Livelisystems: conceptualising social, biological and ecosystem change and development

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Summary

Human activity poses multiple environmental challenges for ecosystems that have intrinsic value and also support that activity. Our ability to address these challenges is constrained, inter alia, by weaknesses in cross disciplinary understandings of interactive processes of change in socio-ecological systems. This paper draws on complementary insights from social and biological sciences to propose a 'livelisystems' framework of multi-scale, dynamic change across social and biological systems. This describes how material, informational and relational assets, asset services and asset pathways interact in systems with embedded and emergent properties undergoing a variety of structural transformations. Related characteristics of 'higher' (notably human) livelisystems and change processes are identified as the greater relative importance of (a) informational, relational and extrinsic (as opposed to material and intrinsic) assets, (b) teleological (as opposed to natural) selection, and (c) innovational (as opposed to mutational) change. The framework provides valuable insights into social and environmental challenges posed by global and local change, globalization, poverty, modernization, and growth in the anthropocene. Its potential for improving inter-disciplinary and multi-scale understanding is discussed, notably by examination of human adaptation to bio-diversity and eco-system service change following the spread of Lantana camera in the Western Ghats, India.

Keywords: socio-ecological systems, livelisystems, environmental change.

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INTRODUCTION

The multiple environmental challenges that human activity poses for the planet's ability to support the adoption of high consumption lifestyles by increasing numbers of people are well known: widespread over-exploitation and pollution of natural systems is causing degradation and loss of local and global ecosystems and natural resource stocks and hence loss of ecosystem services on which human activities are critically dependent (Foresight, 2011; Millennium Ecosystem Assessment, 2005; Raworth, 2012; Rockström et al., 2009). These problems , or rather the socio-ecological systems (SES) with which they are concerned, have multiple characteristics that make them particularly difficult to understand and address: they are cross- or multi-scale, multidisciplinary, dynamic (with multi-dimensional structural changes and transformations), subject to behavioral uncertainty, involve non-linear relations and hence thresholds or tipping points, and have emergent and embedded properties (An, 2012; Anand et al., 2010; Gallopin, 1991; Holling et al., 1998; Ostrom, 2007; Perrings, 2007; Rammel et al., 2007; Rounsevell et al., 2010; SchlÜTer et al., 2012).

Addressing these problems needs (1) better analytical and management processes for diagnosis of problems and development and implementation of solutions and (2) better understandings of fundamental SES processes as they respond to different stimuli. Better cross disciplinary integration of theory, language and information is a key challenge in this (Millennium Ecosystem Assessment, 2005; Milner-Gulland, 2012; Norgaard, 2008; Ostrom, 2009; Waring and Richerson, 2011).

This paper draws on complementary insights from social and biological sciences to propose the foundations for a unifying conceptual framework of dynamic change across social and biological systems. After this introduction the paper is structured in four parts. It begins with a review of existing frameworks that span, or attempt to span, the social and biological sciences in order to assess the strengths and weaknesses of these frameworks and gaps in the overall suite of SES frameworks in use. This leads on to the description of whata 'livelisystems' framework and then consideration of potential applications of the framework. The paper concludes with a brief discussion of strengths and weaknesses of the framework and ways in which it could be taken forward.

EXISTING SES FRAMEWORKS

A range of different cross-disciplinary frameworks and models have been developed and applied for diagnosing problems and developing and implementing solutions in SES. The appendix provides a brief review of a range of different approaches used in these frameworks and models. This starts from simpler frameworks such as the ecosystems services framework (Costanza and Daly, 1992; Millennium Ecosystem Assessment, 2005; Perrings et al., 1992), the Drivers-Pressures-State-Impact-Response (DPSIR) and Framework for Ecosystem Service Provision or FESP (Rounsevell et al., 2010), and livelihoods framework (Carney, 1998; Chambers and Conway, 1992), although this is more of a framework for socio-economic analysis framework which includes ecological systems only as 'natural capital'. Although these are accessible and useful in drawing attention to social and ecological or biophysical variables and processes and their interactions, they find it difficult to give sufficiently symmetrical consideration to these interactions (Milner-Gulland, 2012) and tend to lack theoretical depth.

