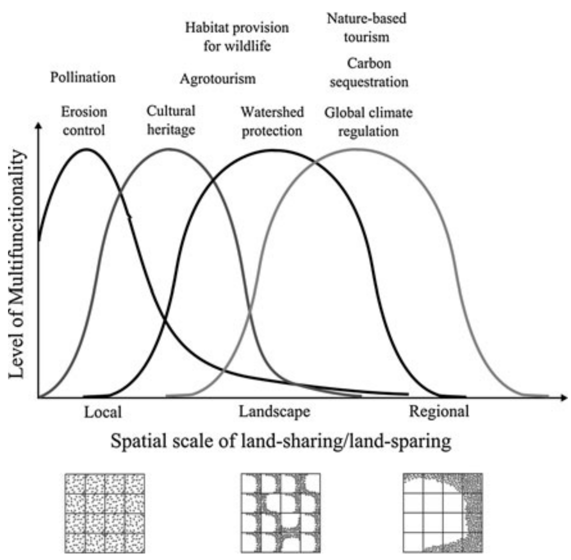

Fig. 1 Ways that multifunctionality can be attained through complementary relationships between food and fibre production and other ecosystem services. Building upon Balmford et al. (2012), there are spatial arrangements that represent the so-called land-sharing (*bottom left*) or land-sparing strategies (*bottom centre* and *right*) between areas allocated to food and fibre production and natural habitat conservation (*grey dots*). Multifunctionality can be attained at different spatial arrangements depending on the particular ES evaluated, as their interactions occur at specific scales

focus on joint ES supply at spatial scales from the landscape to the landholding and the management plot, support the spatial and functional integration of landscape elements (e.g., crops, riparian strips, scattered trees) to enhance synergies or complementarities (Table 1) among ES, under the so-called land-sharing strategy (Tscharntke et al. 2012).

In view of this ongoing debate, further scientific attention should be paid to the procedure of multifunctionality assessments as their utility for landscape planning is constrained by several methodological shortcomings. First, landscape multifunctionality assessments are usually based on the transference of ES values obtained at the ecosystem level, which impedes the integration of the biophysical and socio-economic context and the detection of emergent properties from the landscape level (Gulickx et al. 2013). Second, ES are often assessed at different spatial scales, sometimes arbitrarily selected, which has a significant impact on the value of conclusions and recommendations for decision-making (Hein et al. 2006). Third, the choice of the number and identity of ecosystem functions, services or benefits, or a mixture of them, is conditional on factors as varied as availability of data and models (De Groot et al. 2010) and the ideologies behind scientific debates (Perfecto and Vandermeer 2012). Finally, assessments rarely incorporate stakeholders' visions and preferences meaningfully (e.g., via active involvement in ES selection, ES valuation and/or scenario planning), which limits the value of planning recommendations for producing positive impact on human well-being (Cowling et al. 2008).

Table 1 Definition of key concepts used throughout the article

Concept	Definition
Landscape multifunctionality	The capacity of a landscape to simultaneously support multiple benefits to society from its interacting ecosystems. Landscape multifunctionality is often conceived and assessed as the joint supply of multiple ES at the landscape level.
Joint ES supply	Simultaneous flow of potential benefits from natural systems (ecosystems, landscapes) to human systems (individuals, society) at a particular time and location.
ES complementarity	Trade-off between ES in which an increase in the supply of one ES offsets a decline in another ES, leading to sub- or over-compensation in the total supply of ES.
ES synergy	Relationship between ES in which both ES vary in the same direction as a result of either direct interactions between them or responses to a common driver (Bennett et al. 2009).
Benefits	Portion of the ecosystem service that is consumed by humans to produce human welfare through the utilization of other forms of capital (e.g., physical).
Stakeholder participation	Involvement of stakeholders such as soy farmers or cattle ranchers at some stage during the research process (e.g., ES selection, ES valuation, scenario planning).

Assessments of multifunctionality pursue a wide range of purposes, as reflected by the dispersion in the types of multifunctionality sought and the methodological approaches employed. Such diversity of purposes can also be illustrated through the debate around land-sparing versus land-sharing strategies. The land-sparing strategy is mostly promoted to increase the supply of ES of global relevance, such as habitat protection for endangered species, carbon sequestration, and agricultural production (Phalan et al. 2011). In turn, the land-sharing strategy is usually oriented towards enhancing the delivery of multiple ES relevant to local people, such as protection against natural hazards (Holt-Giménez 2002) and diseases (Mendenhall et al. 2012), biological control (Perfecto et al. 2004), and pollination services (Carvalheiro et al. 2010). By focusing on favouring complementarities in addition to reducing antagonisms among ES, land-sharing not only promotes the current well-being of local people, but also contributes to the resilience of the local socio-ecological system (Tscharntke et al. 2012).

Considering the importance of multifunctionality for landscape planning, it is timely to review the current conceptual and methodological dispersion around its conception and assessment, and the impact of such dispersion on its value for making decisions regarding landscape planning. Initially, we broadly define landscape multifunctionality as the joint supply of multiple ES at a spatial scale larger than the management plot, in order to encompass the scattered literature on the topic and advance towards a more precise conceptualization (Table 1). We draw on a

Table 2 Criteria and attributes used to evaluate peer-reviewed case studies of joint ecosystem services supply and underlying methodological approaches

Aspects	Criteria	Score			
		1	2	3	4
Multifunctionality of what	Position in the ES cascade	Based on landscape composition (and configuration)	Based on ecosystem functions (or intermediate ES)	Based on ES (or final ES)	Based on ES benefits
	Integration of landscape complexity	EF and/or ES fluxes only depends on main cover types of the evaluation unit	EF and/or ES fluxes depends on cover types and other biophysical properties of the evaluation unit	EF and/or ES fluxes depends on cover types and other biophysical properties of the evaluation unit, as well as the biophysical context	EF and/or ES fluxes depends on cover types and other biophysical properties of the evaluation unit, as well as the biophysical and the socio-economical context
The type of multifunctionality	Operative value of JESS definition	Lacking	Based on qualitative criteria	Based on quantitative criteria	Based on complementary relationships among ES
The procedure of multifunctionality assessments	Number of ES	2	3	4	More than 4
	Number of spatial scales	Arbitrary scale	One justified scale	Two justified scales	More than two justified scales
	Evaluation method	Spatial overlap in the distribution of EF or ES	Spatial correlation in the supply level of EF or ES	Functional relationships between pairs of EF or ES	Functional relationships among EF or ES that are made spatially-explicit
	Explanations of JESS	Lacking	Landscape composition	Landscape composition and configuration	Socio-economic factors and (landscape composition and/or configuration)
	Stakeholders participation	Stakeholders are neither identified nor involved in the research process	Stakeholders are identified but not involved in the research process	Stakeholders are involved in the selection and/or valuation of ES	Stakeholders are involved in the selection and valuation of ES and/or planning of scenarios
Purpose of multifunctionality assessment	Targets integration	Have not an explicit target	Human well-being at global scale	Human well-being of local society	Human well-being of local and/or global scales, and the enforcement of biological conservation
	Amount of information for landscape planning	Oriented to the identification of coldspots and hotspots	Oriented to the identification of coldspots and hotspots and analysis of spatially-explicit scenarios	Based on ecological production functions of ES allowing for non-spatially explicit analysis of scenarios	Based on ecological production functions of ES allowing for spatially explicit analysis of scenarios

Scores range from 1 (weakly addressed in the framework) to 4 (strongly addressed in the framework)

ES ecosystem services, *EF* ecosystem function selection of peer-reviewed articles to analyze case studies on the basis of ten criteria that capture the main dimensions of four aspects around multifunctionality assessments (Table 2). After that, we identify and describe types of methodological approaches to assess joint ES supply. A comparative analysis of two case studies is presented with the purpose of illustrating the impact of conceptual and methodological dispersion on conclusions and recommendations. Finally, we propose guidelines to assess multifunctionality in different research contexts and present a unifying approach to assessing a socially-relevant process-based type of multifunctionality for the well-being of local societies.

Methods

We carried out a systematic search of peer-reviewed literature using the Scopus database (www.scopus.com) in January 2013, using the following search string in article title, abstract, and keywords fields: *landscape AND "ecosystem services" AND (multi-functional OR multifunctional OR hotspots OR hot-spots OR integration OR segregation OR "land sharing" OR "land sparing" OR synergy)*. This search resulted in 90 articles, of which 29 presented an assessment of joint ES supply at a spatial scale larger than the management plot.

We evaluated these case studies according to ten quantitative criteria designed to measure the various ways in which they address the four aspects of multifunctionality (Table 2). To answer the "multifunctionality of what", we scored: (i) the position in the hierarchy from ecosystem or landscape attributes to ecosystem functions to ES and benefits (the "ES cascade", Haines-Young and Potschin 2010), and (ii) the integration of landscape complexity levels (e.g., biophysical and socio-economic context) in assessments of ES fluxes. For the type of multifunctionality, we measured (iii) the degree to which the definition of multifunctionality considered relationships among ES. To analyze the procedure of multifunctionality assessments, we scored studies in terms of: (iv) the number of ecosystem functions, services or benefits that are considered, (v) the number of spatial scales, (vi) the evaluation method in terms of the relative importance given to the spatial and functional dimensions of multifunctionality, (vii) the explanations of joint ES supply proposed, and (viii) the level of stakeholder participation along the ES assessment process, and therefore of the incorporation of the social dimension of multifunctionality. Finally, to analyze the purpose of assessments, we measured: (ix) the level of integration of policy targets, and (x) the amount of information for landscape planning.

The 29 case studies were scored for each criterion using a scale from 1 to 4, indicating how strongly the criterion is addressed in the case study (Table 2). To systematize the evaluation process and reduce individual bias, each of the six authors of this article reviewed and scored the 29 articles. Then, we calculated the median of the six independent scores for each criterion. Alongside, we grouped case studies according to two of the ten criteria (stakeholder participation and evaluation method) to develop a typology of multifunctionality assessment approaches. In order to determine the extent to which these groups were able to capture the variability among underlying methodological approaches, we performed a discriminant analysis on raw scores for the ten criteria. Finally, in order to illustrate how different approaches to a same problem can drive to different recommendations, we selected 2 out of the 29 case studies that assessed joint ES supply for the same socio-ecological context, which allowed for a direct comparison of their methodological approaches and conclusions.

Results

We found considerable variability across the 29 case studies in the ten criteria designed to capture the underlying dimensions of the four aspects of multifunctionality assessments. Four typologies emerged after grouping case studies, each one reflecting a distinct methodological approach to assess joint ES supply (Table 3). The four groups differed significantly with regard to all other criteria, as shown in the discriminant analysis (Fig. 2) and the median scores of criteria for each group (Table 3). In the following, we will firstly describe the methodological approaches behind each group of studies. After that, we will analyze the distribution of scores for each criterion, across individual studies and methodological approaches.

Under the spatial approach, studies of joint ES supply focused on the spatial relationships among ES

Table 3 Median scores of criteria used to characterize approaches for assessing landscape multifunctionality

	Operative value of joint ES supply definition	Position in the ES cascade	Number of ES	Number of spatial scales	Evaluation method	Integration of landscape complexity	Explanations of joint ES supply	Stakeholders participation	Targets integration	Amount of information for landscape planning
Spatial approach	1	3	4	1	2	2	2	1	4	2
Socio-spatial approach	3	4	4	1	2	4	1	4	3	2
Functional approach	4	3	1	1	3	3	2	2	4	3
Spatio-functional approach	4	3	4	2	4	2	4	2	4	3

Numbers indicate the degree to which the criterion is addressed by the methodological approach, from 1 (weakly addressed by the approach) to 4 (strongly addressed by the approach)

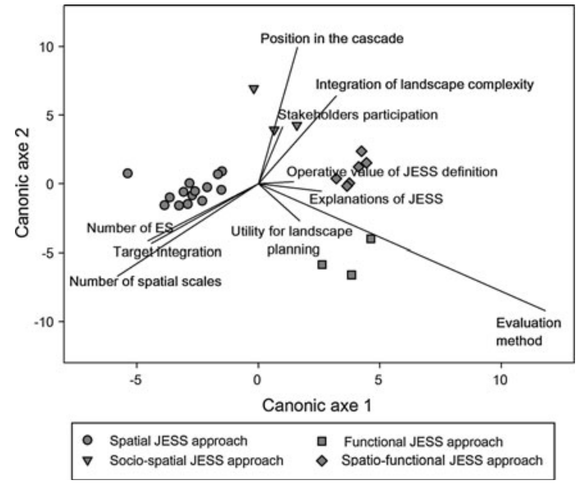

Fig. 2 Discriminant analysis showing the distribution of case studies and underlying methodological approaches across the multivariate space defined by ten criteria. *ES* ecosystem services, *JESS* joint ES supply

with the purpose of identifying spatial overlap of provisioning areas (i.e., ES hotspots). Resulting maps of multiple ES provisioning areas were useful inputs for spatial conservation planning and priority setting. However, the utilization of proxies for mapping ES provisioning areas precluded an understanding of the ecological processes and interactions underlying joint ES supply.

Studies under the socio-spatial approach elicited stakeholders' preferences and values on landscape attributes and used these as ES proxies to spatially project the location (and overlapping) of ES provisioning areas. Stakeholders were more involved in the valuation of ES and less in the selection of ES and the planning of scenarios. The socio-spatial approach shared the shortcomings of the spatial approach, but contributed to the incorporation of social dynamics and human cognitions into ES assessments.

The functional approach to the analysis of joint ES supply focused on the trade-offs between pairs of ES with the purpose of recognizing conflicts and synergies between them. Studies under this approach assessed pairs of ES that changed in response to a common driver, with the purpose of finding an optimal management solution to balance their supply level. Resulting trade-off curves had the potential to identify "small loss-big gain" management options, although they explained little about spatial and/or ecological interactions between ES.

Finally, the spatio-functional approach integrated ecological modelling and mapping of joint ES supply. Under this approach, the assessment of individual ES production functions using ES-specific models was followed by the spatial projection of ES supply derived from models. Stakeholders were not involved in the ES selection and valuation phase. Modelling of ES production functions and stakeholder involvement in scenario planning allowed estimating future changes in joint ES supply.

Next, we analyzed the ten criteria across individual studies and underlying methodological approaches to assess joint ES supply. The definition of multifunctionality in surveyed studies ranged from that lacking of operative value to that defined using qualitative or quantitative criteria to that considering the synergies among ES. Joint ES supply was conceptualized as the result of interactions among ES in less than half of surveyed studies (10/29; frequencies for all criteria in Appendix in supplementary material). Expectedly, these studies implemented assessment approaches that focused on ES functional relationships (functional and spatio-functional). Within approaches with focus on spatial relationships (spatial and socio-spatial), only a few studies adopted either a qualitative (4/18) or quantitative (5/18) definition of joint ES supply. The exception to the trend of not considering interactions among ES was the work of Reyers et al. (2012), which explicitly acknowledged the importance of antagonisms and synergies in the conceptualization of multifunctionality, and highlighted the characteristics of available datasets (e.g., only biophysical values at one point in time) that constrain the assessment of ES interactions.

The component of the ES cascade (i.e., landscape properties, ecosystem functions, ES, and/or benefits, Haines-Young and Potschin 2010) and the number of ES assessed were inversely associated (Fig. 2), and thus these criteria were analyzed jointly. The most frequent condition under the spatial approach was the assessment of more than four ES (6/15). Within this group, Castella et al. (2012) and Grau et al. (2008) assessed two landscape properties (i.e., extent of farmland and forestland) along a time series of remote sensing data to evaluate whether agricultural intensification was sparing land for biodiversity conservation. All socio-spatial studies employed social valuation methods to assess more than four social benefits, mostly as a result of considering stakeholders' demands during ES selection. In turn, most functional studies (6/8) assessed pairs of cascade components, mainly the provision of habitat for wildlife (an ES) and the amount of food or timber produced (a social benefit). Under the functional approach, Wade et al. (2010) and Lusiana et al. (2012) assessed trade-offs between three cascade components, namely, an ecosystem function (plant biomass), an ES (carbon storage), and a benefit (agricultural yield). Finally, all spatio-functional studies integrated the assessment of components of the ES cascade from landscape properties to ecosystem functions and ES, and without detriment for the number of cascade components being assessed (three or more).

The integration of landscape complexity into approaches to assess joint ES supply varied widely across studies. Six out of 29 studies assessed ES on the basis of land cover data only, five of which used spatial approaches. A larger number of surveyed studies (10/29) based the assessment of ES on biophysical attributes of the evaluation unit other than land cover. The biophysical context of the evaluation unit was considered in almost one third of studies (9/29), six of which assessed the influence of landscape context on the persistence of wild populations as part of the analysis of the functional relationships between wildlife habitat and food provision. The few surveyed studies where the socio-economic context was integrated into ES assessments (4/29) included high levels of stakeholder's participation (except for Raudsepp-Hearne et al. 2010).

The number of spatial scales was more uniform across studies and approaches, with most surveyed studies analyzing joint ES supply at one arbitrary spatial scale (19/29) or at one justified scale (7/29), i.e., consistent with either a biophysical or administrative unit. Notably, the spatial scale at which functional relationships were assessed was not justified in any of the functional studies. Only 2 out of 29 studies explored joint ES supply at two different spatial scales. Crossman and Bryan (2009) showed that stakeholders and experts weight landscape- and site-scale metrics differently for prioritizing investment for protecting different landscape components. In turn, Laterra et al. (2012) showed that the resolution of the spatial scale of analysis may drastically modify the influence of landscape composition on joint ES supply. They found that the complementary supply of different ES peaked at intermediate landscape transformation (50 % cropland cover) using 20 km resolution, whereas the reverse was true using 8 km resolution (joint ES supply peaked at 20 and 70 %, and a minimum was observed at 50 % of cropland cover). None of the surveyed studies analysed joint ES supply at more than two spatial scales.

Most surveyed studies based their explanations of joint ES supply on landscape composition (16/29), in spite of evidence highlighting the important role played by landscape configuration (Laterra et al. 2012). Only 4 out of 29 studies considered socio-economic factors in their explanations of joint ES supply, two of which used the spatio-functional approach. For example, Nelson et al. (2009) considered the influence of markets for carbon sequestration on joint ES supply through the analysis of alternative policy scenarios.

The level of stakeholder participation ranged from null participation to involvement in the selection and valuation of ES and planning of scenarios. More than half of surveyed studies (16/29) did not incorporate stakeholders at any stage of the assessment. This situation was common within spatial approaches (11/15), which selected ES based on data availability and/or expert opinion and without regard for their social relevance. Three out of eight studies employing the functional approach used agricultural yields reported by stakeholder. Using a socio-spatial approach, Bryan et al. (2010) and Fagerholm et al. (2012) incorporated stakeholders' perceptions in the valuation of multiple ES, while García-Llorente et al. (2012) elicited stakeholders' preferences on ES under alternative scenarios. Finally, stakeholders participated in the definition of scenarios in only two studies (Crossman and Bryan 2009; Nelson et al. 2009).

The integration of policy targets among surveyed studies ranged from those where explicit identification of policy targets was lacking (6/29) to those aimed at contributing to biological conservation as well as human well-being, at local and/or global scales (11/29). One interesting contrast in the integration of policy targets consisted in the analysis of ecosystem or landscape assets which are just globally-relevant (3/29) versus those that are just locally relevant (7/29). Studies targeted at globally-relevant ES were aimed at identifying areas of spatial coincidence (hotspots) of high biodiversity value and carbon storage and/or sequestration or high productivity of agricultural commodities. Studies targeted at locally-relevant ES were mostly concerned with the supply level of regulation services, which was associated with the assessment of a large number of ES in five out of seven cases.

Providing important information for landscape planning was usually portrayed as the main objective of assessments of joint ES supply. More than half of surveyed studies (15/29) were oriented towards the identification of existing hotspots of ES supply, with little or no prospective value. Only 2 out of 15 spatial studies built spatially-explicit scenarios to explore the effects of policy and planning options on future ES supply (Chan et al. 2006; Reyers et al. 2012). Among studies employing the functional approach, only Lusiana et al. (2012) utilized the quantification of environmental costs and benefits associated with different land-use options to project spatially-explicit scenarios of land-use planning. Finally, Nelson et al. (2009) employed the spatio-functional approach to project spatially-explicit scenarios based on ecological production functions, indicating a promising direction towards increasing the amount of information for landscape planning provided via this approach.

Influence of approach on recommendations: joint ES supply in the Argentine Chaco

The largest variation in most criteria was found between spatial and functional approaches to assess joint ES supply (Table 3). To illustrate how these contrasting approaches may lead to diverging evidence and recommendations, we compare one study using the functional approach (Mastrangelo and Gavin 2012) and another using the spatial approach (Grau et al. 2008) to assess the joint supply of agricultural production and habitat for wildlife in the Northwestern Argentine Chaco (NWACH), at the core of the South American Gran Chaco. This is a subtropical area comprising an environmental and vegetation gradient originally covered by sub-humid forests in the west and dry forests in the east. An accelerated expansion of intensive agriculture during the last two decades in the sub-humid area created contrasting land use/cover patterns: intensive farmland and abandoned forestland in the west and forestland used by peasants for extensive cattle ranching in the east of the NWACH.

Grau et al. (2008) compared the spatial relationships among agricultural output, forest extent (i.e., proxy for wildlife habitat) and peasant production units (i.e., proxy for conservation threat) along a time series in the east and west of the NWACH. They found that land-use efficiency is higher in the west due to the co-occurrence of high production levels as a result of land clearing and intensive farmland, and of low conservation threat as a result of peasant emigration from forestlands. They suggest that increased land-use efficiency outweighs biodiversity loss due to farmland expansion and therefore indicate that the binary, land-sparing pattern of the west offers higher potential to jointly provide agricultural yields and wildlife habitat than the land-sharing pattern of the east.

Mastrangelo and Gavin (2012) evaluated the functional relationships between agricultural yields and bird diversity (i.e., proxy for wildlife habitat) in the west of the NWACH, along a land-use intensity gradient of multiple land-use systems from forests and peasant extensive systems to two types of intermediate-intensity systems to intensive agriculture. They found that the intermediate-intensity, land-sharing systems that integrate pastures and forests provide a higher combination of agricultural yields and wildlife habitat than either undisturbed forests or intensive, land-sparing agriculture.

What conceptual and methodological aspects explain such contrasting results? First, approaches based on spatial relationships are often based on broad land use/cover classifications such as forestland or farmland, which precludes evaluating land-use systems with multifunctional potential at finer scales, such as those integrating trees and pastures or crops on the same land. Second, analysis based on remote sensing data and aggregated population data fail to capture the human and social dimension of land use to address, for example, why do peasants leave their lands, who captures the ES, and how are these distributed among social groups with different vulnerability. Instead, the integration of ecological and social surveys at finer scales allows a view of the relationship between people and the land beyond the biophysical sphere and into the social and cultural one (Rindfuss et al. 2004). Finally, spatial co-occurrence between intensive farmland and abandoned forestlands should not be interpreted as a lasting positive interaction in forest-agriculture frontiers as it is widely documented that wealthy farmers seldom stop expanding farmland in the presence of available lands and with the absence of land-use regulations (Perfecto and Vandermeer 2010), and that the land-sparing pattern is generally a temporary stage in the transition to a cleared landscape (Angelsen and Kaimowitz 2001). Overall, it is evident from this example that different approaches to assess joint ES supply lead to substantially different policy recommendations. A unifying conceptual and methodological approach could be of much help for providing consistent recommendations.

Discussion

The present analysis shows that many conceptions of multifunctionality exist but to date a clear, comprehensive, and operative definition is lacking. As the nature of the phenomenon depends on how it is distinguished by the observer, we propose a classification of multifunctionality that is linked to how the phenomenon is conceived and assessed by researchers. We propose three types of multifunctionality (Fig. 3). First, we distinguish a pattern-based multifunctionality when it is conceived as the joint supply of multiple ES in space, but without regard for the ecological processes underlying this pattern. Second, we define a process-based multifunctionality as the joint supply of ES in space caused by well-understood relationships of synergy or complementarity among them. Third, we propose a socially-relevant, process-based multifunctionality when it is conceived as the joint supply of ES of relevance for local stakeholders, which result from complementary or synergistic relationships among ES. The conception and assessment of multifunctionality are interlinked in such a way that a pattern-based multifunctionality can be detected via spatial and socio-spatial approaches while a process-based multifunctionality can be detected by employing functional and spatio-functional approaches (Fig. 3). In the following, we offer some guidelines to design methodological approaches for assessing landscape multifunctionality under different research contexts. After that, we propose a methodological approach to assess a socially-relevant, process-based type of multifunctionality.

Tailoring approaches to context, scale and scope

Landscapes are under pressure from multiple human demands worldwide, and promoting landscape multifunctionality has therefore become a ubiquitous target

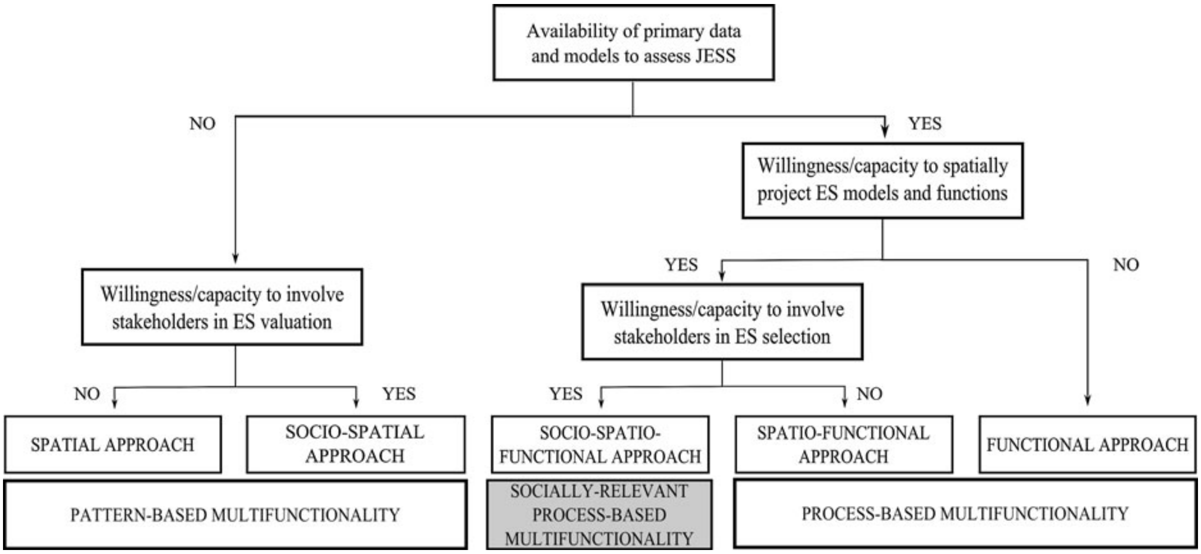

Fig. 3 Decision tree proposed to guide the selection of approaches to assess landscape multifunctionality based on the presence of different barriers and constrains. A spectrum of methodological approaches for the assessment of multifunctionality is proposed based on the relative importance given to the spatial (*right end*) or functional dimension (*left end*) of multifunctionality. Approaches to the centre of the spectrum increasingly incorporate the social dimension and integrate the spatial and functional ones. *ES* ecosystem services, *JESS* joint ES supply

of land-use policies. Assessing the capacity of landscapes to jointly supply multiple ES is key to policy design and at the same time, it is a demanding research endeavour in terms of ecological data and models, and of capacity to undertake transdisciplinary research. As these conditions vary widely among countries and regions, assessing a socially-relevant, process-based type of multifunctionality is not always possible. In order to guide the assessment of joint ES supply, we propose a simple decision tree to design methodological approaches under different types of constraints (Fig. 3).

Where collecting primary data is difficult, models relating landscape attributes and ES are not available, and/or the spatial extent of the study area is large (e.g., country-wide), spatial approaches are useful to identify ES hotspots and prioritize areas for landscape planning interventions. Careful selection of ES proxies is critical to provide realistic assessments using spatial approaches (Eigenbrod et al. 2010). Where there are conflicting demands on ES among multiple stakeholders, spatial data may be used to elicit stakeholders' values and preferences on landscape attributes and ES through participatory mapping methods (Raymond et al. 2009). Meaningful incorporation of the human dimension of ES through socio-spatial approaches can provide policy-relevant assessments of landscape multifunctionality (Rindfuss et al. 2004).

Where primary data and models of ES are available, approaches that model the functional relationships between ES and landscape attributes (and among ES) should be implemented to understand the ecological processes and interactions underlying (joint) ES supply. Such models allow explaining and also predicting the supply of multiple ES and thus, can provide planners and policy-makers with information on drivers of multifunctionality and likely impacts of alternative policies (e.g., Anderson-Texeira et al. 2012). The policy relevance of functional approaches can be greatly enhanced via the spatially-explicit projection of ES models and production functions. The employment of spatio-functional protocols of ES supply assessment (e.g., ECOSER, InVEST) has contributed both to understanding landscape processes underlying ES supply and to informing landscape planning for joint ES supply (Nelson et al. 2009; Laterra et al. 2012). Early involvement of stakeholders for the selection of socially-relevant ES can further increase the utility of spatio-functional approaches.

A unifying approach for assessing multifunctionality based on ES

We have shown that the feasibility and utility of existing approaches to assess landscape multifunctionality varies with contextual conditions, but their components can be virtuously combined to assess a socially-relevant, process-based multifunctionality. As this type of multifunctionality is targeted at increasing local well-being, its assessment should involve local stakeholders from the beginning of the research process, in order to identify and select the benefits that contribute the most to their well-being (Cowling et al. 2008) (Fig. 4). At this stage, social and socio-spatial survey methods such as questionnaires, interviews, and participatory planning GIS might be used to elicit stakeholders' preferences. Deliberative methods such as focus groups should be preferred in contexts where stakeholders have diverging preferences and values on ecosystems and/or are in conflict due to differences in access to relevant ES. This selection may be complemented with other ES that are also important according to experts' opinion.

Bennett et al. (2009) suggest that we should first map the supply of a number of ES based on proxies in order to identify common sets of spatially correlated ES and then select those that occur together (ES bundles) to evaluate their functional relationships. However, we argue that such data-driven selection may not reflect the values and preferences of the stakeholders whose well-being wants to be improved through landscape planning, and instead we call for stakeholder-driven selection of ES if we are to benefit local societies. The role of researchers at this stage is to translate the benefits selected by stakeholders into the ES supporting their supply.

Once socially-relevant ES are identified and selected, we should search for models relating indicators of socially-relevant ES and landscape attributes. Then we should collect primary data on both ES indicators and landscape attributes across environmental and/or land-use gradients (e.g., productivity gradients) to feed existing models or build empirical ones to explain the supply of each socially-relevant ES. Model output should be able to tell us how ES indicators change as a function of landscape attributes along the environmental gradient. Such model output is an ES production function (Paruelo 2011), which shows how the interaction of structure and functioning

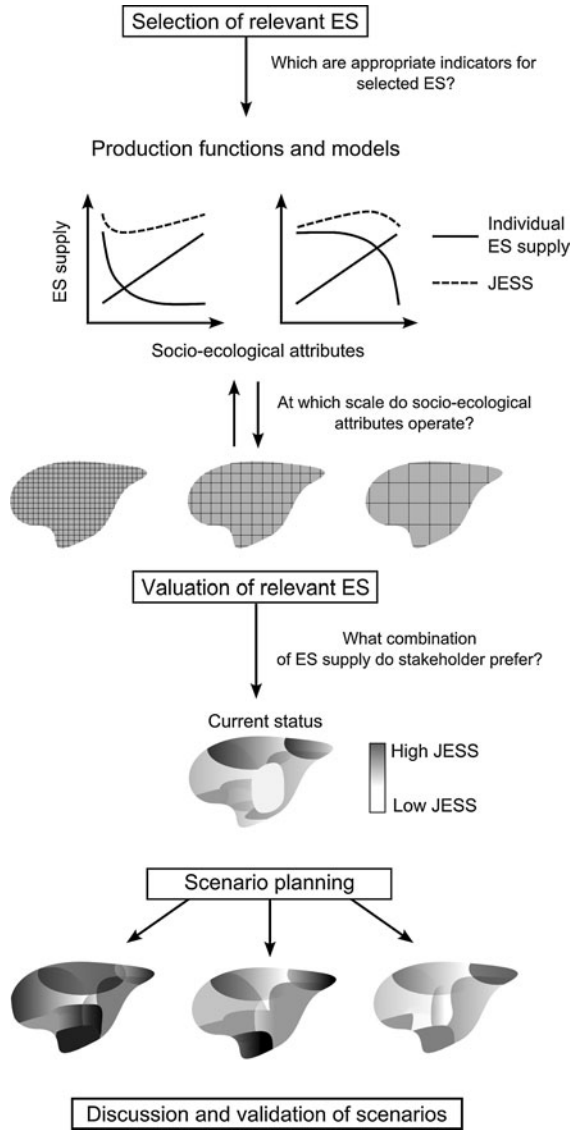

Fig. 4 Methodological approach proposed to guide research for the assessment of a socially-relevant, process-based landscape multifunctionality, and thus to inform landscape planning aimed at improving local well-being. Text in *boxes* indicates instances of stakeholders' participation. *ES* ecosystem services *JESS* joint ES supply. JESS is the sum of the individual ES fluxes

of ecosystems (ecosystem functions in the ES cascade) and social dynamics ultimately leads to resulting levels of ES supply (Tallis and Polasky 2009).

As the level of ES indicators vary both in response to local and landscape factors, the scale at which socio-ecological attributes operate should be carefully considered. Ideally, the production of socially-relevant ES should be evaluated as a function of attributes operating at different spatial scales (ecosystems, landscapes, and regions). When the production of several ES is influenced by a common driver (e.g., agricultural intensification), functional relationships between multiple ES can be assessed and help diagnose the relative utility of land-sharing and land-sparing strategies to reduce trade-offs and enhance complementarities among ES. However, optimization of joint ES supply on the basis of trade-off curves without knowledge on the relative importance of ES for supporting the well-being of local stakeholders or how the benefit is propagated and distributed among them may be misleading. Stakeholders' participation at this stage is necessary to choose preferred combinations in the supply of multiple ES along the production frontier (Smith et al. 2012) and identify "win–win" or "big gains, small loss" opportunities for balancing ES (Defries et al. 2004).

Once ES are empirically assessed by researchers and weighted according to the valuation of their benefits by local stakeholders, supply levels of socially-relevant ES can be mapped by combining ecological production functions and spatial data on landscape attributes (Lavorel et al. 2011). Resulting maps showing the distribution and supply level of multiple ES can then be screened to search for areas of high or low correlation in the supply level of ES, and thus identify the location of ES hotspots and coldspots, respectively. As we know from the previous step how pairs of ES are functionally related, we are able to determine whether a high spatial correlation results from a complementary relationship between ES. This information may be of high utility for landscape planning and design as landscape attributes driving complementarity between ES can be conserved or promoted (e.g., ranchers set-aside of riparian areas), while those driving antagonistic relationships between ES can be de-incentivized or eliminated (e.g., farmers clearing of forest strips between fields).

The relevance for planning and policy of ES assessments increases as stakeholders participate beyond the selection and weighting of ES and their visions and perceptions are incorporated into the planning and validation of scenarios (Cowling et al. 2008). Supply levels of socially-relevant ES can be projected over space by combining ecological production functions and spatially-explicit alternative scenarios reflecting stakeholders' perceptions and preferences on future landscape configurations. Resulting maps have the potential to show the future distribution and supply level of multiple ES under the influence of different drivers, or decision-making paths (*sensu* Wilson 2008). Such scenarios of ES supply may have a high prospective value for landscape planning and design as these allow stakeholders to discuss their common future, and also contribute to explanations of landscape change due to socio-economic processes.

Concluding remarks

By analyzing, on a case by case basis, the way that different studies addressed four critical aspects of multifunctionality assessments, we were able to recognize underlying methodological approaches, their shortcomings and weaknesses, contextual conditions where these may prove useful for landscape planning, and a unifying approach combining their strengths. The evidence presented here suggests that the influence exerted by assessments of multifunctionality on landscape planning can be significantly enhanced if: (i) the targets of multifunctionality assessments are identified at the landscape level and scale, (ii) the type of multifunctionality sought is that emerging from ecological processes and interactions that maximize complementarities among socially-relevant ES, (iii) the procedures of multifunctionality assessments involves stakeholders from the selection of ES to the planning of scenarios, and (iv) the purpose of multifunctionality assessments prioritizes the well-being of local people, especially in landscapes of developing countries where the production of agricultural commodities compromises the supply of locally-relevant ES.

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