Conceptual article

Using trade-offs and synergies in ecosystem services for resource management

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Abstract: Trade-off analysis can be defined as an approach to natural resource management that incorporates multiple objectives for the management of a given area (and its resources) within a decision framework. The analysis of trade-off or synergetic relationships among multiple objectives for a given system is essential for the implementation of interdisciplinary (ecological, social and economic) research results into policy making. While research concerning trade-offs in ecosystem services (ESS) is still nascent, several types of trade-offs/synergies have already been investigated, including spatial trade-offs in the provision of ESSs, temporal trade-offs, trade-offs related to stakeholder values, as well as trade-offs between causally related ESSs (such as provisioning and regulating or supporting services), and trade-offs between economic, social and ecological objectives in land use. The last two types of trade-offs address directly the issue of sustainability. Methods of investigation aim at (1) the quantification of trade-offs/synergies using an array of tools borrowed from modeling, behavioral economics, econometrics, etc.… or/and (2) at ranking ESSs via e.g. multi-criteria analyses (MCA). The Future Okavango (TFO) research project intends to incorporate trade-off analysis in its assessment of ESS in order to support management decisions at the scale of the river basin in the Okavango region. It uses a variety of methods which complement one another and enable the incorporation of the concept of ESS into decision making. A description of the ESSs compared using trade-off analysis, as well as of the methods used and their interrelations constitutes the second part of the paper.

Keywords: Decision making; ecosystem services; path dependency; scale; scenarios; stakeholder perspective; sustainability analysis.

O uso de trade-offs e sinergias em serviços de ecossistemas para a gestão de recursos

Resumo: A análise de trade- off pode ser definida como uma abordagem da gestão de recursos naturais, que incorpora múltiplos objetivos, para a gestão de determinada área e seus recursos dentro de uma estrutura de decisão. Essa análise ou a analise de relações sinérgicas entre vários objetivos de um determinado sistema é essencial para a implementação de resultados de pesquisa interdisciplinar (ecológicos, sociais e econômicos), na elaboração de políticas. Enquanto a pesquisa sobre trade-offs nos serviços de ecossistemas (ESSs) ainda é incipiente, vários tipos de trade-offs/sinergias já foram apurados, incluindo trade-offs espaciais, no suprimento de ESSs , trade-offs temporais, trade-offs relacionados aos valores das partes interessadas, bem como trade-offs entre ESSs causalmente relacionados (tais como provisão ou regulação e apoio a serviços) e os trade- offs entre os objetivos econômicos , sociais e ecológicos no uso do solo. Os dois últimos tipos abordam diretamente a questão da sustentabilidade. Os métodos de investigação objetivam: 1. a quantificação dos trade-offs/sinergias usando uma variedade de ferramentas emprestadas da modelagem, da economia comportamental, da econometria etc., e/ou 2. a classificação dos ESSs via, por exemplo, multi-critérios de análise (MCA). O projeto de pesquisa The Future Okavango (TFO) visa incorporar a análise de trade-off na sua avaliação do ESS, a fim de apoiar as decisões de gestão na escala da bacia hidrográfica na região do Okavango. Ele usa uma variedade de métodos que se complementam entre si e permitem a incorporação do conceito de ESS na tomada de decisão. A descrição dos ESSs comparados utilizando a análise de trade- off, bem como os métodos utilizados e suas interrelações constitui a segunda parte do estudo.

Palavras-chave: análise da sustentabilidade; cenários; dependência do curso; escala; perspectivas das partes interessadas; serviços de ecossistemas; tomada de decisão.

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Introduction

The greatest challenge for broad ecosystem service (ESS) assessment projects, such as TFO, is the applicability of their research results for implementation in decision-making. Despite the popularity of the concept of Ecosystem Services, its practical application in land use management has been minimal. According to Elmqvist et al. (2010), this can be because little is known (i) about how ESSs are interrelated, (ii) about the influence of scale on the demand and supply of ESSs, and (iii) about the potential trade-offs among ecosystem services – especially among regulating and provisioning services (*sensu* Millennium Ecosystem Assessment 2005). Yet, identifying and evaluating trade-offs among ESSs shall and may encourage humans to find new solutions to conflicting problems in land and resource management.

Analyzing the interrelations and interactions among ESSs, in particular trade-offs and synergies, from the ecological and user perspective is necessary to ensure that ecological research results can be implemented via management. Since ESSs are not fully independent, rather they are part of the socio-ecological system and may be mutually dependent, policies affecting one ESS may also affect the spatial and temporal patterns of others (Nelson et al.

2008). In addition, information on relationships among ESSs and relationships between ESS and other objectives of the investigated system (economic, social) may be helpful in untangling conflicts in a structured and transparent manner. Yet, little has been achieved in research on trade-offs among ESSs (Seppelt et al. 2011) and the need for the development of new tools has been highlighted by Burkhard et al. (2012).

This paper depicts trade-offs among ESSs and between ESSs and other land use management goals from a theoretical perspective. It then presents the TFO approach for its trade-offs analysis of ESSs as occurring in the Okavango River Basin, southern Africa.

ESS, sustainability and trade-off analysis: a theoretical perspective

Terminology used in trade-offs analysis

Trade-offs and synergies are types of interrelations among ESSs. *Synergies* occur among ESSs which co-vary positively, that is, when the increase of one ESS enhances the other. For instance climate regulation helps to regulate water flows and water quality. On the contrary, *trade-offs* are characterized by a negative co-variation among ESSs. Trade-offs occur when the increase of one or a group of ESSs occasions a loss or diminution in one or several other ESSs. A typical trade-off is the one occurring between provisioning services (see MEA definition, MEA 2005) and regulating services (Elmqvist et al. 2010). For instance, increased production of agricultural crops may reduce soil quality and consequently also water regulation.

An additional concept which may contribute to identifying relationships among ESSs is the one of ESS *bundle*. According to Raudsepp-Hearne et al. (2010a), bundles of ESSs fluctuate jointly in the same direction when they are affected by a driver. Reasons for ESSs to behave in bundles may be that they are spatially, ecologically, or institutionally related. Thus, bundles may indicate how ecosystem services interact in a system, as well as reveal hidden links among them.

Finally, evaluating trade-offs can also be understood as a cognitive process, namely as a *shift* in valuation in a decision-making process (here on land use) comparing the contribution of ESSs to reaching targeted goals, such as well-being. This perspective is related to the sciences of decision making, such as used in economics and anthropology and will be developed in the second section of this paper.

It follows that trade-off analysis can be defined as an approach to natural resource management which incorporates multiple objectives for the management of a given area (and its resources) within a decision framework (Brown et al. 2011).

Trade-offs and sustainability

We define sustainability as the aim of management and policies to meet ecological, economic and social criteria (Costanza 1993). Hence, the concept of sustainability is based on three goals and it addresses directly the issue of trade-offs among these three goals. Obviously, win-win-win situations in ecosystem management are rare and may prevail only in exceptional cases in untroubled societies. In addition, we should highlight the role of the time and spatial scale dimensions embedded in the concept of sustainability (for a recent publication which also refers to the link with resilience see Derissen et al 2011). For instance, the focus on one economic objective today may have negative effects on e.g. ecological aspects in the long term. Further, the assessment and perception of sustainability also depends on the scale at which indicators are taken, on the scale of analysis. For instance, resource-conserving agriculture was found to increase yields, and thus also economic (but not necessarily financial) outcomes at farm level, in developing countries by Pretty et al. (2006), but these improvements may not contribute to a change in the economic situation at the level of the state. Thus, the analyst needs to monitor selected variables within a given time and spatial frame in order to assess the criteria used to judge the sustainability of a given approach, policy measure or system.

In essence, trade-offs may occur among the ecological, economic and social objectives of land-use and reflect the search for practical concepts on the sustainability of land-use (Cheung and Sumaila, 2008). If we consider that an ecosystem supplies a series of ESSs to a society, we recognize and address the multi-functionality of ecosystems. They are at the basis of our livelihoods in all societies, but at the same time, there is a need to conserve them to support our livelihoods in the future. Thus, the conservation-development conflict is also a matter of managing ESSs in an ecosystem defined over time and space and following complex dynamics.

ESSs are different in nature and some may contribute more than others to fulfilling the social, economic or ecological objectives in land-use management schemes. Although ESSs are not sufficient to cover the full dimension of the economic and social constituents in a system, they crystalize those which are directly linked to the human-environment relationship. Thereby, a trade-off analysis among ESSs can contribute directly to forewarn of trade-offs or conflicts between conservation and development. An example is given by Martin-Lopez et al. (2011) who classify regulatory and supporting services (*sensu* Millennium Ecosystem Assessment 2005) as ecological or conservation aims, while the production of tradable items such as crops or meat for the international market – generating the most income – was an indicator for the desire to 'develop'. In contrast, the social dimension appears in the form of the production of more traditional crops and livestock providing only local benefits. These ESSs were part of the cultural inheritance of inhabitants of the Donãna valley in southern Spain.

Yet, due to the relationships among the different ESSs, not all goals seem achievable at once: one can assume that social and economic ESS are spatially in competition (trade-off) while economically oriented ESS have the potential to negatively affect ecologically oriented ESS. It is the study of such relationships that TFO is aiming at.

Functional trade-offs and synergies

Ecosystems are at the origin of multiple services which interact in complex ways. Causes for the relationships are numerous. Often, trade-offs among ESSs occur simply because they compete for space at the local scale (e.g. (e.g. to produce timber, medicinal products, or food staples). This type of trade-off can easily be represented concretely, e.g. through GIS-based approaches (Law et al. 2012) since such ecosystem services are directly associated to land cover. Current studies of spatial trade-offs/synergies tend to focus on trade-offs among provisioning or final services, and they show excludability or complementarity between two (or more) final ESSs. For instance, the provision of crops on a piece of land often excludes the harvesting of natural wild medicinal plants on the same plot (e.g. Law et al. 2012).

However, spatial trade-offs also occur between provisioning and regulatory services which are causally linked, e.g. crop growth on fields and pollination by wild bees, supported by forest patches (Garibaldi et al. 2011). The analysis of such trade-offs requires a process-based description of the system to detect and quantify relationships among ESSs (Lautenbach et al. 2012). The spatial organization of landscapes potentially and strongly affects trade-offs because it affects the capacity of a given landscape to supply services. The spatial organization also determines whether or not ecosystem functions will be perceived as services at all, and therefore whether they will be valued. For instance, the location of a lake will determine its capacity to deliver recreation services, the position of a forest patch in relation to crop fields will determine its capacity to provide pollination services (see Gómez-Limón and Sanchez-Fernandez, 2010 for indicators). A concrete example is given by Olschewski et al. (2010), who found that economic losses in timber sale, due to a limited reduction of tree density in a *Cordia alliodora* plantation in Indonesia, can be overcompensated by generating pollination services to adjacent coffee agroforestry systems.

Land fragmentation is an important aspect of spatial effects which may affect ESS provision and therefore the nature of potential trade-offs. The ecological and economic consequences of forest conversion and fragmentation for biodiversity, ecosystem functioning, and ecosystem services like protecting soils, water retention, pollination, or bio-control are, however, still poorly understood (Priess et al. 2007). In the Okavango catchment, we expect that fragmented natural habitats will have a strong impact on species diversity and intensively used areas may cut off migration pathways for large mammals, among other effects.

Further, many trade-offs are best presented as time-related pay-offs. Indeed, when two ESSs are causally linked, a change in the level of the underlying ESS may not result in an immediate change in the supply of all dependent ESSs. A time-lag may be related to the resilience of the ecosystem, in terms of its buffering capacity: the effects on the dependent ESSs may become apparent only after the level of

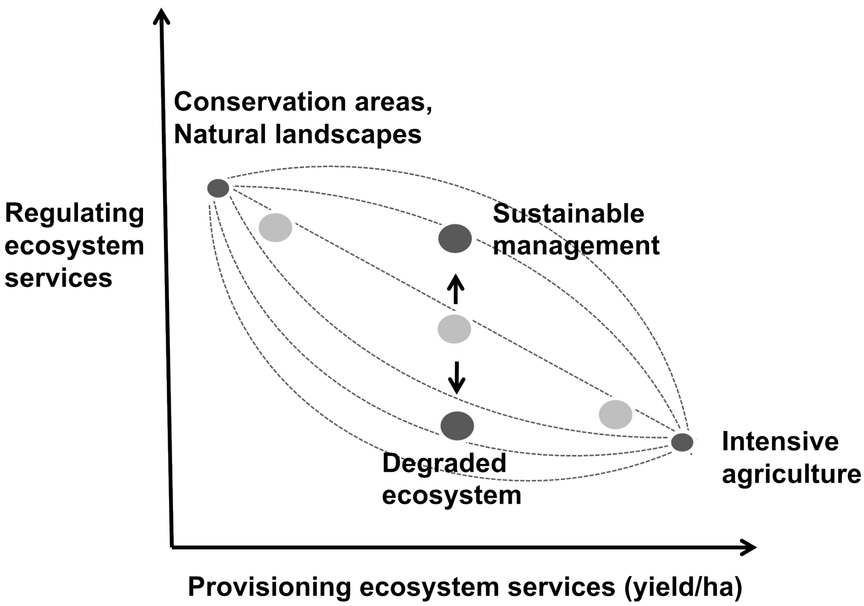


Fig. 1: A model trade-off in the management of ecosystems or landscapes with efficiency frontiers between regulating services and yield per ha as a provisioning service (modified from Elmqvist et al. 2010).

the underlying ESS has reached a given threshold. Such temporal trade-offs typically occur between final (provisioning) ecosystem services and underlying intermediary (regulatory) ecosystem services, such as crop growth and soil fertility. Crop growth depends on soil fertility (soil nutrient stocks, pH-levels, organic matter, etc.) and contributes directly to well-being in the form of harvested yields and food supply. A given yield can be maintained for a given time (in the tropics it could be short), but will inevitably decrease in the medium term if a proper investment to maintain soil fertility regulatory functions does not take place. While such relationships are recognized theoretically (Elmqvist et al. 2010), they are, in fact, difficult to quantify (Raudsepp-Hearne et al. 2010b).

Trade-offs in time between underlying and dependent output have been the focus of environmental economic studies on relationships between production and related income and given environmental features (pollution, degradation, etc…). Many examples concern the management of fisheries, but also rangelands (Domptail et al. 2009). Yet, they have rarely been addressed in spatial terms. The problem of trade-offs among provisioning and regulating services is similar. The provisioning services provide immediate returns while the regulating services ensure the long term basis for the provisioning service. An interesting method of investigation developed in environmental economics for this problem consists in frontier analysis, which depicts a curve of the largest possible amount of one desired output (possibly a well-being indicator or a service) as a function of an underlying service. For instance, Figure 1 depicts possible relationships or trade-offs between regulatory and provisioning services in coffee production. Four types or situations can occur:

- Regulatory services are high and provisioning services are low: conservation landscape (case a)
- Regulatory services are high and provisioning services are medium: sustainable management (case b)
- Regulatory services are low and provisioning services are medium: degraded ecosystem (case c)
- Regulatory services are low and provisioning services are high: agriculture is intensive and probably relies on external inputs. The ecosystem is degraded but functional (case d).

Management has a role to play in which it should aim at influencing the trade-off towards a win-win situation (case b).

A last point concerning functional aspects is that trade-offs and other relationships such as correlation between ESSs (above-mentioned bundles of ESSs) may also be societal. An example is provided by Raudsepp-Hearne et al. (2010a) who report on human communities unwilling to live close to areas with industrial animal production in Europe.

Trade-offs and ecological scales

From a spatial analysis and mapping ESSs point of view ecosystem services are provided on different spatial and temporal ecological scales (Scholes et al. 2013) which have to be explicitly distinguished. An evaluation of trade-offs between ESSs must take into account these various scales as well as their cumulative effects (Roeder et al. this issue). Individual ecosystem services are provided by so-called "service producing units" (Luck et al. 2009) which correspond to ecological levels such as single species, populations or landscapes (Morán-Ordóñez et al. 2013). When assessing ESSs for a trade-offs analysis, it is important to remember that the service- providing units for various ESSs may not be the same and may occur on different spatial and/or temporal scales. And there might be synergies or trade-offs between ESSs occurring at different scales: inter-scale relationships.

Hence, decisions and management on one scale may have impacts on any other scale. For instance, on a regional scale, a conversion of woodland to arable land will not only diminish the provision of timber and firewood or alter supporting services such as Net Primary Production (NPP) while food production increases, but it will also lessen global scale regulating services such as carbon sequestration. In another case, the accumulation in space of local changes in ESSs, say soil quality, which when reaching a larger scale also affect landscape processes and landscape-based ESSs such as wildlife growth.

In addition, directional spatial effects may occur such as changes in the delivery of one ESS by a given ecosystem may affect the delivery of ESSs in a geographically adjacent or spatially dependent ecosystem (Fisher et al. 2009, Fig. 2). This is especially significant for upstream-downstream relationships such as the ones characterizing river basins and for the Okavango River Basin as well, where the Okavango Delta is dependent on the water supply of the upper catchment. Here, depletion or pollution of water resources in the upstream regions or changes in water dynamics, whether anthropogenic or not, can have major impacts on the downstream Panhandle and Delta ecosystems.