Frameworks drawn from both social and ecological theory (Anderies et al., 2004; Holdo et al., 2010; Ostrom, 2005, 2007, 2009) are more analytically challenging to implement and less widely adopted. More fundamental trans-disciplinarity and theoretical integration across social and biophysical disciplines is required with a 'fundamental transformation' involving 'epistemological pluralism' (MacMynowski, 2007). Evolutionary and co-evolutionary theories providing a possible basis for such an epistemologically pluralist trans-disciplinarity are suggested by a number of authors (Gintis, 2007; Gual and Norgaard, 2010; Hodgson and Knudsen, 2010b; Jablonka and Lamb, 2005; Nelson, 2011; Norgaard, 1984; Odling-Smee et al., 2003; Rammel et al., 2007; Waring and Richerson, 2011). Other frameworks offering valuable methodological and/or conceptual insights include living systems (Miller, 1978; Miller and Miller, 1992),Coupled Human and Natural Systems or CHANS (Hummel et al., 2012; Liu et al., 2007), niche construction (Laland and Boogert, 2010; Odling-Smee, 2007, 2010; Odling-Smee et al., 2003), and boundary work (Mollinga, 2010). Useful elements of these then need to be integrated with each other within multi-scale systems theories and approaches.

Consideration of these frameworks (as reviewed in more detail in the appendix) and of the characteristics of SES (as detailed earlier) suggests that a truly trans-disciplinary and valid theoretical framework should have the following characteristics:

- It must be able to represent the characteristics of complex, coupled systems, describing multi-scale, dynamic interactions between and within partially decomposable sub-systems, allowing for emergent and embedded properties , a variety of types of structural change and transformations, uncertainty, non-linear relations, and thresholds or tipping points,
- It should draw on and develop 'boundary' insights, concepts and language from a range of social and natural science disciplines,
- It should not be inherently anthropocentric or ecocentric, but should be capable of both anthropocentric and ecocentric application,
- It should be able to accommodate and mediate a variety of different disciplinary perspectives and investigational approaches and add to, rather than replace, the toolkit of approaches that analysts with different objectives need for studying SES with a variety of characteristics and contexts,
- Ideally it should make separate contributions to the social and biological sciences apart from aiding their integration in the analysis of SESs, and
- It should stimulate innovative and valid conceptual and researchable questions and investigation.

A LIVELISYSTEMS FRAMEWORK

To complement existing frameworks discussed in Appendix 1 and in pursuit of a general conceptual framework with the characteristics put forward above, this paper postulates a set of nested frameworks which set out, with increasing detail, the elements and processes that constitute what 'livelisystems', defined defined as

'*combinations of the functions provided by assets (or resources) and activities undertaken in and by open, structured and actively self-regulating systems in maintaining negentropy (negative entropy) and/or increasing it with informational, material and relational mechanisms for replication or reproduction*' .

This draws on conceptualizations of livelihoods (Chambers and Conway, 1992), living systems (Miller, 1978) and generative replication in complex population systems (Hodgson and Knudsen, 2010b) . It focuses attention in social or ecological system analysis on the functions of resources or assets (Kent and Dorward, 2012b), on activities, on processes maintaining or increasing system order and negentropy, and, as open systems, on relations with external systems. The broad processes and elements of a framework representing these features are set out diagramatically in the black text and block arrows in figure 1.

