Linking functional diversity and social actor strategies in a framework for interdisciplinary analysis of nature's benefits to society

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The crucial role of biodiversity in the links between ecosystems and societies has been repeatedly highlighted both as source of wellbeing and as a target of human actions, but not all aspects of biodiversity are equally important to different ecosystem services. Similarly, different social actors have different perceptions of and access to ecosystem services, and therefore, they have different wants and capacities to select directly or indirectly for particular biodiversity and ecosystem characteristics. Their choices feed back onto the ecosystem services provided to all parties involved and in turn, affect future decisions. Despite this recognition, the research communities addressing biodiversity, ecosystem services, and human outcomes have yet to develop frameworks that adequately treat the multiple dimensions and interactions in the relationship. Here, we present an interdisciplinary framework for the analysis of relationships between functional diversity, ecosystem services, and human actions that is applicable to specific social environmental systems at local scales. We connect the mechanistic understanding of the ecological role of diversity with its social relevance: ecosystem services. The framework permits connections between functional diversity components and priorities of social actors using land use decisions and ecosystem services as the main links between these ecological and social components. We propose a matrix-based method that provides a transparent and flexible platform for quantifying and integrating social and ecological information and negotiating potentially conflicting land uses among multiple social actors. We illustrate the applicability of our framework by way of land use examples from temperate to subtropical South America, an area of rapid social and ecological change.

Most terrestrial ecosystems are shaped by humans (1, 2) and are facing unprecedented human-triggered change from the local to global levels (3, 4). It is no surprise that a large range of research communities and the public at large are taking a growing interest in the dynamics and sustainability of human interactions with the natural environment. This convergence of interests and its accompanying emphasis on the analysis of social environmental systems has resulted in the need to develop integrative interdisciplinary approaches to understand the mutual connections between natural and social subsystems. The Resilience Alliance (5, 6) and the Millennium Ecosystem Assessment (3, 7) programs, as well as sustainability science (8) and land change science (9, 10) research communities, have begun to provide examples of general comprehensive conceptual frameworks and methodological guidelines. They have also begun to highlight the crucial importance of biodiversity in these relationships but heretofore, in a general way.

Generic definitions of biodiversity, ecosystem services (ES), and human wellbeing are not enough to understand the social perceptions and modifications of biodiversity in local and socially heterogeneous situations. Finer levels of resolution are needed, because (*i*) not all aspects of biodiversity are equally important to different ES in different situations and (*ii*) different social actors have different perceptions and needs of ES, differential access to them, and differential desires and capacities to change them. Here, we present a conceptual and methodological framework for the analysis of the links between biodiversity, priorities of different social actors with regard to ES, and land use change at local scales and in specific situations. Building on existing approaches, our protocols emphasize field applicability and cross-disciplinary compatibility, where methods and tools should be compatible with and acceptable by the standards of both the natural and social sciences. We illustrate the framework's applicability to concrete social ecological systems by using examples from temperate to subtropical forest systems of southern South America, an area of rapid social and land use change (11). We also present a three-step matrix-based multiperspective approach to implement the conceptual framework.

Links Between Functional Diversity and Social Actor Strategies

ES are the benefits that humans obtain from ecosystems that support, directly or indirectly, their survival and quality of life (3, 12–14). Here ES are used as a link between the ecological concept of functional diversity and the social concept of social actor strategies (Fig. 1). Paths can be traced from the functional traits (i.e., the physiological, structural, behavioral, or phenological characteristics) of the organisms that make up a local ecological system (Fig. 1 *Right*) all the way to the interests and strategies of different social actors that benefit from them (Fig. 1 *Left*). In turn, land use decisions by these social actors favor or filter out certain organisms and their traits and thus feed back onto the composition and functioning of ecosystems. The value, range, distribution, and relative abundance of functional traits of the organisms that make up an ecosystem are collectively referred to as functional diversity (FD) (15). ES and land use (represented by the lower

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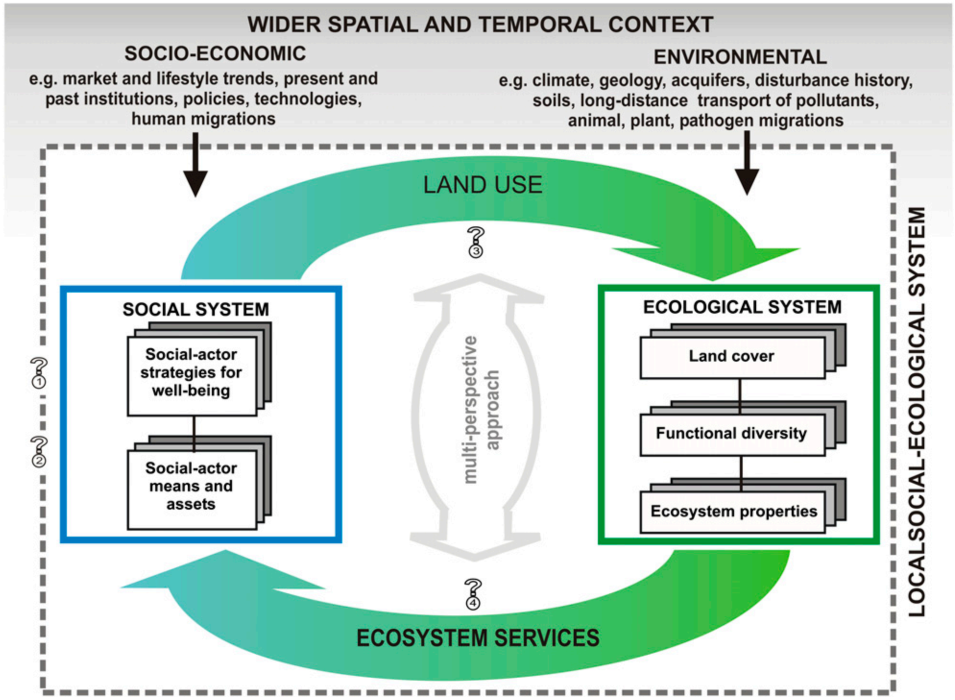

Fig. 1. An interdisciplinary framework for linking functional diversity, social actor strategies, ecosystem services, and land use at the local (patch to landscape) scale. The local social ecological system under study is indicated by the dotted-line box. The wider context is represented in a highly simplified way by the area outside the dotted-line box. Within the local system, the social and ecological components are indicated by the solid-line blue (*Left*) and green (*Right*) boxes, respectively. The thick arrows connecting both components are intrinsically interdisciplinary. The content of boxes and arrows are explained in the text. Multiple rectangles in different shades within the social system and ecological system boxes represent their internal heterogeneity (i.e., a multiplicity of land cover types, functional diversity components, social actor strategies, etc.). The gray arrows at the center represent the instrumental component of the framework: multiperspective approaches, such as the one described in the text and Fig. 3, make the interdisciplinary thick arrows of ecosystem services and land use applicable to concrete local situations (i.e., they move the conceptual structure from left to right and back in the diagram). They also interconnect the internal complexities of the social box with those of the ecological box (i.e., they move the structure back and forth through the layers of internal complexity described above). See *Cross-Cutting Questions* for examples of interdisciplinary questions (indicated by numbered question marks) that can be addressed using this framework.

and upper thick arrows in Fig. 1, respectively) are the main connectors between FD and the economic, social, and cultural heterogeneity among social actors, emphasizing the mechanistic understanding of the ecological role of diversity on the one hand and its social relevance on the other hand.

Ecological Angle: Different Aspects of Biodiversity for Different ES. Biodiversity, understood broadly as the living component of ecosystems, is at the core of human wellbeing, because it affects, and often underpins, the provision of ES (3, 16). FD exerts significant control over different ES (16–20). For example, plant species generally differ in attributes (trait values) that affect ecosystem properties, such as nutrient and carbon cycling (21), trophic transfer to herbivores (22), flammability (23), water capture, retention, and loss (24), resistance to climate variability (25), and feedbacks to climate (26), all of which regulate the environment for humans. Moreover, abundant organisms tend to have a higher impact on these ecosystem properties than do rare ones (27, 28). Thus, some ES significantly depend on the traits of the dominant species (Fig. 2 *Left*). Other ES are based on the range or variety of functional attributes present in the system (Fig. 2 *Center*). Finally, some ES are based on the presence of particular species of special material or symbolic value, even if they are not particularly abundant (Fig. 2 *Right*) (20). Describing biodiversity through the traits of local organisms makes the linkages between biodiversity and ES more explicit and process-oriented than do traditional approaches that describe biodiversity on the basis of species number or abundance only (15, 20, 29).

A number of ecological tools are now available to quantify FD and link it with ecosystem properties and ES. In the case of plants, shortlists of important functional traits that influence ecosystem properties in predictable ways have been developed (30, 31). They include functional traits such as leaf size and chemical composition, seed size and longevity, and canopy and root architecture. These traits have been applied in concrete situations that occur under a wide range of climatic and land use conditions, from comparison of local plots under different land uses (28) to those of vegetation types in different climates (32). Standardized widely applicable and low-tech protocols are available for the measurement of these traits (31). The number of metrics for the quantification of different components of FD is growing quickly (33, 34). Finally, a generic hierarchical method is now available (15) to test the relative importance of the different FD components (such as those in Fig. 2) in determining ES in field situations. This method allows for quantitative assessments of the ES most likely to be enhanced or compromised in the face of changes in FD that are caused by changes in climate, natural extreme events, or land use.

Social Angle: Heterogeneity in the Perception and Appropriation of ES. The ES and the components of human wellbeing identified by the Millennium Ecosystem Assessment were general enough to be applicable to all humans while recognizing that they are context-dependent (3). Although standard classification and economic valuation of ES (13, 35) have proven useful, research to date often ignores differences in individual and societal perception of, benefit from, and access to ES (7, 36, 37), and some services, especially nonprovisioning ones, are difficult to assign

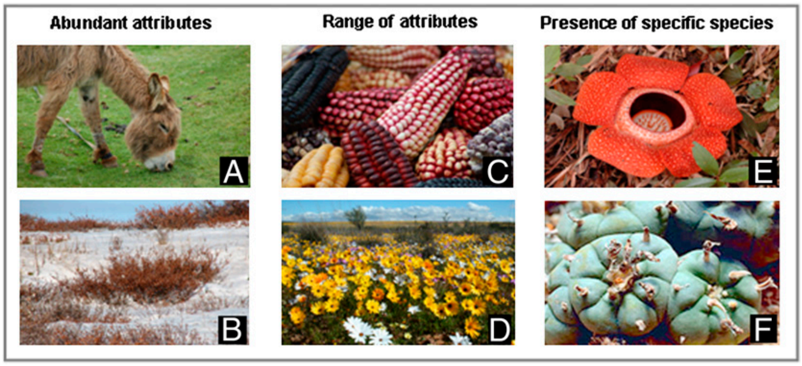

Fig. 2. Dependence of ecosystem services on different components of functional diversity. Different ecosystem services provided by biological communities differentially depend on three main components of functional diversity. Abundant attributes refer to the functional trait values of the locally most abundant organisms (plants in this example). Range of attributes refers to the variety of trait values in the community. Presence of specific species refers to the presence of species that are not necessarily abundant within their trophic level but bear particularly important attributes. (*A*) Vegetation types in which the most abundant plants have tender nitrogen-rich leaves favor fodder provision for free-ranging livestock in Argentina. (*B*) Large deciduous shrubs, which seem to be expanding across the Arctic, are tall enough to stick up above the snow and thus, modify albedo in the spring; this albedo effect, combined with their high transpiration rates in summer, alters energy balance and creates a positive feedback to warming in Alaska. (*C*) The simultaneous cultivation of several varieties of corn, potatoes, and beans with differences in harvest season and tolerance to drought, cold, and pests contributes to food security in the Central Andes. (*D*) The spring flowering of several hundreds of endemic species, displaying a great variety of colors, sustains a flourishing nature-based tourist industry in Namaqualand, an otherwise marginal region of South Africa [Reproduced with permission from B. Reyers (Copyright)]. (*E*) The now endangered carrion flower (*Rafflesia* sp.) attracts visitors and thus, contributes to rural livelihoods in Thailand. [Reproduced with permission from Steve Cornish (Licensed under the Creative Commons Attribution 2.0 Generic Licence).] (*F*) The peyote cactus (*Lophophora williamsii*) has long been central to the religious and artistic lives of some societies in North America. [Reproduced with permission from the U.S. Fish and Wildlife Service, in accordance with Fish and Wildlife Service copyright policy.]

economic value. A growing number of researchers are investigating these differences, especially in regard to equity and conflict (38–41). Our framework directly connects the strategies of different social actors and their reliance on different ES to specific components of FD and ecosystems.

The social actors, or in this case, the stakeholders, considered here are those individuals, groups, entities, organizations, or institutions with direct or indirect claim to land use or ES. Different stakeholders develop different strategies to maintain or enhance their social position and wellbeing (42, 43), including access to ES. In this way, social actors are linked to land and resources through their livelihoods and dependence on certain ES. For example, subsistence farmers rely directly on ES for food, fuel, and shelter, business corporations use ES for improving profits, and nongovernmental organizations use ES in campaigns to protect the environment. In developing their strategies, different social actors perceive and value ES differently (44). Political power and wealth influence which groups have access to and control over land, ecosystems, and thus, ES (45). Access and control over land, in turn, can generate social conflicts, power struggles, and strategic alliances (46). Often, groups with marginal or compromised access to ES also face various stresses such as increased rates of disease and poverty, increasing their vulnerability (47).

Although measures of social actor strategies and human wellbeing and the tools to analyze them have long been developed, they are only in the nascent stage of development for explicit application to a full range of ES. Stakeholder strategies, priorities, and reliance on ES, however, can be addressed through surveys and structured and semistructured interviews of individuals and then, clustered into stakeholder groups through focus groups, workshops, or community mapping exercises (48). Although individual interviews provide deeper insight into personal perspectives, group methods provide social context where people discuss, negotiate, prioritize, reflect on, and mutually reshape their points of view, attitudes, and behavior (49). Finally, participatory and nonparticipatory observation and discourse analysis can elucidate aspects of the relationship between social actors and ES that are not immediately obvious from their discourse (50).

Framework for Linking the Ecological Role and the Social Relevance of Biodiversity

Based on the above, we propose a framework for linking the social and ecological dimensions of land use at fine resolutions from patch to landscape (Fig. 1). Local social ecological systems (Fig. 1, dotted-line rectangle) are situated within wider spatiotemporal human environment contexts that usually exert considerable influence on them. In certain circumstances, changes in the local system can produce changes in the wider context (51) [for example, when similar management decisions on smallholder properties (e.g., to plant or remove trees) taken together have a strong influence on landscape connectivity for forest organisms] (52). However, the predominant direction of influence is from large to small spatial scale. Examples include the usually one-way influence of crop prices (set in the international market) or changing climatic trends on land use decisions by individual landowners (11, 53).

Within the local system, the social component (Fig. 1 *Left*) consists of social actors interacting with each other and using ES in the deployment of their strategies, with different degrees of awareness of their value. The main social actors considered here are subsistence farmers, commercial cattle ranchers, agribusiness companies, and regional governmental conservation agencies. Their strategies are variously modified by conflict and cooperation with other social actors and by factors from the wider context, such as climate change and variability, global market prices, and legislation implemented by governments to comply with national regulations and international conventions.

To obtain the ES necessary for their strategies, these actors perceive, access, and use ecosystems and their FD in very different ways (Fig. 1 *Left*, lower box). Subsistence farmers perceive the forest as a major source of food and medicine (browse for goats, wild fruits, wild honey, bushmeat, and pollen and nectar for domestic bees) and fuel (firewood and charcoal). They, therefore, place a high value on all three components of FD (the three columns of Fig. 2). For example, they value the abundance of plants whose leaves have high nutritional value for goats and plants with high wood density for fuel, irrespective of the species (Fig. 2 *Left*). They also value the presence of certain plant and animal species of high nutritional (e.g., the trees *Prosopis* spp., *Zizyphus mistol*, and *Acanthosyris falcata*, the lizard *Tupinambis* spp., and the wild pig *Tayassu* spp.), medicinal (e.g., the vines *Aristolochia* spp. and the snake *Boa constrictor*), symbolic (e.g., the jaguar *Panthera onca*, the toad *Ceratophrys* spp., and the bottle tree *Chorisia insignis*), or commercial value (e.g., the hardwood tree *Bulnesia sarmientoi*, the parrot *Amazona aestiva*, and the capybara *Hydrochaeris hydrochaeris*) (Fig. 2 *Right*). Above all and consistently with their risk avoidance strategy based on the low-intensity use of a high number of ES (54, 55), subsistence farmers value the presence of a range of different biological attributes (Fig. 2 *Center*). Examples are flowers and fruits available at different times of the year as a sustained source of food and trees with different architectures and wood densities for different fuel (e.g., open fires, closed ovens, and charcoal making) or timber uses (e.g., poles, crates, furniture, and tool handles).

The strategy of cattle ranchers, however, tends to maximize profit through the intensive and specialized use of a small number of ES that sustain products destined to the market. They, therefore, prefer biological attributes that are concentrated to the best values for their commercial scale exploitation. In other words, they prefer FD components in Fig. 2 *Left* and *Right* over those in Fig. 2 *Center*. For example, ranchers place more value on the abundance of good-quality grass fodder (Fig. 2 *Left*) and to a lesser extent, the presence of particular species (Fig. 2 *Right*), such as trees with nutritious pods and good shade for their free-ranging livestock (*Prosopis* spp.) or high commercial timber value (*Aspidosperma quebracho-blanco* and *Schinopsis* spp.). The use of resources that are marginal in quality for cattle or spatially or seasonally sporadic is not commercially viable. Moreover, ranchers can easily buffer the variability in ES (e.g., seasonal fodder shortage) or meet their needs for food or medicine with products (substitutes) from the market. For these reasons, they tend to place little value on the range of functional attributes (Fig. 2 *Center*).

Agribusiness companies represent an extreme case where the strategy is specialized in the high-intensity, short-term use of a single ES (e.g., soil fertility) that results in high annual crop yields (mostly soybean but also corn, wheat, and sorghum). This social actor group may not view any component of FD as a provider of ES or at least, the sole provider owing to its use or large substitutes. Indeed, any preexisting plant cover is seen as an obstacle, because it does not contribute to the use strategy and involves costs to remove. Soil fertility may be an exception, because it is strongly determined by the characteristics of the preexisting plant cover and therefore, could be valued. However, because agribusiness companies typically exploit plots of land for a very short time and then move elsewhere, the role of the plant cover as a determinant of longer-term soil fertility is often not valued.

Finally, regional conservation agencies value the forest as a source of education, recreation, and genetic resources for the future and a reservoir of carbon for global climate regulation. They, therefore, value all three components of FD. Unlike subsistence farmers, however, these agencies adhere to a view of biodiversity that holds that the more species present and the greater the difference in these species, then the better will be all ecosystem processes and services (56). They also tend to put high value on the presence of specific species (Fig. 2 *Right*), particularly endemic, endangered, or otherwise emblematic vertebrates (the jaguar *P. onca*, the tapir *Tapirus terrestris*, the giant armadillo *Priodontes maximus*, and the harpy eagle *Harpia harpyja*) or long-lived large-statured trees (e.g., *Aspidosperma* spp., *Schinopsis* spp., and *B. sarmientoi*).

These different views of the land and its ES result in land use conflicts and alliances that change according to the circumstances. In our examples, common alliances are those between subsistence farmers and conservation agencies (both of which value the natural landscape highly, albeit for different reasons) against commercial livestock ranchers and agribusiness companies. However, subsistence farmers and agribusiness join forces against conservation agencies when the latter tries to enforce stringent antideforestation regulations, because both groups need to remove trees for different reasons (fuel, fencing, and clearing for agriculture).

Social actors make land use decisions according to the priorities explained above and the pressures that they receive from external factors (Fig. 1 *Left*, upper box). For example, commercial farmers allocate their land to cattle ranching or agriculture by deforesting their land and cultivating it or renting it out to agribusiness companies. This decision is based on expected returns, which depend on the relative prices of beef and grains as well as rainfall trends. Both cattle ranchers and agribusiness companies manage the land as large homogenous patches aimed at providing a small number of ES. Their land is disconnected from the surrounding landscape to various degrees from informal agreements to patrolled fences. Subsistence farmers typically exert a low-intensity exploitation of their unfenced lands for the provision of multiple ES. This commonly results in a heterogeneous landscape with gradual transitions between patches. There are usually no set asides for fallow, reserve pasture or forestry use. In contrast, commercial farmers and agribusiness companies often can afford to set aside part of the land cover temporarily or permanently or protect particular species, if they decide to do so. Conservation agencies exert different degrees of control over the land, ranging from exclusion of any extractive use in relatively small patches (e.g., the core of national parks) to regulation of agricultural and extraction activities over larger areas (e.g., in buffer zones), with various levels of enforcement.

Through these land use decisions and the infrastructure (e.g., fences, roads, water points, and irrigation systems) and disturbance regimens that they impose on plant and animal communities (e.g., frequency and intensity of grazing, cutting, harvesting, and burning), different social actors select for different land cover configurations (Fig. 1, upper thick arrow). In other words, they deliberately or unintentionally manipulate land cover, FD, and ecosystem properties to obtain particular combinations of ES that are used locally or remotely. The proportion of the landscape that is directly or indirectly manipulated by each social actor ultimately depends on their relative political power and access to ecosystems (39, 41, 57, 58).

As illustrated in Fig. 1 *Right*, the ecosystem properties that result from these activities form the ecological system in our framework. Within the envelope of climatic and geological conditions, these properties determine the capacity of the ecological system to provide ES available to all of the social actors involved. Ecosystem properties, including biodiversity, thus result from and contribute to the ecological basis of the social actor strategies. The ES derived from these properties, in turn, affect decisions and thus, provide a feedback from ecosystems to social systems, closing the loop (Fig. 3, bottom thick arrow). This can lead to the conflicts and alliances described above. For example, large-scale afforestation projects may contribute to global efforts to regulate climate, but depending on the functional attributes of the tree species used, they can lead to drastic declines in understory productivity and diversity, reduced stream flow, and increased flammability (59). This triggers changes in behavior of small holders whose livelihoods depend on these ecosystem properties, such as abandonment or further intensification of their farms, which, in turn, feed back onto further changes in the structure of the whole landscape. Far from being only the recipients of ES, therefore, social actors produce both benefits and costs to others in the process of manipulating the land to obtain such ES. Some examples of integrated social ecological questions that can be addressed using the present framework are presented in *Cross-Cutting Questions*.

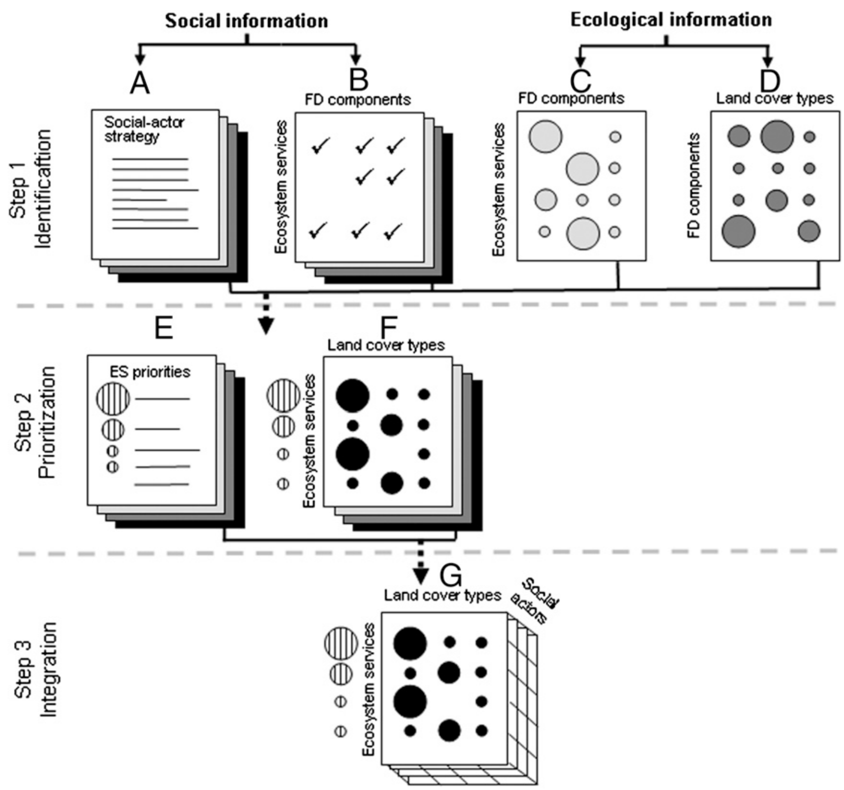

Fig. 3. Integrating social and ecological information on the links between biodiversity, ES, and land use. This diagram outlines a matrix-based multiperspective approach to simultaneously collect and integrate social and ecological information. The text has further descriptions of concepts, methods, and examples. FD, functional biodiversity; ES, ecosystem services. *B*–*D*, *F*, and *G* represent matrices, and the horizontal and vertical labels next to them indicate the content of their columns and rows, respectively. *A* and *E* represent qualitative or at least, nonvectorial information. Multiple rectangles in different shades in *A*, *B*, *E*, and *F* represent a multiplicity of social actors considered in parallel (one per social actor). In *B*, the checkmarks represent simple association between an ES and a specific component of FD recognized by an individual. In *C* and *D*, circles of different sizes represent the degree of association (quantitatively measured or established as a rank value) of FD components with ecosystem properties and services (light gray circles in *C*) or land cover types (dark gray circles in *D*). In *E* and *F*, striped circles of different sizes represent the collective ranking of ES in parallel social actor groups (one rectangle per group). Black circles represent a ranking of land cover types according to their capacity to provide such ES. In the multidimensional matrix *G* (a single matrix incorporating all social actors), black circles have identical meaning as in matrix *F*, but the importance rank of different ES (e.g., their order from top to bottom, denoted by the striped circles) can vary in the *Z* (depth) dimension according to their relevance to the strategies of different social actors.

Multiperspective Approach for Linking Social Actor Strategies, ES, and FD. The application of the proposed framework to the characterization and analysis of real social ecological systems requires flexibility but, at the same time, disciplinary rigor should not be killed for interdisciplinary integration. Whenever possible, existing methods of the various research communities should be used (e.g., for the internal components of the social and ecological systems in Fig. 1). However, integrated social ecological questions, such as those in *Cross-Cutting Questions* and in particular, those involved in the thick arrows of Fig. 1, require interdisciplinary methods that can accommodate multiple stakeholder perspectives on ES.

Approaches seeking to address multiple stakeholder perspectives share three key features. First, they have a strong interdisciplinary character drawn from the various social and environmental sciences. Second, they explicitly accommodate the perspectives of different social actors. Past studies often used researcher-defined categories of ES, which may have little meaning to certain social actors; the incorporation of social actor-defined ES, identified and described in their own terms, is arguably essential to understanding the land system in question. Third, multistakeholder perspectives facilitate participation between social actors and researchers, a presumed requisite in finding suitable solutions for sustainability.

On the basis of a preexisting method (41, 60), we developed a three-step matrix-based multiperspective approach to implement the framework illustrated in Fig. 1. It incorporates the three features mentioned above in synthesizing social, ecological, and land use information in a single consistent system that is transparent both to the social and ecological fields. The main contribution of the approach is that it provides a transparent and flexible platform for (*i*) quantification and integration of social information (needs and perceptions of different social actors) and ecological information (FD, ecosystem properties, and land cover) and (*ii*) negotiation of potentially conflicting land use strategies using different FD components and derived ES.

The method starts with the identification of relevant ES and their links with different components of FD from the perspectives of the researchers and the different social actors involved in the study (Fig. 3 *Top*). Social actors are asked to identify ES in their own terms as the benefits that they obtain from the environment and describe which FD components they associate with the provision of each ES (Fig. 3*A*). For example, fodder provision for cattle is associated with certain abundant plant attributes, such as large tender leaves and leafing early in the season, or with the availability of green leaves from different plant species throughout the year. Sometimes, it is positively associated with the presence of particular species of high nutritional value (e.g., some legumes) or negatively associated with the presence of poisonous species (e.g., some Solanaceae). Individual interviews are preferred in this first step to cover a wider spectrum of information and more insight into individual perceptions. All of the ES identified by different individuals and the different FD components associated with them are then compiled into a single social actor-specific matrix (Fig. 3*B*). In parallel, ecologists measure the ecosystem properties underlying the ES (e.g., green biomass production, protein content, and digestibility in the fodder example). They analyze the degree in which such ES are associated with different FD components (e.g., abundance in the local vegetation of certain values of leaf area, toughness or nutrient content, presence of a wide range of attributes such as different plant heights, or presence of certain species) (Fig. 3*C*). They also quantify how these FD components occur in different land cover types in the landscape (Fig. 3*D*). Note that the matrix in Fig. 3*C* is analogous to that in Fig. 3*B* only using the categories of the natural sciences. The construction of the matrix in Fig. 3*C* is independent in principle from the construction of that in Fig. 3*B* and should be based on current scientific theory and evidence. However, these two matrices are complementary and can enrich each other. The matrix in Fig. 3*B* can be used to inspire and guide further scientific inquiry; that in Fig. 3*C*, however, provides a quantitative scientifically based test of the associations between the ES and FD components identified in the matrix in Fig. 3*B*.

The second step (Fig. 3 *Middle*) is the prioritization of ES and land cover types by each social actor group. This step is most effectively achieved in parallel single social actor focus groups. ES are prioritized by social actors in terms of their relevance to their dominant strategy (Fig. 3*E*). Because the ultimate end is performing multistakeholder analyses with as little bias as possible to any particular group, the prioritization is best carried out using arbitrary rank values. However, the method is amenable to more quantitative units, such as money, mass, or energy, if required by the circumstances. The ranking of land cover types in terms of their capacity to deliver particular ES is carried out in a similar way (Fig. 3*F*). The results from ecological research carried out in the first step (Fig. 3 *C* and *D*) are incorporated at this step as information to assist the assessment of the FD components and ecosystem properties in each land cover type. However, it is not expected to influence the prioritization of ES and land cover types, which, at this stage, should consider only the perspectives of the social actors.

The third step (Fig. 3 *Bottom*) is the integration of information on ES, their associated FD components, and land cover types from the perspective of multiple social actors and researchers. This multidimensional matrix (Fig. 3*G*), containing multiple perspectives (different social actors) and sources of information (e.g., social and ecological), is at the crux of this integrated method and is a major source of information for both new scientific inquiry and practical action. Specifically, it allows a synthetic transparent identification of the potential ES, biological tradeoffs, and sources of social conflict and negotiation in a landscape. During this third step, the priorities of different social actors are considered jointly, and the ecological and social consequences of decisions by some actors on other actors become apparent.

The specific role of the researchers in this context is to provide quantification of and mechanistic insight into the links between FD components, ecosystem processes, and different ES identified by the social actors. They are also in a good position to anticipate the long-term consequences of social actor actions and identify common patterns, discordances, vacuum areas, and probable tipping points. Examples of the issues that can be dealt with at this stage include (*i*) identification of possible conflicts and shared interests in ES between social actors, (*ii*) identification of ES hot spots (clusters of stark conflict or win–win potential), (*iii*) identification of situations in which social conflict arises from purely social factors or is also the unavoidable consequence of ecological tradeoffs, (*iv*) assessment of the potential for delivering multiple services of different ecosystems and FD components in a landscape, (*v*) identification of consensual indicators of the capacity of different ecosystems to deliver ES, and (*vi*) identification of social actor strategies, ecosystems, ES, or FD components for which new critical knowledge is needed. These include areas in which the views of researchers and some social actors do not coincide and also, emergent issues, such as those arising from new land use practices and markets or invasion by new species.

Other methods meet or can be adapted to meet the three-criteria approach to our framework. For example, agent-based models (61, 62) and participatory mapmaking of ES (63) provide valuable opportunities to explore multiscale connectivity issues that are important for regional planning and would otherwise be difficult to visualize. Landscape-scale mapping of multiple ES (64–66) is developing rapidly but rarely contemplates a formalized way to translate between different perspectives like we do here.

Discussion

It is often unclear how biodiversity relates to the needs and interests of the different sectors of society. Recent international initiatives (e.g., DIVERSITAS, Global Land Project, Millennium Ecosystem Assessment, and Resilience Alliance) have greatly contributed to raise awareness on the mutual interdependence between these two issues. We have taken this approach a step further by presenting a framework that incorporates the complexity inherent to biodiversity and the multiple perceptions and needs of heterogeneous societies. It retains both the ecological information (including different components of FD) and the social information (role of ES in different social actor strategies) that are crucial to understanding the links between ecosystems and society. In this sense, the framework presented here elaborates on that proposed by the Global Land Project (67) by operating at a finer level of resolution through the links between different components of the social system (social actor strategies) and the ecological system (FD components).

A fruitful interdisciplinary approach needs to meet the criteria of generality, practical applicability, and cross-disciplinary compatibility. We have presented a framework for linking FD and social actor strategies that satisfies such criteria. What does our framework ultimately add to existing approaches to the interdependence of people and ecosystems? First, it goes beyond the acknowledgment of the generalized importance of biodiversity for human wellbeing into the detailed connections of specific components of biodiversity with the specific interests and priorities of different social actors. Second, by stressing the importance of different biotic components in the deployment of different social actor strategies, it does not necessarily require reducing the value of ES or land cover types to a single currency (money or something else). As such, it should be widely applicable and particularly relevant in areas of high asymmetry between different social groups. Third, the perception and decisions of different social actors are incorporated formally in the process of knowledge generation rather than as a complement to it. Fourth, the approach presented here is transparent enough and has levels of resolution fine enough for people on the ground to directly understand how their needs and actions influence and are influenced by pattern and process in ecosystems. By focusing on the links between different components of FD, different ES, and land use decisions from the perspective of multiple social actor strategies, our framework and practical tools intend to contribute both to fundamental science and also to the construction of user-oriented (39) approaches to ES and biodiversity management and planning.

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INAUGURAL ARTICLE

Box 1. Cross-Cutting Questions

Some interdisciplinary questions can be usefully addressed by using the framework presented in Fig. 1. Questions 1 and 2 represent overarching inquiry at the level of the whole local social ecological system (dotted-line rectangle in Fig. 1) and its links with the wider context. Questions 3 and 4 are more specific and focus on the top and bottom thick arrows of Fig. 1, respectively. By using the approach outlined in Fig. 3, the questions can guide multiple social actor inquiries and actions.

Question 1. Can FD and social actor strategies be linked through consistent syndromes and causal paths across different regions?

Question 2. How can changes in these links affect the sustainability of local socio-ecological systems? Are there particularly critical linkages or thresholds with the potential to trigger major shifts?

Question 3. How do social factors drive land use decisions, and how do these, in turn, affect different components of FD and ecosystem properties?

Question 3.1. How are ES called on in alliances and conflicts between social actors concerning the allocation of the land to different uses?

Question 3.2. What are the spatial and social webs of actors that provide and benefit from different ES?

Question 3.3. How do land use and the biophysical context interact in generating the FD and ecosystem properties that underpin the provision of different ES?

Question 4. How do different components of FD and ecosystem properties affect key ES for different stakeholders?

Question 4.1. Are there any consistent associations between different components of FD (i.e., local abundance of certain plant or animal traits, variety of such traits, or presence of certain species) (Fig. 2) and particular ES and social actors?

Question 4.2. Can conflicts or synergies among different social actors and land uses be traced back to consistent syndromes and tradeoffs in biological traits through ecosystem processes and services?

Question 4.3. Do different social actors identify critical thresholds in the provision of ES? Is there any regularity across such thresholds in terms of type of social actor, ES, or spatial-temporal scale?

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