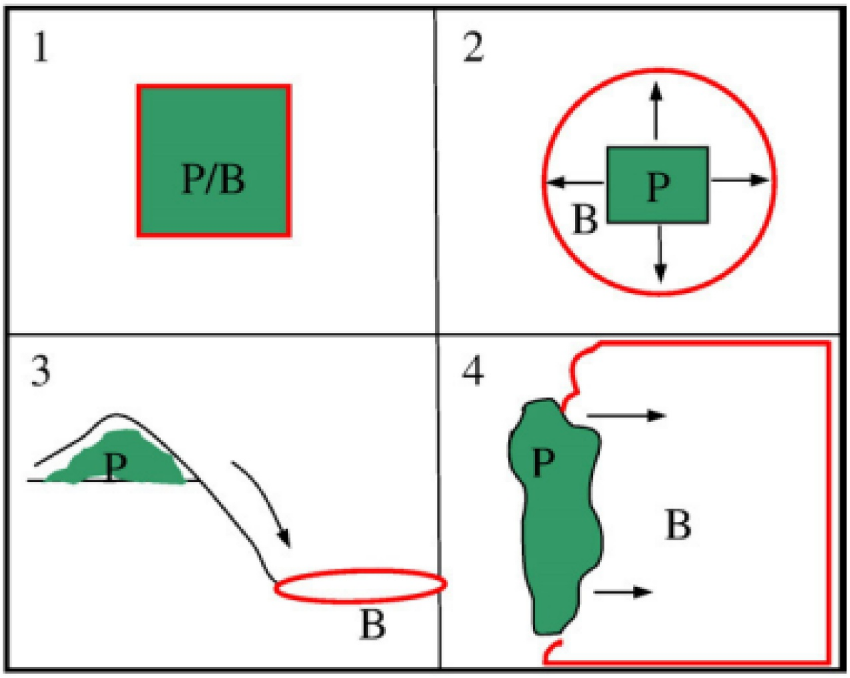


Fig. 2: Possible spatial relationships between service production areas (P) and service benefit areas (B). In panel 1, both the service provision and benefit occur at the same location (e.g. soil formation, provision of raw materials). In panel 2 the service is provided omni-directionally and benefits the surrounding landscape (e.g. pollination, carbon sequestration). Panels 3 and 4 demonstrate services that have specific directional benefits. In panel 3, the most important one for the Okavango River Basin, down slope or down-stream units benefit from services provided in uphill areas or upstream, for example biodiversity services in the Delta provided by the pulse water system of the Okavango River. In panel 4, the service provision unit could be coastal wetlands providing storm and flood protection to a coastline (source: Fisher et al. 2009; explanatory text modified).

The interaction of spatial and temporal scales must also be considered when evaluating trade-offs between ESSs. A change today in a given ecosystem usually has not only immediate but also subsequent impacts on the desired regulatory ESSs. These effects may occur in the given ecosystem or in spatially-dependent ecosystems, or even at another scale all together. Indeed, each ESS depends on ecosystem functions having their own specific pace (temporal dynamics). In the above mentioned case of the woodland conversion to arable land, the change in provisioning services is immediate and local while the global effect on climate change may take place after a time lag. On the opposite, infrastructure building such as roads or dams may have little local immediate impact on e.g. biodiversity but important regional long term impact e.g. on migration of species. Here, cumulative effects are of major importance. Ecological complex dynamics exhibiting time-lags and spatial directionality make the assessment of trade-offs and their valuation more difficult (Costanza 2008). That is why it is important to assess ecosystem services at the appropriate scale with regard to both space and time (Millennium Ecosystem Assessment 2005). In general, an assessment or a model valid at one scale cannot be assumed to be valid for another scale (Kremen et al. 2000, Millennium Ecosystem Assessment 2005).

Finally, the (e)valuation of trade-offs occurring at different spatial and temporal extents also depends strongly on the stakeholders that work on different spatial scales (see following section).

Trade-offs and stakeholders: a decision-making process

As mentioned earlier, trade-off analysis is also a process preparing decisions, and assesses the perception that decision makers and land managers have of functional trade-offs. When involving stakeholders in the analysis, one can define trade-offs as human decisions taken in situations of transformation and changing values. People decide about trading one quality or one aspect of their life against another (Chan et al. 2012). For instance, when adapting to the transformations and welcoming the promises of modern markets, people both accept short-term new costs and are willing to trade the long-term quality/sustainability of their environmental resources (Raudsepp-Hearne et al. 2010b). Hopefully, with growing awareness and information about the long-term consequences of such trade-offs will cause decisions to change.

Interestingly, the values attributed to any given ESS, or to any other economic, ecological and social goal, may vary with the stakeholder group, especially if the stakeholders are characterized by different scales of intervention (Martin-Lopez et al. 2011, Zia et al. 2011, Potschin and Haines-Young 2011). Stakeholders responsible for the management of large areas tend to favor regulating services while local stakeholders prioritize provisioning services (Fu et al. 2011). Results from Martin-Lopez et al. (2011) indicate that stakeholders put a higher value on regulating services affecting them directly and occurring at the scale to which they relate: i.e. international consumers value climate regulation, while local stakeholders prioritize soil fertility regulation.

Trade-offs may also be rooted in the geographical repartition of costs and benefits around the provision of an ESS (Fisher et al. 2009). This is the case for the ESS water supply, which is generated upstream, while most benefits arise at the mouth of the river. Winners and losers are located in different geographic regions and the management of the cost-benefit trade-offs at two local scales involves negotiations between parties based on the stakeholders' respective values (Vignola et al. 2012).

Dealing explicitly with perceived trade-offs in ecological, economic and social targets among local groups of stakeholders and comparing local and higher level (e.g. regional/national) stakeholder perception can help to understand how land use has been managed until today (Martin-Lopez et al. 2011) and may help deal with the conflicting objectives of the groups involved in a transparent and constructive manner.

Overview of tools for trade-off analysis

Tools and methods for the analysis of trade-offs and synergies are still being developed. This is the object of a working group set up within the newly established Ecosystem Service Partnership (www.es-partnership.org) (Burkhard et al. 2012). To our knowledge, the methods commonly used to investigate functional relationships among ESS include:

- Boxplots to depict the relationship between two ecosystem services (Lautenbach et al. 2012)
- Efficiency frontiers between two ecosystem services (Elmqvist et al. 2010) or between ESS and well-being (Cheung and Sumaila 2006, Domptail et al. 2009), often computed using optimization models.
- Correlation analyses based on maps for the different ESS (Raudsepp-Hearne et al. 2010a)
- Linear regression analysis as well as some basic descriptive statistic measures (Swallow et al. 2009)
- Scenario analyses using computer models (Lautenbach et al. 2012)
- GIS-supported map analysis: spatial correlation of ESSs at different levels of provision (Law et al. 2012)
- Model-based, integrated valuation of ecosystem services and trade-offs (Bagstad et al. 2013, Kareiva et al. 2011)

Analyses of Trade-offs among stakeholder values for given ESSs in decision-making processes rather involve:

- Scenario analyses combined with Multi-Criteria-Analyses (deliberative or not) (Zia et al. 2011, Brown et al. 2001) – also for trade-offs among stakeholder values.
- Redundancy Analyses and Hierarchical clusters (Martin-Lopez et al. 2011) for trade-offs among stakeholder values.
- Preference assessments (Conjoint Analysis, Choice Modeling) (Takatsuka et al. 2005)
- Monetary valuation and Cost-Benefit-Analyses (Mmopelwa & al. 2009)
- Anthropological studies (using questionnaires and observation) of contexts in which values are produced, performed and applied in decision making (Raymond et al. 2009).

Trade-off research in The Future Okavango (TFO) research project

TFO investigates trade-off/synergy relationships among all of the ESSs mentioned in Table 1. In practice, we concentrate on trade-offs related with changes in the ESS water supply, the provisioning ESSs and two supporting ESSs (environmental settings and wild species diversity). Trade-off and synergy relationships are identified from a (natural) science perspective as well as using stakeholder participation. This approach has the potential to create the link between natural science identification and social science valuation.

ESS Water supply

Not surprisingly, water is a key element in the study area, underlying the ESS provision of most other services. At the river catchment level, the project undertakes a functional analysis of water flows and investigates (with the help of a land use simulation model) trade-offs between the provision of freshwater and related ecosystem services depending on water supply as an intermediary ESS (e.g. provisioning of food through irrigated agriculture). At first, the focus is on crop growth, livestock growth, tree growth and other goods dependent on water.

The valuation of the trade-offs associated with water is the object of two further analyses. First, the trade-offs between crop production and water supply through irrigation will be the subject of monetary valuation using a bio-economic model which enables the identification of a shadow price for water and soil fertility. This analysis is conducted at the farm scale, for given land use management options and under given levels of water scarcity. Second, current preferences for trade-offs among water supply, water quality, livestock growth, recreation and wildlife growth will be assessed among different groups of stakeholders: i.e. among farmers and tourists especially. A conjoint analysis compares the impact of different water supply levels on these ESSs via 5 water-use scenarios outlining different interventions. The hypothesis here is that different user groups will value trade-offs differently.

Provisioning services and well-being

Crop (including vegetable) growth, tree growth, wildlife growth, livestock growth, and the provision of natural resources for construction purposes (mainly thatching grass) are the main provisioning services investigated in TFO, as they are directly related to the needs of the local population. From a functional point of view, these services are directly correlated with land cover and land use choices. Reeds and a given type of thatching grass only grow in the wetlands and are dependent on water supply, the other services (and a second type of thatching grass) result from potentially competing land uses: agriculture, natural forest areas and pastures, respectively. Mapping of land cover to visualize trade-offs among the land use-related ESSs is carried out using a land use model.

Each of the mentioned provisioning ESSs (Crop, tree, wildlife, livestock growth, and the provision of natural resources) contributes directly to well-being, either in terms of subsistence or as an income generator. The decision process for resource allocation (e.g. land, labor and cash expenses), which aims at maximizing human well-being, reflects individual preferences for different ESSs. Thus, user choices take into consideration existing trade-offs among and between ESSs. TFO investigates the trade-offs at the scales of individuals, of households – especially with regard to gender- and of communities, i.e. in the TFO core sites. Using survey analysis and experiments following a revealed preferences approach, we attempt to understand the decision making processes within households and their impact on the availability of ESSs. The hypothesis is that women and men assign different values to ESSs, use them differently, and thus make different choices concerning the application of resources (work) in pursuing their livelihoods. An anthropological analysis also provides a qualitative assessment of values on provisioning ESS using qualitative interviews, focus group discussions, paired comparisons (Bernard 2000, Burton 2003) and landscape value mapping (Raymond, et al. 2009). The aim is to understand how values for the different ESSs are formed, and on what they depend.

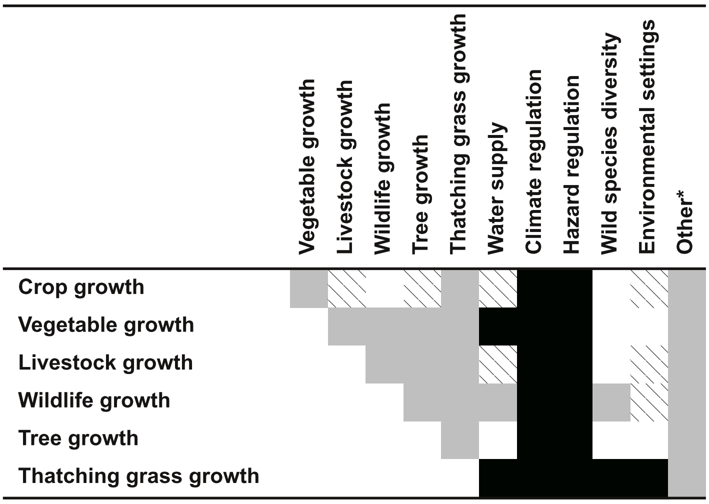
Using the same anthropological research methods, we assess trade-offs perceived by land-users between provisioning ESSs and other strategies available to ensure livelihoods and well-being (e.g. wage labor). This trade-off is expressed through the choice land users make to use ESS for their own subsistence only or to trade ESSs on markets in order to access cash and thereby reach other strategies for increasing one's well-being. For the analysis, the implications of access to resources and entitlement are important. Via cash and other strategies local people seek to increase their well-being. Specifically, new markets for crop and other collected resources (thatched grasses) might sharpen their view of the perceived trade-offs between conservation and the extraction of provisioning ESS as the need for cash resources increases. This analysis is completed by a quantitative investigation from a resource economics perspective based on the use of a bio-economic farm model. The model delivers a shadow price for farmers' labor time and for cash resources and can simulate scarcity increase due to degradation and increased resource demand. When resources are used to ensure farmers' livelihoods through agricultural and other activities (Hecht 2010), in the medium and long run, shortages will increase and the value of ESS should rise. Using bio-economic modeling we can also investigate the temporal effects of balancing trade-offs through an alternation of periods of extractions of ESSs and periods of non-use (resting a pasture, fallow, ban on harvest/collection) to allow for the regeneration of the ecosystem.

Sustainability analysis: spatiotemporal and causal trade-offs

The functional assessment of complex causal trade-offs (apart from the case of water, which we mentioned earlier as a key feature) between the above mentioned provisioning services and supporting services is investigated first from a natural science perspective. This relates to soil quality, intermediary service in TFO, environmental settings and wild species diversity - both final and intermediary to other provisioning services such as wildlife growth. Information on soil quality and nutrient cycling, which are functions supporting provisioning services, is provided by a detailed analysis comparing different land use options (e.g. industrial agriculture versus conservation agriculture) on a very small scale (plot). Further, botanical and ecological assessments seek to identify functional and spatial thresholds for the stability of biological communities and habitats in the sense of "state and transition systems" (Westoby et al. 1989). This means that the threshold determines when a system shifts from a given biological community to another. The hypothesis is that increasing land allocation for provisioning services (such as crop production) drives habitat fragmentation processes which may result in the extinction of local and regional species. Testing this hypothesis requires the conduction of biodiversity assessments in comparable biophysical systems under different land-use intensities at the landscape scale (expressed in terms of land cover types and fragmentation). Space-for-time approaches are used to analyze probable impacts of land-use change on wild species diversity by attributing ecological integrity scores. A habitat model is also computed. Note that while this analysis is functional, the drivers of land use change are social, especially the development of new markets for locally produced crops. In addition, trade-offs and synergies resulting from competing demands on food production, timber harvesting and the protection of biodiversity in emerging land management concepts in the Okavango river basin will also be addressed by using earth observation data on different spatial and temporal scales. These contribute to the understanding of the present state and variability of ecosystems as well as their changes within the last decades.

The socio-economic assessment, on the other hand, investigates causal time-lagged trade-offs through which the issue of sustainability is clearly represented and involving the comparison of thanks to multiple criteria. The focus of the analysis is the comparison of values attributed to provisioning services versus those attributed to supporting services (soil fertility, environmental settings and wild species diversity). A first approach stemming from the anthropological perspective provides the valuation of trade-offs and synergies within the whole complex of goods depending on the ESS "Environmental settings" (e.g. beauty of landscape, recreation, spiritual values, sense of place) together with the ESS "Wild species diversity" and the related

Table 1: Overview of relationships among ESSs (trade-offs or synergies) investigated in TFO assigned to disciplines. Cells with a grey color indicate a socio-economic evaluation; cells with white color a functional (ecological) evaluation; a pointed cell indicates the potential for an interdisciplinary socio-ecological evaluation; black indicates that this trade-off is not investigated by the TFO project (source: own). *Other strategies for generating well-being (leisure, casual labor, employment)



final service of “Wildlife growth”. The hypothesis is that different groups of stakeholders will hold different values for these ESSs and thus will perceive trade-offs differently: for instance farmers suffering from human-wildlife conflicts vs. conservationists/tourists. Additionally, a monetary value of trade-offs between the supporting ecosystem function “Soil quality” and the provisioning service “Crop growth” will be provided using bio-economic modeling (Domptail 2011). Management is expected to shift the value of the trade-offs and the analysis aims at identifying win-win management options. Finally, the perception of trade-offs among ESSs may largely depend on institutional settings and property rights over the different services. Here a governance approach will be used, in which field experiments conducted among land users in order to determine the efficiency of alternative institutions for the management of the natural resources and the cooperation behavior of land users in the light of degradation risks linked to individual and collective use of the ecosystem.

Trade-off synthesis analysis

Exploratory scenarios are developed in TFO and serve as a support to present the trade-offs investigated elsewhere by TFO in a context (i.e. different scenarios) in which they can be understood and compared by stakeholders. A multi-criteria analysis (MCA, Brown et al. 2001) incorporating as criteriatit to stakeholders and researchers will be conducted by the ecological-economics group in order to foster the building of values and preferences for trade-offs among ESSs of stakeholders. Alternatively we look at interrelationships between ESS conservation and other objectives that were not necessarily known by stakeholders before the scenarios were created (Krütli 2010). During a participatory valuation exercise, if possible deliberative, stakeholders will be incited to develop a sense for their own preference and eventually that of others.

We advance the hypothesis that different stakeholder groups will prefer different scenarios, based on their own value of the different ESSs. The different stakeholder groups and their values may be characterized by specific resource access, assets ownership, interest and whether they are benefiters or managers/providers of ESSs, and whether they are active at the large or at the local scale. The advantage of using the MCA as a synthesis tool over the calculation of a Total Economic Valuation (TEV) for each scenario is its greater transparency and capacity of addressing such conflicts. If only final values are provided, a monetary TEV meanwhile, masks trade-offs, assumes equal weights among the ESSs in their contribution to well-being and/or/ natural capital. It does not differentiate between those who bare losses and those who enjoy gains (Hanley & Spash 1993).

Conclusion

In fact, trade-off analysis offers the most effective way to date to find sustainable management options for water and land use, options whose attractiveness lies in their consideration of social, economic, and ecological factors on all scales, from the individual to the planetary.

Challenges linked to trade-off analysis are three-fold. First, relevant and suitable criteria for the measurement of ESSs and other possible objectives for the system investigated must be identified, measured and monitored at the appropriate space and time scale. Second, the functional relationships between given ESSs, taking here as well scale differences and time-lags into consideration must be identified. Third, information on how both the ESSs and their interrelations vary as a function of land use is crucial. These three tasks are mainly the focus of scientific work and of the positive and structured analysis of the socio-ecological system. Yet, while quantities or qualities of ESSs can be compared through the use of tools such as scenario building, the final evaluation of the trade-offs is in essence the value, the weight, that stakeholder individuals or groups attribute to one ESS as compared to another. Thus, the final trade-off valuation can only take place through an active involvement of stakeholders and within a process of decision making.

This procedure is followed in the TFO research project where the functional analysis of the Okavango River Basin constitute a main goal, while n parallel, several techniques are deployed to measure, capture or foster the formation of stakeholder values for the identified ESS. Finally scenario building, through its participatory evaluation using MCA, constitutes an attempt to bring stakeholder valuation and the scientific measurement of the trade-offs together.

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