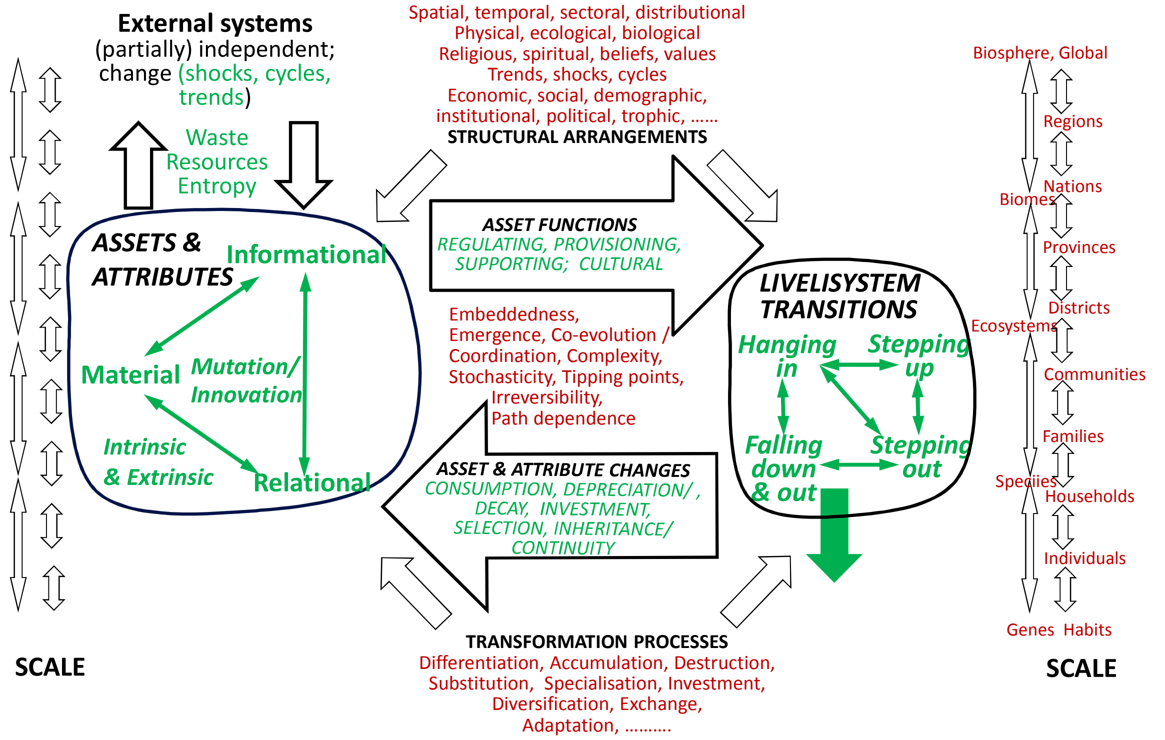

Figure 1. Livelisystems: broad processes and elements, sub categories, and potential characteristics†

†All arrows represent potential causal effects of one set of elements on another set of elements.

This represents processes maintaining or increasing system order and negentropy as 'livelisystem transitions' (on the right) , and links these to resources (on the left) termed 'assets and attributes'. Assets, their properties and their attributes are affected by and may or may not affect external systems (shown in the upper left of the figure). An important distinction is made between asset properties (their essential and potential features) and asset attributes (the expression of an asset's properties in a particular ecological and social context). In the remainder of this section asset properties are considered as intrinsic to assets themselves. Assets by their attributes perform functions which effect livelisystem transitions, and they are themselves affected by these transitions. These processes operate at different scales, with lower level systems operating within higher level systems and affected by other livelisytems within the same higher level systems. However they are also components of and therefore affect higher level hierachies, often with 'sub-livelisystems' acting as assets within a higher level livelisystem. These cross scale interactions are indicated by the vertical arrows on the sides of figure 1. Finally, livelisystem transitions and assets and attributes are arranged in structures which may be transformed by a variety of processes.

We now develop this conceptualization further by detailing categories of livelisystem transitions, asset functions, asset changes, assets and attributes, and flows between livelisystems and external systems. These categories are set out in figure 1 in green text and line arrows and discussed in turn.

Building on a conceptualization originally of livelihood aspirations and transformations (Dorward et al., 2009), four possible livelisystem transitions are defined – hanging in (maintaining the status quo), stepping up (increasing levels of existing sets or subsets of activities and/or assets and asset functions), stepping out (engaging in new activities with different assets and asset functions), and falling down and out (failing to maintain the status quo and falling back to a livelisystem with lower attainment of sets or subsets of activities and/or assets and asset functions, possibly failing to maintain the livelisystem and survive). As noted earlier, these livelisystem transitions draw on asset functions and cause asset changes. The concept of asset functions is discussed more fully in Kent and Dorward (2012b)[1]. It is related to and includes ecosystem services, which, following Wallace (2007), Boyd and Banzhaf (2007), Jax (2010), and Kent and Dorward (2012b) are defined as 'those services (or goods and services) which are provided by ecosystems and actually and directly valued and consumed' by people. Ecosystem services are then a subset of ecosystem functions, defined by Kent and Dorward (2012b) as 'the primary, intermediate and final (ecosystem) processes which support and deliver goods and services'. As with Jax's consideration of ecosystem processes, this avoids difficulties in distinguishing between intermediate and final services.

Following the MEA we then categorize these functions as regulating, provisioning, supporting and cultural (Millennium Ecosystem Assessment, 2005) as it is recognized that this is a helpful classification of functions performed by all forms of capital – for example physical, social, and human as well as natural capital (Waage et al., 2010). Asset functions can be further and usefully classified into more detailed categories: Dorward et al. (2005), for example apply the concept to analysis of livestock roles in poor rural people's livelihoods in Mexico and Bolivia and categorize these in terms of production, consumption, accumulation, buffering, insurance, protecting and social integration functions. Kent and Dorward (2012b) add to this 'transformative functions', which involve different kinds of physical transformations: livestock for example may transform dispersed, low nutrition quality forage in one season and make this available as concentrated high quality human food at a later season. This involves spatial, qualitative and temporal transformations.

Livelisystem transitions affect assets (their properties) and their attributes in a variety of ways. Asset and attribute depletion (including loss of properties needed for particular functions) may occur where asset stocks are directly consumed, destroyed, decay or 'depreciate' at a faster rate than they are generated or renewed within or outside the livelisystem or where processes (for example generation of waste) undermine them. On the other hand there may be accumulation where 'investment' or other positive effects lead to faster generation and renewal than consumption, destruction, decay or depreciation. Processes of asset (and property) and attribute gain or loss lead to differential selection of assets and attributes and, with the information transfer mechanisms for replication or reproduction inherent in our definition of livelisystems, this leads to inheritance ('the passing of information concerning adaptive solutions from one entity to another', (Hodgson and Knudsen, 2010a) p239).

Selection and inheritance constitute two of the three necessary processes of Darwinian evolution, the third being variation. This is a characteristic of assets, which are hierarchically and structurally embedded combinations of material, informational and relational resources (they are hierarchically embedded in different scales as discussed earlier and they are structurally embedded in that relational resources are normally embedded in some form of informational resource, and informational resources are always embedded in some form of material resource). Informational and material resources coincide with the two core elements identified in Miller's living systems theory, matter-energy and information (Miller, 1978) and with Odling Smee's (Odling-Smee, 2007, 2010) conceptualization of informatic and physical (material and energy) resource components of ecological inheritance systems (though these are then separated from not integrated across genetic inheritance systems). Relational elements describe claims and obligations that systems or sub-systems have on or to other systems or subsystems.

The ‘material, informational and relational’ categorization of assets can be applied in two ways. First, as is implicit in the outline above, as regards asset composition: assets are made up of material, informational and relational elements. The categorization also applies in a second way in describing the mode of operation of the asset: does an asset make material, informational and/or relational contributions to livelisystems in performing its functions in a livelisystem? While the material, informational and relational categorization is useful in examining the fundamental composition and operation of assets, assets may also be categorized in a variety of other ways. Thus, for example, it may be helpful to categorize assets as natural, physical, social and human capital in some analyses of social or socio-ecological systems.

It is also helpful to categorize asset attributes. No categorization is shown in figure 1, for reasons of space. It should, however, be clear from the framework that differences in asset properties and their expression in different contexts mean that their contributions to different services, and hence their attributes, will also vary between contexts. .

Drawing on and adding to livestock attributes identified by Dorward et al. (2005) (see also Alwang and Siegel (1999)) suggests, as an illustrative starting point, a list of attributes set out in table 1. . Asset attributes and their components must be defined relative to asset functions, as illustrated in table 1. Different functions and attributes may have more or less relevance to different social and ecological processes and analysis (and many assets will be ‘sub-livelisystems’ with their own emergent, embedded and non-linear properties). