Elasticity in ecosystem services: Exploring the variable relationship between ecosystems and human wellbeing

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Abstract

Although ecosystem services are increasingly recognized as benefits people obtain from Nature, we still have a poor understanding of how they actually enhance multidimensional human wellbeing, and how wellbeing is affected by ecosystem change. In this paper we develop a concept of 'ecosystem service elasticity' (ES elasticity) that describes the sensitivity of human wellbeing to changes in ecosystems. ES Elasticity is a result of complex social and ecological dynamics and is context dependent, individually variable and likely to demonstrate non-linear dynamics such as thresholds and hysteresis. We present a conceptual framework that unpacks the chain of causality from ecosystem stocks through flows, goods, value and shares to contribute to the wellbeing of different people. This framework builds on previous conceptualizations, but places multidimensional wellbeing of different people as the final element. This ultimately disaggregated approach emphasizes how different people access benefits and how benefits match their needs or aspirations.

Applying this framework to case studies of individual coastal ecosystem services in East Africa illustrates a wide range of social and ecological factors that affect can ES elasticity. For example food web and habitat dynamics affect the sensitivity of different fisheries ecosystem services to ecological change. Meanwhile high cultural significance, or lack of alternatives enhance ES elasticity, while social mechanisms that limit access to ecosystem services reduce elasticity.

Mapping out how chains are interlinked illustrates how different types of value and the wellbeing of different people are linked to each other and to common ecological stocks. We suggest that examining chains for individual ecosystem services can suggest potential interventions aimed at poverty alleviation and sustainable ecosystems while mapping out of interlinkages between chains can help to identify possible ecosystem service trade-offs and winners and losers. We discuss conceptual and practical challenges of applying such a framework and conclude on its utility as a heuristic for structuring interdisciplinary analysis of ecosystem services and human wellbeing.

Key words: Conceptual framework; East Africa; Wellbeing; Coastal ecosystems; Environmentalists' paradox

SECTION 1: INTRODUCTION

The Millennium Ecosystem Assessment conceptualized ecosystem services as contributions from nature to human wellbeing and drew on the 'capability approach' proposed by scholars such as Amartya Sen (Millennium Ecosystem Assessment 2003, Robeyns 2005). This provided a broad conceptualization of wellbeing, including security, material assets, health, social relations, and freedom. Subsequently the concept of wellbeing has become increasingly central to research and policy on ecosystem services, and sustainability generally (Bizikova 2011). However, significant gaps still remain in understanding how ecosystems actually contribute to different people's wellbeing (Butler and Oluoch-Kosura 2006, Carpenter et al. 2009) and to alleviation of poverty, which is is also increasingly recognised to be multidimensional and dynamic (Alkire 2007). The lack of understanding has particular implications for poor people who are often more reliant on ecosystems for their food, physical security, and livelihoods (Duraiappah 2004, Bizikova 2011) and disproportionately affected by changes in ecosystem services.

The ecosystem service concept alludes to a positive relationship between ecosystem quality and human wellbeing. However, this relationship is complex and often indirect with the result that the wellbeing of people in particular places and times can be more or less coupled to ecosystem quality. For example, while it is clear at the aggregate global scale and in the long run, that humanity depends on the biosphere for survival (Dasgupta 2001), aggregate indicators of human wellbeing at the global scale appear to show that wellbeing has improved over recent years despite the ongoing degradation of ecosystems (Raudsepp-Hearne et al. 2010). At smaller scales, people may experience improvements in wellbeing in the face of ecosystem degradation, when this enhances the opportunities for human development (e.g. Wunder 2001). Conversely, conservation may enhance ecosystems with little benefit, or even harm to the wellbeing of local people, for example by exclusion from reserves (Dowie 2011, Kamat 2014) or where 'ecosystem disservices' such as crop raiding by wild animals impact local farmers (Woodroffe et al. 2005). Such examples of 'negative elasticity' may represent temporal or spatial effects – either that degradation will impact the wellbeing of people in the future, or in other places, or that benefits from ecological enhancement take time to materialize or are enjoyed by distant beneficiaries. However, what these examples demonstrate is that in particular places and times, and for particular people, the relationship between ecosystem quality and human wellbeing is variable and complex.

We can refer to the human-wellbeing impacts of ecological change using the concept of 'elasticity', which captures the responsiveness of one variable to changes in another (York et al. 2003). For example, in economics, the price elasticity of demand captures how much demand will change in response to a change in price. Here we apply the concept of elasticity to ecosystem services and explore the elasticity of human wellbeing to ecosystem change (henceforth 'ES elasticity'), i.e. how human wellbeing changes in response to increases or declines in ecosystem quality. We propose that studying ES elasticity challenges us to engage with the complexities and context dependency of the ecosystem-wellbeing relationship, and can facilitate a better understanding of the role of ecosystem services in human wellbeing. While, the term 'ecosystem quality' implies a value-laden assumption of quality which depends on who deems an ecosystem service to be desirable. In practise, most social ecological studies have used proxies for 'quality' such as forest cover, biodiversity, fish biomass (e.g. Cinner et al PNAS).

In Section 2 we explain the concept of ES elasticity and review what can be learned from existing literature about the nature of ES elasticity. Section 3 introduces a conceptual framework that aims to shed light on the processes and contextual factors that lead to high or low ES elasticity for particular groups of people, by specifying the elements that link ecosystem condition to the their wellbeing as well as the 'multipliers' which affect the elasticity at points along this chain (Figure 1, Table 1). Section 4 then applies this framework to examples of coastal ecosystem services from East Africa and discusses some of the challenges and complexities that are uncovered. Section 5 discusses how this research can contribute to identifying policy responses and points of intervention for enhancing the wellbeing benefits from ecosystem services.

SECTION 2: INTRODUCING ES ELASTICITY

Elasticity describes how one variable changes in relation to changes in another and can be formally represented as:

Elasticity = change in wellbeing / change in ecosystem stocks

Thus high, positive elasticity means that human wellbeing is sensitive to changes in ecosystem quality and increases or declines as ecosystem quality does. Examples include the loss of storm protection services from mangroves severely impacting coastal people's security (Das and Vincent 2009), or successful conservation of charismatic species promotes the livelihoods of tour guides. Meanwhile low elasticity means that changing ecosystem quality has minor impacts on wellbeing, and negative ES elasticity describes situations in which wellbeing actually changes in opposition to changes in ecosystem quality (Figure 1a).

[Figure 1 here]

Elasticity will vary depending on the nature of the ecosystem-wellbeing link such that explaining or even forecasting ES elasticity challenges us to really understand both ecological and social dimensions and context of such linkages.

Elasticity has important implications for environmental management and poverty alleviation. Prescriptions for community-based conservation presuppose a self-evident and universally experienced positive elasticity that creates the necessary incentives for conservation (Roe et al. 2012). However, this may overlook or underplay the importance of delayed effects, tradeoffs, and social disparities in terms of who benefits. Where conservation efforts are characterized by low or negative ES elasticity for some people, they may resist or sabotage such efforts. An example is the widespread low compliance with fisheries regulations and marine protected areas in the tropics

(Wood et al. 2008). Thus failure to recognise or address low or negative ES elasticity can ultimately lead to failures in conservation initiatives (McClanahan 1999, Pascual et al. 2014).

ES Elasticity is also core to understanding human vulnerability to environmental change and factors that are critical to adaptation. Low elasticity for example, would be desirable in situations of climate change that degrade ecosystems, in order to minimize the harm experienced by people. Conversely, high elasticities would be desirable in situations of ecological rehabilitation and recovery, so that people benefit as much as possible from improving ecosystem services and are also incentivized to support for continued rehabilitation.

Although ES elasticity can be represented by the sign and slope created by a linear relationship between ecosystem quality and human wellbeing (Figure 1a), there is little evidence to suggest that this relationship will be a straight line. Rather, research into social-ecological systems has shown non-linear relationships and thresholds to be common (Liu et al. 2007, Barbier et al. 2008, Barrett and Constas 2014). For example, people's wellbeing may be relatively unaffected by initial losses of ecosystem quality, but below a certain threshold, further degradation leads to the breakdown of critical functions and impacts on wellbeing. This results in a non-linear relationship in which elasticity is low when ecosystem condition is good but increases sharply when ecosystem condition is below a certain threshold (Figure 1b).

Hysteresis and path dependency are also common features of complex social-ecological systems ((Scheffer et al. 2001). For example Figure 1c could illustrate a situation in which cultural benefits from an ecosystem depend on skills and other intellectual assets that are lost when ecosystem quality falls below some threshold level (E_1). Recovery of these assets may not occur (if at all) unless the ecosystem recovers to a much higher quality (E_2). Thus the expectation of non-linear changes in social-ecological systems emphasizes the importance of context and history in understanding ES elasticity.

ES Elasticity can be conceptualized as an aggregate system-level attribute, but given the importance of individual experiences and circumstances for the understanding of wellbeing (Coulthard et al. 2011), it will vary between people based on their relationship to, and dependence on, different processes or components of the ecosystem. For example ES elasticity will be higher for people with ecosystem-based livelihoods than people not directly dependent on local ecosystems. These individual elasticities will be affected by the range of individual assets and the institutional arrangements that determine how individuals and groups benefit from nature (e.g. Leach et al. 1999, Ribot and Peluso 2003, Hicks and Cinner 2014). Thus when there are improvements in ecological quality people endowed with 'mechanisms of access' (Ribot and Peluso 2003) stand to benefit more than those denied access.

While much research has focused on factors affecting the supply of ecosystem services, less attention has been given to the 'demand side' (Lele et al. 2013, García-Nieto et al. 2013). Elasticity will be affected by these contextual factors, such as the availability of and access to alternatives to ecosystem services, such as non-ecosystem-based employment, imported foods, technological innovations or non-ecosystem based social practices, that may compensate for declines in local ecosystem services (Millennium Ecosystem Assessment 2003)[1] and will reduce ES elasticity for people who have access to them. Additionally, many ecosystem services may only contribute to wellbeing under particular circumstances (Andersson et al. 2015). For example wild foods may only be important during times of food shortage, storm protection during storms, and cultural services in the context of a culture that regards them as significant. ES elasticity would only be high when circumstances supporting the demand side of ecosystem services are present.

[1] In practise these substitutes are often also ecosystem services (e.g. imported food) from elsewhere but in many cases this represents a subsidy from ecosystems outside the scope of the system under study.

SECTION 3: A CONCEPTUAL FRAMEWORK TO INTERROGATE ELASTICITY

The previous section highlighted that ES elasticity can be determined by a range of social, ecological or contextual factors. Thus advancing understanding of ES elasticity requires an interdisciplinary effort that integrates the strengths of existing literature on production, tradeoffs and valuation of ecosystem services and the growing literature on human wellbeing and it's connection to natural resources. Taken alone, each of these branches of the ecosystem services literature is insufficient to explain ES elasticity because of a partial view over the ecosystem-wellbeing relationship. For example landscape-scale modelling of ecosystem services has led to an improved understanding of generation of different ecosystem services (e.g. Goldstein et al. 2012) but has generally not evaluated how these services actually contribution to people's wellbeing. Ecosystem service valuations based on aggregate measures of willingness to pay such as market prices, provide indications of the welfare value of ecosystem services, but are criticized for downplaying non-monetary aspects of wellbeing and failing to disaggregate to reflect how benefits are distributed in society. Meanwhile frameworks for the study of wellbeing are now being applied to assess specific ecosystem service contributions to different aspects of life (e.g. Abunge et al. 2013), and the impacts of conservation (Milner-Gulland et al. 2014), but the majority of wellbeing research has limited appreciation for ecological dynamics and change. Meanwhile, studies that explicitly compare wellbeing to ecological change are often correlational thus lacking a specific theory of causation or experimental evidence of how particular ecosystem services actually contribute to wellbeing (e.g. McNally et al. 2011).

This section presents a conceptual framework that explicitly maps out the social and ecological links between ecosystems and wellbeing for different beneficiaries, and aims to understand how the wellbeing contribution of ecosystem services is shaped by people's individual condition and context over time. We acknowledge that this contributes to a plethora of ecosystem service conceptual frameworks (e.g. Costanza et al. 2007, Bateman et al. 2011, Reyers et al. 2013, Fisher et al. 2013, Díaz et al. 2015) that have been developed to facilitate thinking or enquiry about the complex reality of ecosystem services. Most frameworks generally have focused on specification of the ecological generation of ecosystem services to the detriment of understanding how they actually contribute to wellbeing (Fisher et al. 2013).

Our framework builds on the 'cascade model' proposed by Haines Young et al (2010) and subsequently developed and adopted by TEEB (The Economics of Ecosystems and Biodiversity) (Braat and de Groot 2012). The cascade model aims to conceptually clarify the steps by which ecosystems generate value. We augment this approach by returning to the MA's focus on multidimensional wellbeing rather than aggregate value as the end point, which requires addressing additional complexities highlighted by the more holistic model of Fisher et al (2014). We incorporate these into a more linear and operational flow like the cascade, while emphasizing the disaggregation of beneficiaries (Daw et al. 2011).

This framework is shown in Figure 2 and described in Table 1. It represents a chain of elements (a-f) that link from **Ecosystem stocks** to **Wellbeing contribution**. Each element has an influence on the next and the degree of this influence ultimately determines how people's wellbeing is influenced by ecosystem stocks and ecosystem change. This breaks down the overall ES elasticity between ecological stocks and wellbeing into the elasticity between each pair of elements. For example, elasticity of Flow (b) to Stocks (a) can be represented as:

Elasticity of Flow(b) to Ecological stocks (a) ($E_{b,a}$) = change in b / change in a

and the product of the elasticities between elements is the overall relationship between ecosystem change and wellbeing change:

ES elasticity ($E_{f,a}$) = $E_{b,a} \times E_{c,b} \times E_{d,c} \times E_{e,d} \times E_{f,e}$ = change in f / change in a

This explicitly acknowledges that ES elasticity can be affected by any of the biophysical or social processes along this chain.

Elasticity between the elements (a-f) is influenced by five 'multipliers' (i-v) that represent the things that explain or parameterize the relationship between adjacent elements. For example **Flows** (b) interact with *Human Inputs* (ii) to determine the quantity of **Goods** (c) (for clarity subsequent references to elements in the framework are formatted as bold and multipliers as italics). Thus the multipliers determine the elasticity between adjacent elements and together, the ES elasticity of the overall chain between ecological stocks and wellbeing.

As with the cascade and MA frameworks, the arrows run from left (ecology) to right (wellbeing) reflecting the focus on elasticity and how ecosystems cause change in wellbeing. However, as emphasized in more social-ecological conceptualizations of ecosystem services (e.g. Reyers et al. 2013), causal influences in the other direction ('feedbacks' in Figure 2), are important for the development of ecosystem quality and human wellbeing over time. For example, extraction of **goods** impacts on **ecosystem stocks** and *valorization* incentivizes and thus drives *human inputs*.
In contrast to the cascade model, adapted by TEEB to support valuation (Braat and de Groot 2012), **value** (an aggregate quality) is positioned before **share** and **wellbeing** contribution to individual beneficiaries. This distinguishes the aggregate processes of **valorization** from the disaggregated processes of *access*, and n*eeds, gaps and aspirations* that determine the **wellbeing contribution** of ecosystem services for different kinds of people. *Valorization* may in some cases reflect the *needs, gaps and aspirations* of the same people whose wellbeing is of interest. For example, the *valorization* of local cultural services is linked to the *access*, and *aspiration* of the same local people who may be the subject of a local assessment of ecosystem services (Table 2). However, *valorization* of traded ecosystem services reflects motivations and aspirations of a different and often distant group of people. For example the market price of aquarium fish is determined by the aspirations of distant consumers as well as the availability of substitutes from other regions or aquaculture. This case illustrates why, for a disaggregated analysis, *valorization* is considered independently from the *needs, gaps and aspirations*, of local people.

'Ecosystem Stocks' (a) represent natural capital or 'Ecological assets' (Bateman et al. 2011) can be affected by a wide range of impacts that may be external to this particular chain, such as climate change-driven disturbance or infrastructure development, or that represent feedback from within the chain, such as extraction of **Goods**. A long tradition of research has documented the impact of human activities or environmental change on ecosystems. Stocks could be represented by a single indicator of ecosystem quality (e.g. live coral cover) but it may be more appropriate for to include a range of processes and interactions within Stocks. For example, supporting services that maintain structure and functionality of ecosystems (Mace et al. 2012), are included within 'Ecosystem Stocks' as they do not directly contribute directly to wellbeing.

'Flows' (b), the biophysical processes that are potentially directly useful for humans and are equivalent to Mace et al's (2012) 'final services'. They are generated by, but are importantly distinguished from Ecological Stocks (Vira and Adams 2009). The complex and multifaceted relationship between the two (Mace et al. 2012) is represented by the multiplier *Ecological Dynamics (i)*, which encompasses variable production functions or biodiversity-ecosystem service relationships (Mora et al. 2014).

Goods (c) are the objects from ecosystems that are experienced or used, and valued by people (Bateman et al. 2011) and include provisioning services as well as regulating and cultural services. **Goods** are not solely biophysical, but are co-produced from **Flows** by *Human Inputs (ii)* (Lele et al. 2013) such as labour, capital, or the presence of people to appreciate or benefit from them.

The **Value (d)** of **goods** is an aggregate indication of the value of total benefits generated by an ecosystem service, as calculated by standard valuation, although it can be calculated in non-monetary terms. **Value** is determined by societal process of v*alorization (iii)*, such as the structure of markets, or cultural norms (Bateman et al. 2011). As such, *valorization* represents the 'demand side' of ecosystem services at an aggregate level and it is the contextual conditions that lead a **good** to be of more or less interest and/or use to people in general.

Ecological Stocks, **Flows**, **Goods** and **Value** (a-d) generally reflect the 'cascade model' used for ecosystem service valuation (Groot et al. 2010, Bateman et al. 2011) and are aggregate quantities. The remaining elements focus on *who* accesses **value** and *how* it contribute to their wellbeing (Daw et al. 2011, Coulthard et al. 2011). **Share (e)** is an explicit expression of the absolute amounts of **value** received by different people. This distribution is determined by the multiplier *access (iv)*, representing the range of assets, institutions, laws, social norms and structures (such as class, gender, ethnicity) that give people the ability to benefit from ES (Leach et al. 1999, Ribot and Peluso 2003). *Access* reflects power dynamics for example as people compete to capture **shares** or when other powers limit *access* in order to reduce impacts on **ecosystem stocks**.

Wellbeing contribution (f), reflects how an ecosystem service actually translates into wellbeing outcomes for an individual or group of beneficiaries. Wellbeing assessment is increasingly supported by a range of theoretical and methodological. An emerging consensus emphasizes the importance of assessing both objective circumstances of a person as well as their own subjective evaluation of how well or badly they are doing (McGregor 2004). Objective evaluations of wellbeing exclude the person's own perspective on what matters in their lives, and how they feel about how well or badly they are doing. Meanwhile, subjective evaluations can be misleading about objective circumstances – a person can report themselves to be doing fairly well, when they are clearly ill (documented by Sen's concept of Adaptive preferences, which depicts how people living in poverty, may know no other lifestyle, or bear the ills of poverty without complaining (Sen 2001). Objective circumstances can be evaluated using a list of basic human needs required to avoid harm (Doyal and Gough 1991), such as having clean water. This basic needs approach focusses the framework on poverty alleviation, as it identifies those people whose below a threshold minimum condition and who suffer harm as a result. Meanwhile subjective wellbeing can be assessed by a range of quantitative or qualitative instruments to measure quality of life (Gough and McGregor 2007). However, assessment of a person's wellbeing, even combined with an assessment of the **shares** they access, is not sufficient to evaluate how ecosystem services actually contribute to wellbeing. This requires understanding of the individual circumstances that mean that a **share** translates into a w**ellbeing contribution**. As emphasized by the capability approach of Sen and others, “different people need different amounts of and different kinds of goods to reach the same levels of wellbeing” (Robeyns 2005). Hence *needs, gaps and aspirations* (v) constitute the multiplier between **share** and **wellbeing contribution** and aims to capture the individual circumstances that determine whether a **share** contributes to wellbeing. *Needs, gaps and aspirations* include objective and subjective dimensions and are affected by ‘internal’ factors (such as personal illness or disability and individual preferences) as well as ‘external’ factors such as substitutes (e.g. imported food) and events (e.g. storms) that affect what an individual or group needs from ecosystems. *Needs, gaps and aspirations* thus reflect the demand side of ecosystem services on a more individual basis than *valorisation*.

The distinction between *access* and *needs, gaps and aspirations* are illustrated by comparing a rich person with *access* to wild foods but who does not benefit because they have no Need for them to a poor person who has Gap in their nutritional security, but lacks Access to wild foods and hence has no Share. In both cases, wild foods make limited contribution to well-being, but this is due to Needs, Gaps and Aspirations in one case and Access in the other. In this sense *access* represents the ability of people to benefit from a share, whether or not that ability is realized, and echoes Sen’s (2001) distinctions between capabilities and functionings. Where *needs, gaps and aspirations* are low, patterns of *access* may not be obvious. However, if *needs, gaps and aspirations* increase (e.g. during a food shortage), patterns of *access* may become more obvious as people struggle to benefit from the available **value**.

SECTION 4: EMPIRICAL APPLICATIONS OF THE CHAIN FRAMEWORK TO UNDERSTAND ELASTICITIES

The chain framework is applied to five different regulating, provisioning and cultural coastal ecosystem services studied in East Africa by the SPACES (Sustainable Poverty Alleviation from Coastal Ecosystem Services, www.espa-spaces.org) project (Table 2, Figure 3, Box 1). The cases illustrate a range of biophysical and social factors that lead to high or low ES elasticity. Examples of low ES elasticity include shoreline protection from reefs where biophysical dynamics mean that wave attenuation is not sensitive in the short term to changes in ecological quality (low **stock**-**flow** elasticity). In the example of livelihoods for female traders, increasing value of landed fish resulting from fisheries management is unlikely to improve female traders' livelihood if they cannot access that fish due to competition with male traders with higher buying power (low **value**-**share** elasticity due to limited *access*). The aquarium fishery provides examples of high ES elasticity deriving from ecological and social factors. Many aquarium fish species are dependent on temperature-sensitive corals and thus sensitive to impacts of coral bleaching (high **stock**-**flow** elasticity), while connection to global markets generate a high price for the fish (high **goods**-**value** elasticity). The shade from mangrove trees example suggests that gleaners would be sensitive to loss of mangrove trees (high **share**-**wellbeing contribution** elasticity) due to their *needs, gaps and aspirations* for shade and a lack of alternative shade. Identity and sense of place of fishers would be sensitive to an inability to maintain catches of large fish because they are *valorized* by the community (high **goods**-**value** elasticity) particularly for fishers whose identity and standing within the community depends on fishing (*access*) and who lack alternative sources of pride or respect (lack of alternatives leading to high **share**-**wellbeing contribution** elasticity).

[table 2 here]

The linear arrangement of this conceptual framework, draws specific attention to the connections and elasticity between ecosystems and human wellbeing. However it also risks a linear and isolated representation of different ecosystem services and blindness to complexity created by feedbacks and interactions between different ecosystem services as Norgaard (2010) warns. In reality ecosystem services are interlinked and bundled as shown by Figure 3, which illustrates the differential impact of coral bleaching on different fisheries and how food fish landings generate different kinds of **value** (income, food) and how different groups *access* different **shares** of that **value** and benefit to different extents.

Mapping how different types of benefits accrue to different people in this way is essential for understanding linkages and trade-offs. An increase in the cost of fish in Figure 4 would represent an increase in *valorization* of fish for income but would also decrease *access* of poor consumers to fish for food.

[Figure 4 here]

Multiplier effects in local economies may indirectly benefit multiple rounds of beneficiaries, such as tourism enhancing prices for local producers who can in turn hire more labor. In some cases such indirect benefits may be important for the wellbeing of many people (e.g. Ashley and Mitchell 2007) in which case they would need to be included in the aggregate calculation of **value.** Value chain analysis can then identify how different people have *access* to different shares of this **value.**

SECTION 5: POLICY RELEVANCE OF ANALYSING CHAINS AND ELASTICITY

We suggest ES elasticity can be applied to understanding opportunities, vulnerabilities and potential interventions to improve wellbeing in any conditions of ecosystem change. Vulnerabilities of people result from high elasticities to ecological decline, or from processes that change multipliers and reduce elasticity (e.g. loss of access). Opportunities result from high elasticities when ecological enhancement is possible or where interventions can change multipliers to increase the wellbeing contribution of ecosystem services (Table 3).

[Table 3 here]

The chain framework applied to any individual ecosystem service can help to identify important multipliers (and points of ES elasticity) as opportunities to reduce vulnerability or enhance or maintain the contribution of ecosystem services to wellbeing and also to evaluation the relative impact of interventions affecting different parts of the chain. The framework broadly suggests six different classes of interventions to increase wellbeing described and exemplified in Table 4.

[Table 4 here]

Secondly, understanding the elasticities within different chains and distribution of benefits as illustrated in Figure 4 facilitates an assessment of trade-offs linked to different interventions. This information can be analysed with decision-makers – for example through use of scenarios exercises or 'toy models' and other interactive techniques (e.g. Tim M. Daw and others 2015)– to discuss the trade-offs associated with different courses of action. This is particularly relevant to interventions such as Payments for Ecosystem Services, or Community-based Conservation where crude assumptions about benefits and their distribution may lead to negative outcomes in terms of compliance and ultimately, 'success' in ecological and social terms (Pascual et al. 2014).

Application of this framework clearly is not without challenges. The data requirements for populating the chains in order to analyze elasticities are considerable, requiring a coordinated interdisciplinary effort incorporating ecologists and a diversity of social scientists. In addition practical application of the elasticity concept may be challenging in highly dynamic settings where elements and multipliers change so rapidly that scientific efforts to characterize elasticity are continuously behind the course of events. In such circumstances, the framework maybe best used as a frame to guide rapid, qualitative and participatory diagnoses of ES elasticity and the resulting opportunities.

Modelling, particularly recent innovation and development of "end-to-end" models (Fulton 2010) may provide a framework to synthesis diverse types of information (from biophysical to social), to explore how patterns of elasticity emerge and can be modified. Modelling approaches range from simple empirical relationships between **Ecosystem stocks**, **Flows** and **Goods** and some measure of wellbeing, to simulation models that have explicit representation of socio-economic and ecological processes and their temporal and spatial dynamics. Existing modelling approaches mostly focus on the biophysical dynamics, with only simple representation of **Goods** (e.g., catches) and **Values** (e.g., net economic profits) and occasionally **Share** for different groups or sectors (e.g. along the value chain e.g. Christensen et al. 2011)). The subjective and context dependent nature of wellbeing suggests that participatory modelling may provide a way to better represent the right-hand side of the chain from **value** to **wellbeing contribution**. For example, to explore the trade-offs between different stakeholders under scenarios of fisheries management in coastal Mombasa, outputs from ecological models were linked to a rule-based model describing the interactions between different groups of fishers, fish traders and their wellbeing (Tim M. Daw and others 2015). Other modelling approaches such as agent-based modelling (Murray-Rust et al. 2013) also offer potential for disaggregating individual Shares and Wellbeing Contribution .

SECTION 5: CONCLUSION

Given the complex and as yet poorly understood relation between ecosystem services and human wellbeing, ES elasticity emerges as a core concept that leads to a focus on critical relationships between ecosystems and wellbeing. These relationships are expected to be non-linear, complex and context dependent.

We present a heuristic conceptual framework of an ecosystem service chain to help analysis of elasticities of different ecosystem services. This framework promotes and facilitates structured assessment of ecosystem services-WB relationships as a common starting point for interdisciplinary analysis that aims to provide important insights in to trade-offs and possible policy levers. It can facilitate a pro-poor and pro-wellbeing approach to understanding how and who is able to derive what benefits from changes in ecosystems, and in different mechanisms along the chain. This adds to existing ecosystem services frameworks that may overlook issues of access, needs and aspirations or ecological dynamics critical for understanding ES elasticity. Application of such a framework across different ecosystem services, contexts and for different people may generate patterns that could advance both ecosystem services theory and practical guidelines for pursuing environmental management for human wellbeing.

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BOX 1 – ES Elasticity in East African coastal ecosystem services

Shoreline protection service:

Between three and four million people on the East African coast are likely to benefit from Shoreline Protection and reduced risk due to coral reefs (Ferrario et al. 2014). The ability of a coral reef system to provide wave attenuation in the face of disturbances is affected by the height of the reef as well as the species composition and abundance of live coral, relative to the abundance of eroding organisms, such as parrotfishes or urchins (Perry et al. 2008). The balance between these determines if a reef grows or erodes such that impacts such as coral bleaching can result in reefs starting to erode away. Nevertheless, ES elasticity of shoreline protection is low in the short term (Sheppard et al. 2005) (Sheppard et al. 2005) because a high proportion of wave energy is dissipated by historically accreted reef (Ferrario et al. 2014), and because skeletons of complex corals remain after they have died. Over time coral skeletons will break down as a result biological erosion or storms (Graham et al. 2007), leading to increased wave energy reaching the shore (Sheppard et al. 2005). ES elasticity would therefore be low at first, and increases in the elasticity may be avoided through management of bioeroding populations on the reef, or through natural recovery of corals.

Livelihood support for female traders

The roles of people in the coastal Kenyan fishery are highly gendered. Women do not participate in catching finfish and their primary role is buying, frying and selling low-value fish it to local consumers (Yang 2013, Matsue et al. 2014). In sites around Mombasa, competition between traders to access fish can be high, particularly when catches are low. Male traders, who tend to have greater capital and access to transport such as bicycles (Yang 2013) have priority access to larger and higher value species. Heavy fishing effort by illegal beach seines, although damaging to the ecosystem, generate high volumes of low-value fish (McClanahan et al. 2008), while protected areas, enforcement against illegal gears and lower fishing effort increases catch rates, fish size and individual fishers' revenues (McClanahan 2010). However, the gendered access conditions suggests that such ecological improvements might negatively impact the livelihoods of female traders due to lower total catches and a shift in catch composition to high-value species favoured by male traders (Tim M. Daw and others 2015).

Shade from Mangroves service:

The way that mangroves are valued by people is influenced by culture, and the level of dependence on mangroves for livelihoods and well-being (James et al. 2013). Even within households, men and women value resources differently based on gendered resource use practices (UNEP-WCMC 2014). The apparently insignificant small stand of mangrove trees (small *Ecosystem Stock*) adjacent to Lalane village in N. Mozambique contribute to the wellbeing of certain groups. Women gleaners for example, spend many hours in the sun at low tide collecting shells. With little or no alternative shade in the vicinity, the mangroves improve gleaners' subjective wellbeing by providing a cool sanctuary from the heat which increases enjoyment of the activity and improves social relations. Thus this service demonstrates a high ES elasticity despite the very limited ecological stock; the removal of these trees would negatively impact on the wellbeing of gleaners due to their high Accessibility (*Access*) and needs and lack of alternatives (*Needs and Gaps*) for the shade from these mangroves.

Aquarium trade:

The ornamental coral reef wildlife trade supports a multi-million dollar industry (Grey et al. 2005), and can provide significant levels of income to local fishers on coral reefs in developing countries (Máñez et al. 2014). Small and brightly coloured reef fishes, corals and shells are targeted for collection which can lead to local extinction of desirable species (Thornhill 2012). Many of the finely branched coral species and coral dwelling fish prized by aquarium collectors are highly susceptible to coral bleaching and other stressors (Loya et al. 2001). Thus the aquarium trade demonstrates high ES elasticity; overcollection, or shifts in coral community composition due to bleaching can result in large reductions in provision of species to the aquarium trade (*Flows*) despite relatively small changes in overall ecosystem health (*Ecosystem Stocks*).

Identity:

People often develop an identity associated with a place as a result of the activities and relationships that people engage with there (Stedman 2002). Place based identities often emerge alongside activities such as fishing. For example, individuals from a fishing community may strongly identify with the reputation of having skilled fishers, from a close and supportive community, who engage in successful community conservation initiatives, and boast a productive and reliable fishery. The identity in this case is based on the same **stocks, flows** and **goods** as a fisheries livelihood service. But, identity is also dependent on specific attributes of the **good** (i.e. consistently large landings) and gain meaning (*valorization*) through a history of social or community engagement. Individuals who are fishers and who belong to the community have *access* to this identity. How important fishing, community, and recognition is to them and the extent to which they feel a sense of identity or belonging to another social group (*needs, gaps and aspirations*) will determine how this pride, identity and sense of belonging contributes to their subjective and relational wellbeing. Because of the dependence of this identity on environmental quality and social engagement, a drop in environmental quality or social participation can rapidly affect the validity of a person's place-based identity, suggesting a high ES elasticity.

Tables

Table 1. Explanations and examples for the elements and multipliers. See Table 2 for examples.

Element *Multiplier*	Explanation
Impacts	*Internal or external factors affecting Ecosystem Stocks*
a. Ecosystem stocks	**The condition, volume or diversity of ecosystems, 'natural capital', includes 'supporting services'**
i. Ecological dynamics	*Dynamics which determine the production of Flows from Stocks.*
b. Flow	**Biophysical processes potentially directly useful for humans**
ii. Human inputs	*Human factors that combine with Flows to co-produce Goods*
c. Good	**Things and services directly experienced or used by, and valued by people**
iii. Valorization	*Processes which determine the societal value of Goods*
d. Value	**Aggregate worth of benefit from goods produced, regardless of distribution**
iv. Access	*Processes which determine who can access Goods and benefit from their value*
e. Share	**The amount of value that each person/group actually benefits from**
v. Needs	*The contextually and personally determined needs and aspirations of a group/person which can be satisfied by ecosystem services*
f. Wellbeing contribution	**The improvement in wellbeing experienced by a group/person as a result of their Share meeting their Needs**

Table 2. Five coastal ecosystem services from East Africa (see Box 1) mapped out using the chain framework, with examples of low and high elasticity deriving from different parts of each chain. Multipliers contributing to low or high overall ES elasticity are shown in bold.

	Overall Low ES elasticity		Overall High ES elasticity			
Ecosystem service:	**Shoreline protection from coral reefs**	**Livelihood for female fish traders**	**Aquarium trade**	**Shade from mangrove trees**	**Identity/Sense of place**	
Ecosystem Stocks	- Coral abundance and composition - abundance of eroding organisms - Secondary carbonate producer abundance	- Fish biomass - Habitat structural complexity	- Coral abundance and species composition - Abundance of coral reef fishes	- Mangrove structure - Mangrove biomass	- Coral abundance and species composition - Abundance of coral reef fishes	ECOLOGICAL COMPONENT
Ecological Dynamics	***- Coral and coralline algae growth rates*** ***- Parrotfish and urchin erosion rates*** ***- Other erosional processes***	***- Food web dynamics*** ***- Determinants of productivity (temperature, food)*** ***- Stock-recruitment relations***	***- Habitat effects*** ***- Coral growth*** ***- Reef fish production*** ***- Determinants of productivity (temperature, food)***	*- Mangrove growth rates* *- Mangrove competition*	***- Fish-habitat interactions*** ***- Reef fish production*** ***- Determinants of productivity (temperature, food)***	
Flows	- Wave attenuation	- Fish production (potential catch)	- Provision of coral reef organisms for collection	-Amount of cover -Type of cover	- Large, high value coral reef organisms for collection	
Human Inputs	*- Shoreline property - use of beach for recreation, cultural or livelihood activities* *- - use of calm lagoon for fishing/transport*	*-Fishing effort (time of fishers)* *-Fishing vessels and gears*	*- Collection effort* *- Gears, knowledge*	*-Frequency of use* *-Type of use*	*-Engaging in fishing* *-Engaging in community activities (sea weed farming)*	
Goods	- Protected property - Boat trips for fishing or transportation	-Volume and type of landed of fish	- Coral for export - Small fishes for export	-Shade -Privacy -Shelter	-Large fish & Octopus landings -Sea-weed farm -Fish and sea weed diversity	
Valorization	*- Cost of artificial protection* *- Cost of replacement* *- property market value*	*-Market connectivity* *-Fish price* *-Consumption and demand patterns*	***-Fish and coral price*** ***- Market connectivity*** ***- Demand from importing countries***	*-Time spent working in the sun* *-Availability of other forms of shade*	*-Broad community engagement* *-History of engagement* *-Common culture, admiration for fishers*	SOCIAL COMPNENT
Value	- Value of secured property - Value of maintained tourism and recreation	-Total landed value -Total value added along the supply chain	- Total exported value - Value added along the supply chain	-Value of health benefits from sun protection	-Collective identity and pride as a community with skilled fishers, a productive fishery, successfully engaging in community projects	
Access	*- What is required to own property on shoreline* *- How can people access shoreline/lagoon*	***- Gender roles*** ***- Capital to purchase and transport fish*** ***- Relationships with fishers and customers***	*- Collecting expertise* *- Relationships with exporters* *- Capital to set up aquaria for storage*	*-Proximity of mangrove trees*	*-Being known as a fisher* *-Belonging to the community* *-Access to community activities*	
Share	- Who has property/ dwelling on shoreline - Who uses the shoreline and for what	-Value added captured by each value chain actor -Individual earnings	-Value added captured by each value chain actor -Individual earnings	-Individual frequency of use	- Relative status and recognition within community	
Needs, Gaps and Aspirations	- How much property owners want/need that property - Availability of insurance - Important of beach access for those using it	-Alternative sources of income -Cultural affinity to livelihood -Number of dependents e.g. children	- Alternative sources of income - Number of dependents e.g. children	**-Dependence on beach activities** **-Time spent working in sun** **- Lack of other shade**	-Other home (i.e. migrants) -Other occupation -Importance of relationships	
Wellbeing Contribution	- Increase in physical security - Support for livelihood and cultural through use of beach	-Contribution to household income	- Contribution to household income - Relationships with international partners - Increased knowledge	-Health benefits of being in the shade -Improves subjective wellbeing	-Improves subjective wellbeing through pride -Improves relational WB through a sense of belonging	

Table 3 – Implications of high and low elasticities for policy and environmental management

Elasticity:	**Low (or negative) elasticity** No alignment between social and environmental goals		**High (positive) elasticity** Social and environmental goals are aligned	
Ecological change:	Increasing quality	Declining quality	Increasing quality	Declining quality
Implications for environmental management	Lack of incentives to support enhancement	Lack of incentives to be concerned with degradation	Good for ecosystem based poverty alleviation	Risk and vulnerability to ecological change
Possible policy responses	Intervene on multipliers to increase wellbeing contribution for target groups (*Valorization* and Access). Monitor human inputs and impacts.	Don't assume self interested management e.g. CBNRM will succeed. External support for conservation. Separate policy responses required for environmental and social goals.	Analyse multipliers to ensure elasticity stays high for target groups (especially Access)	Address ecological impacts and/or change multipliers to reduce elasticity and protect people from impacts (e.g. intervene on needs). Support availability and access to substitutes for ES.

Table 4. Interventions to improve wellbeing suggested by the ecosystem-wellbeing chain conceptual framework.

Location on the ecosystem-wellbeing chain	Example
Reduce *Impacts* to improve or protect **stocks**	Habitat restoration by replanting of cleared mangroves
Manipulate *Ecological dynamics* to increase **Flows**	Semi-enclosed aquaculture to increase production of useful species

Facilitate *Human inputs* to increase the production of **Goods**	Training or equipment to support exploitation of unexploited goods or services
Enhance v*alorization* to increase the **Value**	Value addition such as certification, marketing or branding of fisheries products
Support *access* for particular groups to increase their **Share** of benefits	Promote representation of marginalized groups (e.g. women) in resource management bodies
Directly meet people's n*eeds, gaps and aspirations* to reduce the **wellbeing contribution** so that they are less vulnerable to ecological change.	Provision of sanitation infrastructure so people do not depend on mangroves

Figures

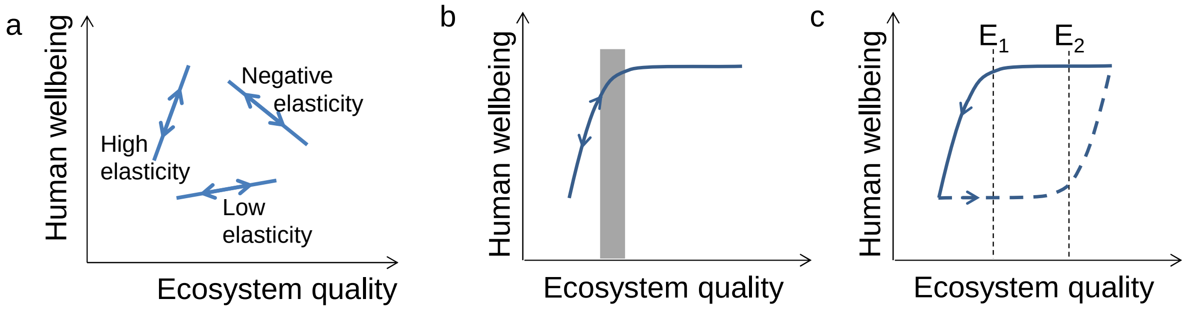

Figure 1 – The ecosystem quality elasticity of human wellbeing (elasticity). a) Examples of high, low, positive and negative elasticities. b) A threshold (shaded) in the ecosystem quality-wellbeing relationship leading to different elasticities at different levels of ecosystem quality. c) Hysteresis in the ecosystem quality-wellbeing relationship such that elasticity is different when ecosystem quality is declining from when ecosystem quality is increasing.

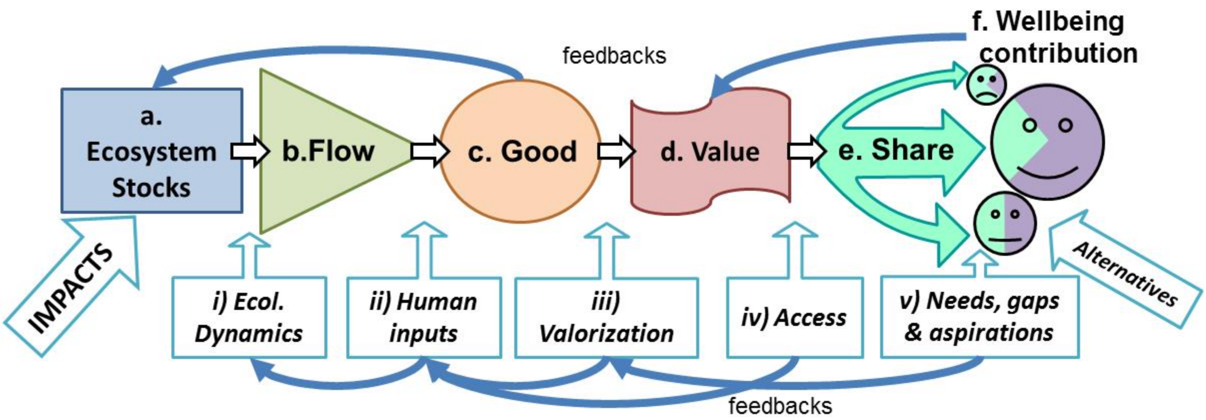

Figure 2 – A framework to interrogate ecosystem-wellbeing relationships and shed light on factors affecting ES elasticity. Ecosystem services are represented as a chain of elements (a-f) that link ecosystem stocks to wellbeing (See Table 1 for definitions, Table 2 for examples and text for further elaboration).

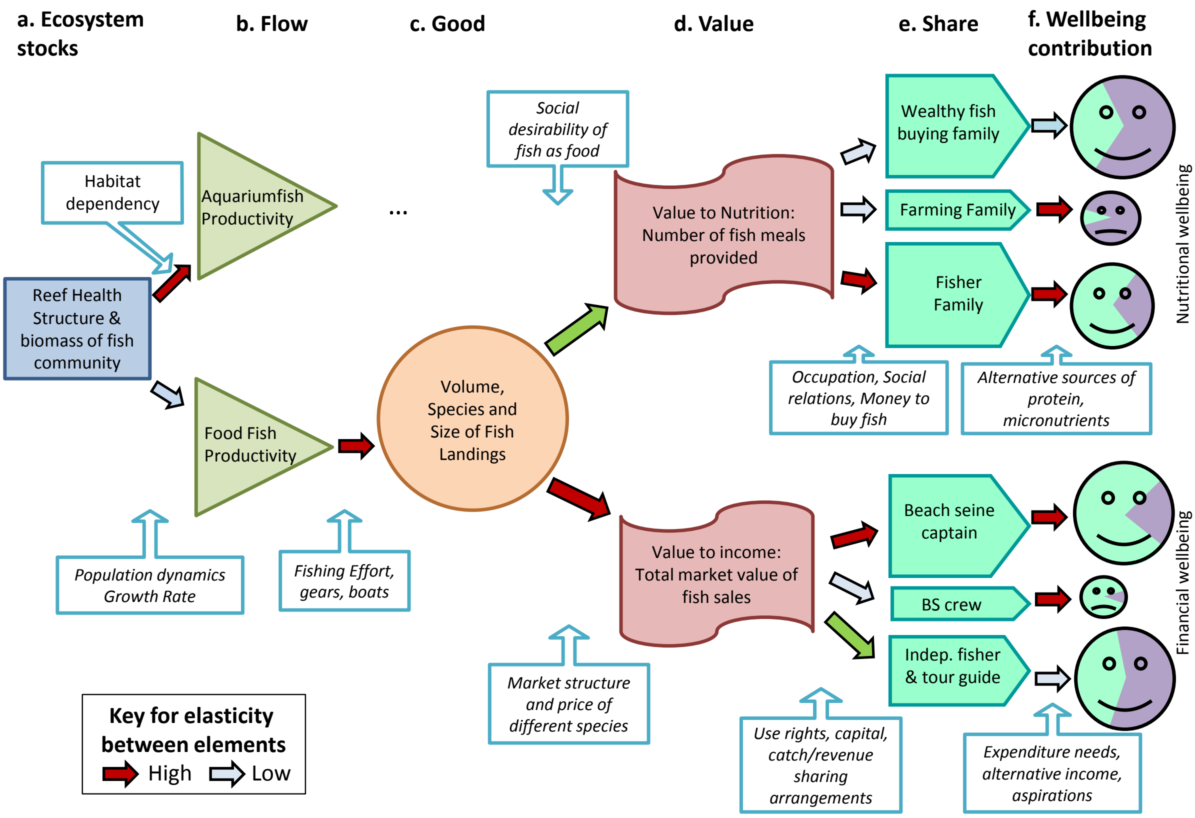

Figure 4. The branching of an ecosystem services-wellbeing chain by consideration of multiple flows from a given stock, multiple values of a good and multiple groups of people receiving different shares of that value which contributes to each's wellbeing dependent on their Needs, gaps and aspirations. The aquarium fish chain is only illustrated as far as the flow. Arrows between each element highlight high or low elasticity between elements along the chain.

Figure 3. Images representing the five ecosystem services in Table 2. A. The wave attenuation provided by the coral reef offshore at Bamburi beach, Mombasa, provides calm waters and beachfront for recreation in the evenings. B. Female fish traders buying fish from fishers in Kenya. C. Colourful corals and associated fishes of high value in international aquaria trade. D. People resting in the shade of a tree in Vamizi, Mozambique. E. Fishermen bringing large reef fish ashore.