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Social-Ecological Dynamics of Ecosystem Services: Livelihoods and the Functional Relation between Ecosystem Service Supply and Demand—Evidence from Socotra Archipelago, Yemen and the Sahel Region, West Africa

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Abstract: In aiming to halt global biodiversity loss, it is essential to address underlying societal processes. The concept of ecosystem services claims to bridge between biodiversity and society. At the same time there is a considerable research gap regarding how ecosystem services are provided, and how societal activities and dynamics influence the provision of ecosystem services. Interactions and dependencies between ecosystem services supply and demand come to the fore but context-specific dynamics have largely been neglected. This article is a critical reflection on the current research of ecosystem services supply and demand. We argue that there is a functional relation between the supply and demand for ecosystem services, with the two influencing each other. Scientific interest should focus on both the temporal and spatial dynamics of ecosystem services supply and demand. Presenting two studies from Socotra Archipelago, Yemen and the Sahel regions in Senegal and Mali, West Africa, we illustrate that the society behind the demand for ecosystem services is highly interrelated with ecosystem services supply. We thus advocate the adoption of a social-ecological perspective for current research on ecosystem services supply and demand in order to address these context-specific temporal and spatial dynamics.

Keywords: dynamics of use; ecosystem services; social-ecological system; spatial and temporal dynamics; supply and demand

1. Introduction

Global biodiversity still continues to decline [1,2]. Biodiversity loss is regarded to be one of the "grand challenges" for humanity, alongside climate change, globalisation, demographic change and food security. The changes in biodiversity alter ecosystem processes and functions, and subsequently influence the ability to provide goods and services to society [3,4].

There has been great progress in recent years in understanding and assessing ecosystem functions; at the same time, the benefits that humans derive from ecosystems are more and more appreciated in the social sciences [5]. The ecosystem services (ES) concept has helped raise awareness about the societal relevance of ecosystems [6]. Furthermore, the concept has proved its purpose to support the maintenance of biodiversity, at least since the publication of the TEEB (The Economics of Ecosystems and Biodiversity) reports [7,8], and the recent constitution of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). The ES concept promises to bridge between society

and nature, namely society's demand for certain services and the supply from ecosystems to satisfy these needs.

At the same time there is a considerable research gap regarding how societal activities and dynamics influence the provision of ES [9,10]. From a system-related perspective, the interlinkages between nature and society come to the fore [11,12] while nature-society interactions, particularly the dynamic aspects of ES, have largely been neglected [13,14].

This article advocates the adoption of a social-ecological perspective on ES in order to better understand the dynamics in supply and demand as well as any interlinkages that exist. We argue that there is functional relation between ES supply and demand, where both nature and society interact and influence each other. Here we present the latest results from two ES studies in the West African Sahel region and Socotra Archipelago, Yemen, respectively, and show that temporal and spatial dynamics in both, nature and society do occur. Finally, we critically reflect on current ES research and ultimately deduce future directions for research.

2. Conceptual Reflection: The Social-Ecological Perspective

From a social-ecological perspective, dynamics of supply and demand for ES represent historically and culturally specific societal relations to nature [15]. For the empirical analysis, they can be conceptualised as social-ecological systems (SES) [12] (Figure 1). Societal actors influence the natural system and related ecosystem functions. It is via the latter that nature provides ES, but also ecosystem disservices that harm society. Societal actors directly or indirectly influence the SES via intended management activities or unintended side effects thereof [16]. The four mediating dimensions of knowledge, practices, institutions and technology shape the social-ecological structures and processes as the core part of the SES [16]. Biodiversity plays a critical role at different hierarchical levels of the ecosystem functions and services. It acts as a regulator of the ecosystem processes that underpin ES, and can be a final good in its own right [17,18]. Hence there is an urgent need to consider biodiversity in all its complexity, including its relation to and interaction with the ecosystem and society [9,19–22].

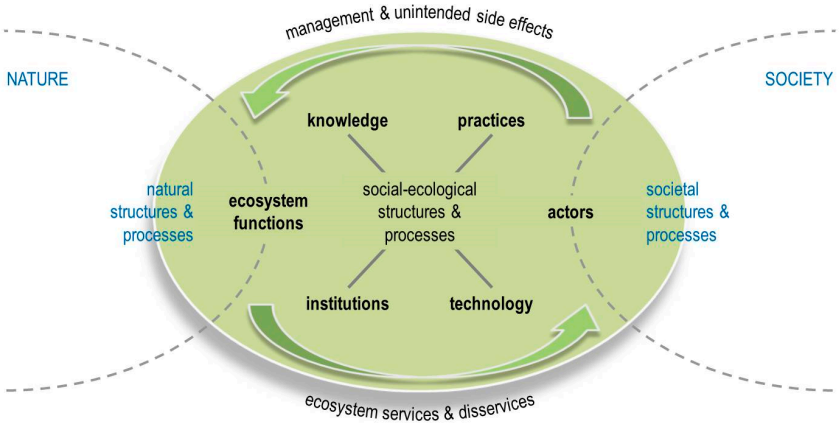

Figure 1. The concept of social-ecological systems [22].

The ES concept is generally discussed as being adequately conceived to address the relation between nature and society [6]. Focusing on the interlinkages between society and nature, it inherently captures this social-ecological perspective [11,12,23]. The ES concept has increasingly been included in research objectives, policies and international initiatives such as The EU Biodiversity Strategy to 2020 [24] as well as the IPBES Conceptual Framework [25]. These activities resulted in different research projects to map and assess biodiversity and ES by applying the conceptual dichotomy of ES supply and demand [5]. These authors [5] interpret ES supply as the capacity of a particular area to provide a specific bundle of ES within a given time period. ES demand is understood as the need for

specific ES on the part of society, particular stakeholder groups or individuals [26]. This demand is interrelated with other factors, e.g., behavioural norms, consumption patterns, demographic changes, technical regimes or socio-economic conditions [27]. As yet, a variety of different methods from both the natural and social sciences and the humanities have been developed in order to address the respective research questions on the supply [28] and demand [29] for ES.

Shortcomings still exist in the application of the ES concept [23]. The authors argue that the social-ecological nature of the ES concept must be elaborated more carefully. The recent discussion on relational values [30] is a first step in this direction of underlining the social-ecological nature. Besides intrinsic and instrumental values, relational values address those values that pertain to all manner of relationships between nature and people, including relationships that are between people but involve nature [30]. This means e.g., hiking in nature is not only valuable due to a beautiful and remote landscape but also due to being together with good friends for this hiking tour.

However, the dynamic aspects of ES supply and demand have hardly been considered yet [13]. While in some cases ES providing and benefiting areas overlap, in others they do not. In case of spatial disconnection of areas providing and demanding ES, the concept of ES flow is applied. ES flows can thus reflect the spatial relationship between ES supply and ES demand. The flows can work passively through biophysical processes (e.g., climate regulation), actively through societal processes (e.g., transport and trade), or through a combination of both [27]. However, up to now there have been very few attempts to quantify ES flows. In addition, temporal dynamics, such as historic and future land use change, can also influence ES supply and demand [13]. Finally, a recent study [31] on marine and coastal ES explores the social and ecological dynamics of ES, called ecosystem service elasticity. The authors present a conceptual framework that unpacks the chain of causality from ecosystem stocks through flows, goods, value, and shares to contribute to the well-being of different people. However, this framework does not address the functional relation between ES supply and demand, i.e., that nature and society mutually influence each other via spatial and temporal dynamics of ES supply and demand.

Against this background, this article will contribute to the discussion on the dynamics of ES and calls for a social-ecological perspective in current research on ES supply and demand.

3. The Social-Ecological Dynamics of Ecosystem Services: Empirical Evidence

Below we present two studies from the West African Sahel and the Socotra Archipelago, Yemen demonstrating the spatial and temporal dynamics of ES supply and demand, respectively. Both studies particularly exemplify the functional relation between ES supply and demand as well as temporal and spatial ES dynamics. However, spatial effects are more pronounced in the Sahel case study whereas temporal effects are more important in the Socotra case study, and hence are illuminated accordingly.

3.1. Spatial Dynamics of Ecosystem Services Supply and Demand: The Case of the West African Sahel

The case study of the West African Sahel illustrates the complex interactions between societal factors and ES demand and supply. The SES (Figure 1) investigated here consists of relations between actors such as villagers, farmers and migrants, and different ecosystem functions such as primary production. This relation is mediated by practices (e.g., seasonal migration), knowledge such as local knowledge about soil and plants, technology such as irrigation schemes or use of fertilizers, and institutions such as social networks or migration policies. Important ES are food production, i.e., crop yields, an example for disservices are pests. The actors influence the system for example by agricultural management or unintended side effects thereof [32]. In this way, the SES concept introduced above allows for an analysis of the specific functional relation between ES supply and demand, with a special focus on spatial dynamics.

The majority of the rural population in the West African Sahel depends on subsistence and small-scale farming. The Fulani, Wolof and Dogon are the largest ethnic groups in the Sahel. The Wolof

and Dogon are traditionally farmers, while the Fulani are traditionally semi-nomadic pastoralists. Climate change, especially increasing temperatures and rainfall variability, impacts on ecosystems and poses considerable risks to society. Linguère in Senegal and Bandiagara in Mali (Figure 2) are areas in the semi-arid Sahel zone which have always suffered from drought periods and from land degradation. The Bandiagara region in Mali is predominantly inhabited by the Dogon and Linguère in Senegal by the Fulani and Wolof.

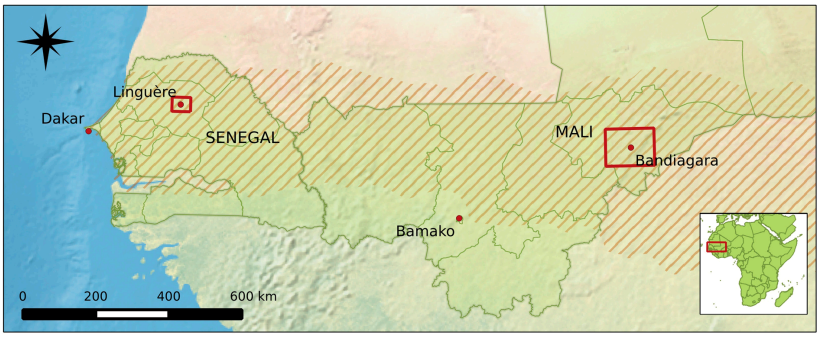

Figure 2. Location of study areas in Senegal and Mali (red rectangles). Shaded areas indicate the Sahel's extent, delimited by the 250 mm/a isohyet in the north and 900 mm/a in the south.

Our study followed an inter—and transdisciplinary research approach which integrated natural-scientific and social-scientific knowledge, as well as practical knowledge. The natural-scientific analysis investigated interactions of climate change and land degradation. Changes in temperature, precipitation and vegetation have been analysed by combining global remote sensing techniques with high-resolution images and detailed field work on a local scale [33,34]. The social-empirical research investigated perceptions of environmental changes affecting the local population, as well as their motives for migration and migration patterns. The data collection combined qualitative interviews, focus group discussion and participant observation. In 2012, a survey was conducted with 905 individuals in villages in Bandiagara (324 questionnaires) and Linguère (337 questionnaires) and with migrants from these regions in Bamako (121 questionnaires) and Dakar (123 questionnaires). The survey solely included the Wolof, Dogon and sedentary Fulani [34]. The same questionnaire was used for both study sites. Interviewees and survey participants were selected randomly and differed with respect to age, education, ethnicity, gender, and migration experience. The sampling of the survey participants based on a quota sample and defined three age categories (18 to 30 years, 31 to 50 years, 51 years and older); while the qualitative interviews were also conducted with younger people [32,35]. For the integration of natural-scientific and social-scientific data, Bayesian Belief Networks were used as modelling method [36].

Varying rainfall patterns, but also human activities have contributed to massive changes in flora, fauna and soils. After an extremely dry period from the 1970s to the 1990s, rainfall has been increasing in both regions, but its temporal variability is increasing too. These changes have caused an increase in vegetation in many areas (the so called 'greening phenomenon'). This trend is supported by farmer-managed agroforestry, reforestation programs and nature conservation measures [33,34]. Given the crucial role of agriculture, the demand for ES when it comes to food production and livelihoods is considerable. Local farmers and livestock breeders demand particularly provisioning ES such as crops, wild fruits, fuel wood and fodder, but also supporting services, particularly soil formation, and regulating services such as purification of water. The main economic activities in Bandiagara, Mali are rain-fed agriculture, particularly the cultivation of groundnut, sorghum and millet, as well as vegetable gardening, primarily onions by the Dogon. Linguère, Senegal is a traditionally silvo-pastoral zone. Together with livestock breeding, cropping represents an important occupation for the Wolof and the sedentary Fulani [35]. Shrubs and trees provide considerable ES and thus play a

major role in people's everyday life in both study areas. They are a main source of firewood and timber, and are traditionally used for cooking, construction, medicine, and for religious purposes. Leaves and fruits are used for animal feed, and the selling of firewood and charcoal is a common practice which makes a considerable contribution to the income of the local population. In both study sites a survey was conducted with 905 participants in total (Mali: 445; Bandiagara: 324 and Bamako: 121, Senegal: 460; Linguère: 337 and Dakar: 123).

The strong significance of rainfall patterns is very apparent in rain-fed agriculture in the study areas. The majority of the population in Linguère and Bandiagara rely on small-scale farming and livestock breeding. They adapted to the seasonal dynamics in order to satisfy their needs. In this regard, human migration within the countries, especially to urban centres and the capitals, is a significant characteristic of the culture in the region. Few respondents migrated within the departments of Linguere and Bandiagara, while the majority from both study areas moved either to long-distance destinations within the country (i.e., rural departments of Kaolak, Tambacounda and Matam in Senegal or Ségou and Sikasso in Mali) or—in the case of respondents in Mali, to Cote d'Ivoire. One third of respondents chose the capital as destination [35]. The distance between Bamako and the Bandiagara region is at around 670 km, while the distance between Dakar and Linguère is at around 310 km. This means a whole-day journey by bus.

The survey showed that a vast majority in both study regions (87%) have personally experienced migration [32,36]. While in Mali the share of men with migration experience is higher than for women (94% male vs. 70% female), there is no significant difference between the migration experience of men and women in Senegal (80% male vs. 78% female) [35]. Regarding the duration of migration, seasonal (3 to 9 months) and temporary (10 months to 5 years) are the most dominant types. These results highlight the strong interdependence of ES supply and migration [32]. The seasonal variability in the food production system required adaptation strategies from the local people, namely migration to other regions, among other strategies presented below.

Climate change particularly influences crop yields in this region, and thus the ES-dependent food supply [37,38]. Altered rainfall and land degradation directly influence ES supply and compromise the income basis of rural households, because these factors impair both agricultural production and returns [36,39,40]. The dynamics at work in the ES supply trigger a complex compensatory process. More diversified sources of income and multi-local income become relevant for a large proportion of the population as a result. Local people apply different compensatory strategies (Figure 3). Migration is just one coping strategy: increased money transfers from migrants seem to be more important than increasing the number of migrants. The migration of entire families is very rare in both study regions. Usually only few family members migrate to find employment, while another part of the family remains in the village and is still depending on local food supply. The money earned in migration is then targeted at supplementing the agricultural outcome [35]. Other adaptation strategies entail falling back on alternative ES: the selling of livestock represents the most important coping strategy in both areas. The two regions differ with regard to activities such as the selling of wood, or collection and selling of wild fruits, herbs and straw, and the pursuit of gardening activities. In Bandiagara, Mali, in particular, the income from irrigated agriculture alongside small dams, seasonal waterholes or small rivers plays a crucial role. Wood or wild fruits, herbs and straw are mainly traded against crops at the market.

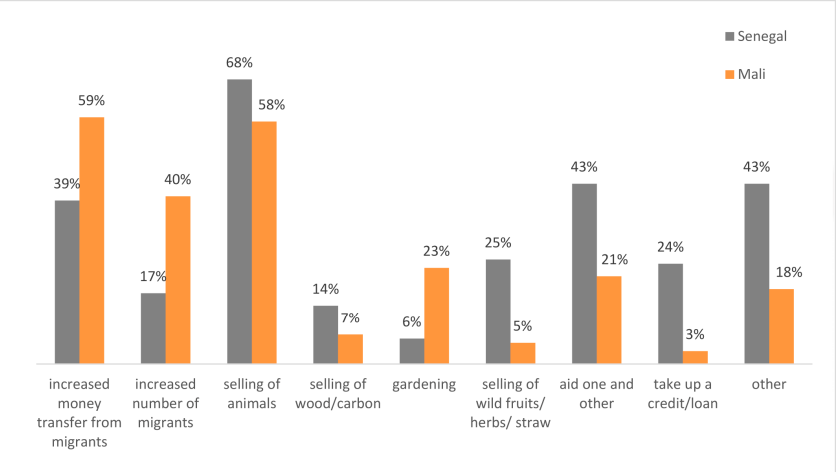

Figure 3. Distribution of strategies to compensate for bad harvests (multiple answers possible) in both study regions, Linguère, Senegal and Bandiagara, Mali. The figure illustrates the livelihood activities for those people whose family is involved in an agricultural activity. This is the case for 854 individuals (=100%) (Senegal n = 411; Mali n = 443) [32].

The decrease in crop yields in rural areas makes it necessary to find ways of generating multiple sources of local income in other economic sectors at different places, thus contributing to the spatial as well as temporal alteration of the demand for ES. Seasonal migration (3–9 months) in particular is a traditionally long-established strategy to deal with the seasonality and variability of rainfall, and thus food production. People leave the village during the dry season, when there is little work to do on the fields, and move to the cities to work in the construction or service sector, or, in the case of women, in the domestic sector, for example. They return to the villages for the harvest season [32,36]. This seasonal migration decreases demand in the region of origin. For example, there is less demand for firewood required for cooking and thus shrubs and trees can recover during this period. This temporary shift of residence might also compensate for the alteration of ES supply .Though our study did not quantify the demand for ES during periods of migration and local harvest periods, the results of the social-empirical analysis suggest that people respond to decreasing rainfall and crop yields by extending their duration of migration, either by leaving the village earlier or by staying longer in migration—or by increasing the number of migrants within the household [32,35,36]. The interplay of one ES supply and demand for other ES has an explicitly spatial characteristic here. Besides migration, the demographic dynamics are of great relevance for spatial-temporal dynamics of ES demand and supply: Both regions still experience high population growth with a current annual growth rate of around 3% in Bandiagara and 2.4% in Linguère as a consequence of high fertility rates and a young age structure [40]. Overall, it must be assumed that population growth is associated with an increase in ES demand, notwithstanding the high mobility of the population in both study regions. The level of formal education of the population must be considered here as one of the most important social characteristics. The lower the level of formal education, the more likely the survey participants are to rely on agriculture as their main source of income. Agriculture is an economic activity for 58% of respondents, but only for 18% of participants with a high education level. Participants with a higher level of formal education are more likely to be involved in business, administration, or health, i.e., sectors which are not directly depending on ES. Among the survey participants, the level of education is considerably low: only 24% have obtained formal education, and the level of education is significantly lower among women than men [41]. Furthermore, people fall back on alternative ES within the given SES, such as the collection of wild fruits and wood in order to compensate for deteriorating environmental conditions (Figure 3). These strategies might also augment the pressure on ES. For example, the most dominant adaptation strategy, i.e., the selling of animals, can increase

the demand for ES in other target areas where the animals move to, as animal husbandry poses high demands on ecosystem services particularly fodder and water.

Summing up, the study from West African Sahel illustrates the strong dependence on crop yields for agricultural production and food supply. The seasonality of this ES supply is crucial. Overall, the complex dynamics in the ES supply trigger complex compensatory processes which in turn have impacts on both ES supply and demand. Migration, particularly seasonal migration, is one of the most important drivers with great impacts on spatial and temporal dynamics, but must be considered in conjunction with social differences such as age, gender, and education level.

3.2. Temporal Dynamics of Ecosystem Service Supply and Demand: The Case of Socotra Archipelago, Yemen

The case study of the Socotra Archipelago is a fishery-based SES representing complex social-ecological processes. In particular, the interaction between local fisher communities (actors) and ecosystem functions such as marine primary productivity is investigated. The seasonal variation in ES supply, namely fish biomass, and its impact on societal structures and processes (i.e., adaptation of local livelihood strategies) is examined. This interrelation is considered as being shaped by the mediating dimensions [16] of practices (fishing customs of local fishermen), technology for fishing, knowledge about the local monsoon patterns and institutions such as local associations or policies. In this sense, applying the SES concept as described above (see Figure 1) helps analyzing the respective functional relations between ES supply and demand with a particular focus on temporal dynamics at this case study site.

The Socotra Archipelago, part of Yemen, lies in the northern Indian Ocean, at the Horn of Africa (Figure 4). It is globally recognised for its outstanding biodiversity and endemism, the reason why the entire island group was designated a UNESCO World Heritage Site in 2008 [42,43]. The archipelago is characterised by a unique cultural heritage: the Socotri people speak a unique non-written pre-Islamic language of ancient origin, and their culture host a wealth of traditional knowledge on the sustainable use of natural resources and biodiversity [44–46]. As for Yemen as a whole the human island population of some 60,000 ranks very low on the Human Development Index (HDI) (rank 168 for Yemen in 2015, HDI 0.482 [47]).

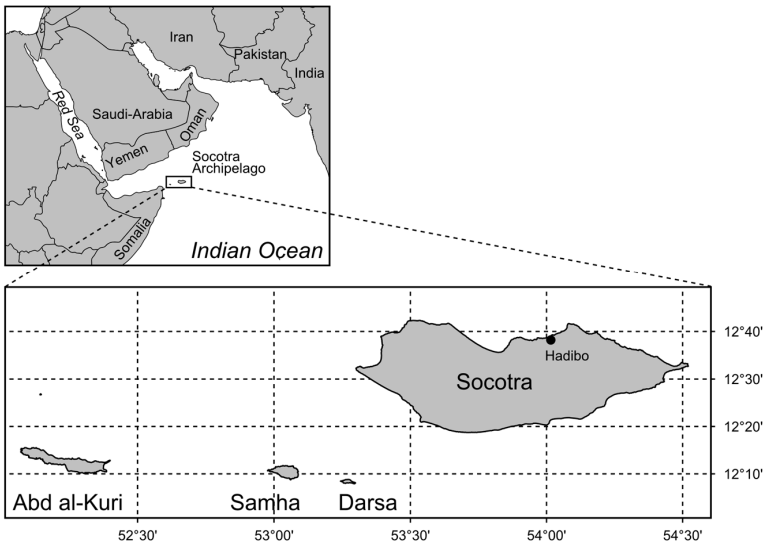

Figure 4. Overview map of the Socotra Archipelago, showing its geographic position in the Indian Ocean.

The research program started in 2007 and was conducted in four coastal pilot areas at the north Coast of Socotra Island, including six study villages, and fourteen permanent subtidal monitoring sites

in close proximity to these villages. In particular the research focused on marine and coastal ecosystem services being critical to a changing subtropical social-ecological island system, environmental variables determining key ES as well as the socio-economic context of the local fisher communities. Biological and environmental data were generated between 2009 and 2013 primarily by subtidal visual fish biomass estimates, in-situ recording of environmental and ES data, analyses of ocean-color based environmental proxies (i.e., Chlorophyll a), carbon-based productivity models and sea surface temperature. A pilot study on ES supply and demand was completed in 2011. In 2013 empirical social research addressing the vulnerability of local livelihoods was conducted. In particular a household survey in the six study villages (45 questionnaires) was accomplished. Furthermore, focus groups discussions in each village were organized. Two types of groups were distinguished, fishermen from the village (5 to 7 participants per group) and women groups (5 to 15 participants per group). Finally, key informant interviews with 7 experts from 4 different institutions (administration, tourism, protected area team, and fishery organizations) were conducted. The variation and dynamics of ES demand were captured by respective questions during the interviews and from anecdotal reports by the communities, based on existing knowledge [44–46]. The methods and further results are primarily documented in [48–51].

The islands are subject to the alternating monsoon seasons in the northern Indian Ocean: the 'weak' and wet winter or north-east monsoon (November–February) and the 'strong' and dry summer or south-west monsoon (May–September). This seasonally reversing monsoon system creates particular oceanographic conditions around these islands during the summer monsoon, which result in seasonally very high marine primary productivity levels, providing the basis for exceptionally high productivity of fish (Figure 5, representing the related key ES) and other marine biomass [44,51].

Socotra ranks among the most productive inshore marine areas in the Indo-West Pacific. Fish biomass and community pattern are highly seasonal, linked to the monsoon dynamics and the associated local upwelling systems [51,52]. The seasonally varying marine productivity pattern [49] accordingly results in a strong temporal variability of key ES supply, namely fish biomass (Figure 5) [48].

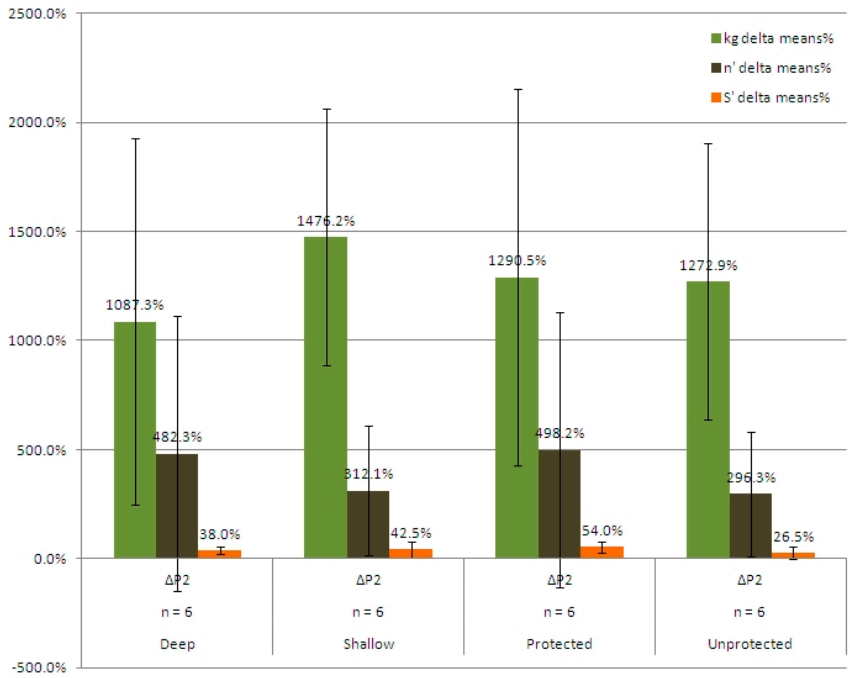

Figure 5. Comparison of the mean difference (%) at six study sites of fish biomass (green), fish individuals (brown) and fish diversity (species) (orange) between the post-monsoon and the pre-monsoon seasons on Socotra Archipelago, according to depth (deep versus shallow) and protection status (protected versus unprotected) [53].

The inhabitants of the coastal plains rely primarily on rural fisheries, while the population of the island interior consists of semi-nomadic pastoralists whose main source of livelihood is livestock herding. Both population groups complement their livelihoods with a variety of additional services provided by the specific ecosystems they dwell on, and by traditionally exchanging (trading) benefits among themselves and with the other group, respectively, especially at times of seasonal supply shortages [45,46]. The income of the coastal dwellers, mainly fishermen, is relatively low and highly dependent on fishing during the non-monsoon periods, which contributes more than half of the annual income, including the direct consumption (Figure 6a). Moreover, if compared to the actual effort (time and energy) allocated to the different livelihood activities (Figure 6b), the revenues from fishing in the non-monsoon periods make it the economically most viable activity compared to all other sources of livelihood, which contribute relatively little to the total income. Therefore, the total income of a fishing family on Socotra Archipelago is highly dependent on a temporal (seasonal) ES supply pattern. As with marine productivity patterns also terrestrial productivity is partly climate-dependent, with fodder for livestock becoming increasingly scarce in the interior during the dry period (before the onset of the monsoon).

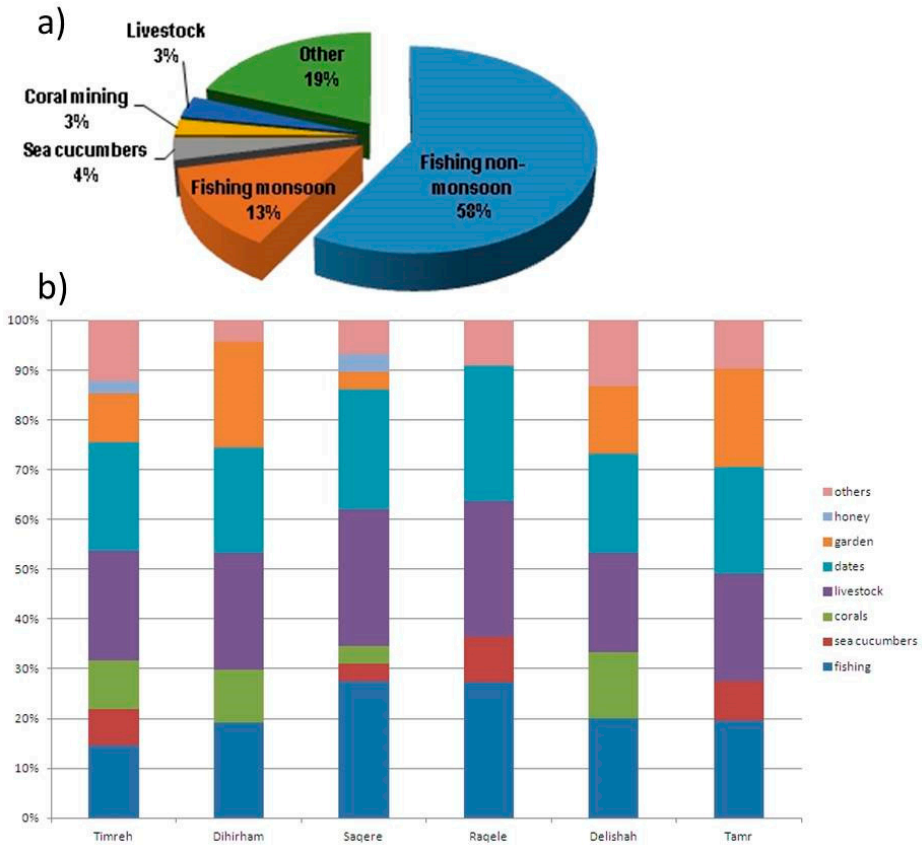

Figure 6. ES benefits to the small-scale fishing (household) economies, (**a**) showing the diversity and relative share of economic income sources across the year (differentiating between the contribution of fishing during the monsoon and non-monsoon periods, and (**b**) comparing the relative effort (time and energy) expended on different livelihood activities throughout the year; based on assessments in six coastal villages [54].

Communities traditionally offset the resulting shortages of fishery products for subsistence and marketing during the end of the pre-summer monsoon period (when biomass is fished down) and during the summer monsoon (when fishing is not possible due to the harsh sea conditions) by engaging in an array of alternative but economically less productive livelihood activities [45]. People

fall back on alternative marine ES (e.g., coral mining) or even on alternative ES in different ecosystems (e.g., livestock, horticulture). Fishing families relocate their livestock to the interior during the wet (green) periods, thus providing meat from the interior to the coastal population during the summer monsoon when fishing ceases. Likewise, pastoralists from the island interior profit from seasonal migration to the coast with their livestock during the dry seasons when fodder for livestock becomes scarce [44,55]. This intricate web of responses to temporal ES supply patterns is vested in cultural norms and enforced by traditional leaders such as the clan elders and tribal sheikhs, whereby migration patterns and the regular exchange between fishers and pastoralists are also significant for socialization processes among the people as important element of the social system and essential for their identity. Environmental changes such as climate change, which potentially impact on temporal replenishment processes, are bound to result in a pronounced socio-economic vulnerability of both the fishing and the pastoralist population, not least because of limited economic alternatives and socio-cultural adaptation capacities [50,56]. The latter relates to the ability or potential to adjust to changing conditions e.g., modify practices by learning or changing to different technologies [56].

The study from Socotra, Yemen, presented here, illustrates that the users behind the demand for ES are highly dependent on one key ES (i.e., the fish biomass relevant for food production and household economies). The provision of this key ES is subject to strong temporal variation, being significantly correlated to the monsoon patterns, and consequently to the fishing behavior of the local communities. This temporal dynamic in the ES supply triggers complex compensating processes in society, including falling back on alternative ES or alternative ecosystems.

4. Discussion

Both empirical studies underscore the existence of relevant and complex spatial and temporal dynamics in both ES supply and ES demand. The study from the West African Sahel illustrates in particular the spatial dynamics. People in this region adapted to the seasonality in the agricultural systems by means of seasonal and temporal migration to other regions, particularly urban centres. These migration activities are deeply rooted in culture and are part of the local livelihood strategies. Climate change is now exerting additional pressure in terms of altered rainfall patterns and land degradation. Besides migration, the people tend to compensate by falling back on alternative ES. The decrease in ES supply thus intensifies societal processes such as human migration, a local livelihood strategy and a significant characteristic of the culture in the region, but also influences other compensation strategies for crop failure. The study from Socotra Archipelago illustrates in particular the role of temporal dynamics in ES supply, in this case fish biomass related to the Monsoon. The population concerned has to cope with the strong seasonal variability of marine ES, i.e., by adjusting consumption and cooperative socio-economic activities. People from the coast are provided with meat from the interior during the summer monsoon, when fishing ceases.

Furthermore, the results confirm a previous study [29], who conclude that temporal and spatial dynamics have not yet been sufficiently integrated into studies of ES supply and demand. The concept of ES flows seeks to bridge the gap between spatially separated 'provider' areas and 'recipient' areas [27]. Problems emerge when services and goods are part of a complex supply chain and it becomes difficult to locate the demand [57]. However, the temporal dynamics in both ES supply and ES demand, as exemplified at our study sites (i.e., seasonality in fish biomass and temporal human migration) are not yet represented in the concept of ES flow.

From the social-ecological perspective described above, which addresses the social-ecological structures and processes including spatial and temporal dynamics in nature and society, we argue that this ES demand and supply relation is even more complex. Both studies provide evidence for the diversification of livelihood strategies due to varying ES supply (reduced ES supply: crops—during the dry season and fish biomass—during the monsoon) (Figure 7). As result of food shortages, remaining ES demand leads to the diversification of livelihood strategies including migration or the practice of other (alternative) livelihood activities. The need for livelihood stability (i.e., the need for stable

income for survival and other needs all year round) triggers a shift to a second or third-desired income source in case of the preferred income source declines. The West African study affirms the occurrence of societal processes such as human migration with both a temporal and spatial dimension such as seasonal migration and rural-urban migration, respectively as livelihood strategy (Figure 7). Whereas the Socotra study supports the relevance of falling back on alternative ES, such as coral mining, horticulture or livestock breading as alternative livelihood strategies. Both studies highlight the dependency on ES supply throughout the year. As a result it is important to focus ES analysis on ES bundles (i.e., sets of ecosystem services that repeatedly appear together across space and time [58]), rather than on isolated ES as well as to expand ES analysis to livelihood analysis including all compensation strategies. These results are in line with another study [31], that argues that the relationships between ES and human well-being are complex interrelations between nature and society.

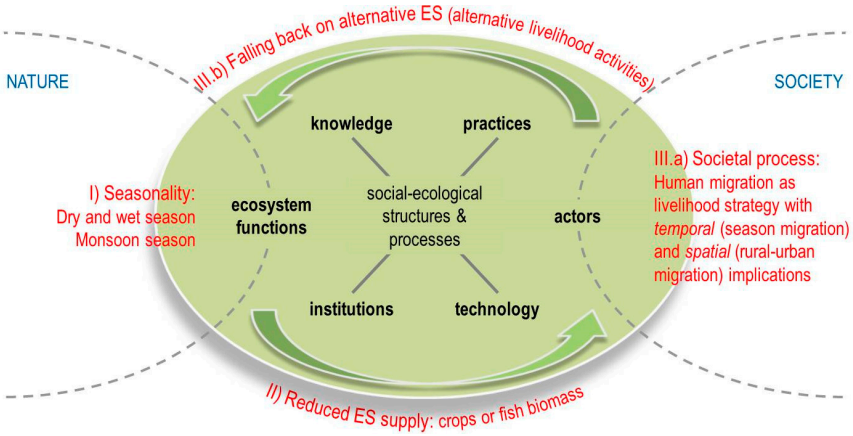

Figure 7. Diversification of livelihood strategies: The concept of social-ecological systems applied to the case study sites illustrating the diversification of livelihood strategies (III.a and III.b) as a result of reduced ES supply (II) due to seasonal variation (I).

Our article particularly highlights the functional relation between ES supply and demand. Both case studies showcase that there is seasonality in ES supply, i.e., fish biomass in the Socotra study and food supply in the West African study and this temporal dynamic determines complex compensation strategies in society. As the people are highly dependent on the supply of food, they fall back either on other marine and even terrestrial ES (Socotra study) or migrate to other regions (West African study). The local people adapted their livelihood strategies to the seasonal variations in ES supply. ES supply and demand are interrelated, with temporal (seasonal ES supply) and spatial dynamics (human migration) influencing each other. In literature, ES demand is the "need for specific ES by society, particular stakeholder groups or individuals" [26]. The results from the West African Sahel indicate that by following this understanding of ES demand, one fails to address the functional chain of the ES supply and demand relation. This empirical study clearly demonstrates that variability in the seasonality of ES supply (crop yields) directly influences societal processes such as human migration, a historically rooted adaptation strategy. ES demand is not a static term and instead stands in a functional relation to ES supply. This result goes beyond the current debate, i.e., [29] that differing conceptions of demand (such as desired goods or utilised goods) alter our understanding of ES. We argue that ES demand has to be considered in a functional relation to ES supply with ensuing spatial and temporal implications.

Finally, referring to the current research on mapping and assessing ES, our results underline the findings from other authors [28] claiming that there is an urgent need to develop methods and concepts for deepening our understanding of the social-ecological processes behind the supply and demand for ES in order to improve our ability to map ES for decision making.

5. Conclusions

The present article refers to the current debate on ES supply and demand against the backdrop of two empirical studies. Addressing the current debate from a social-ecological perspective we conclude that

- ES supply and demand stand in a functional rather than a static and linear relation to each other: nature and society exert mutual influence. Changes in ES supply can impact on ES demand and vice versa.
- there are interdependent temporal and spatial dynamics in both ES supply and ES demand.

To sum up, this is what we call social-ecological dynamics of ES. We thus argue to (1) not analyse isolated ES, but rather look at all relevant ES bundles, and (2) expand ES analysis to livelihood analysis including all compensation strategies.

From a policy perspective our study highlights the importance of acknowledging these dynamics of ES supply and demand. We claim that this aspect has to be considered in biodiversity policies and deliberation processes such as the assessments of IPBES. Without considering these dynamics dependency of societal groups on respective ES, and interrelation of altered ES supply triggering societal process, cannot be integrated into decision making processes.

These conclusions point to novel research directions. Particular attention should be given to the social-ecological dynamics of ES. From a conceptual perspective, these dynamics have to be integrated into current ES frameworks. The temporal and spatial dynamics of both ES supply and ES demand have to be considered, particularly their interdependency. Further empirical studies are needed in order to be able to draw general conclusions. New and problem-oriented research questions arise about how to compensate for variations in ES supply, and about the consequences of falling back on alternative ES and/or alternative ecosystems, such as conflicts of use, access to ES or regulation of ES.

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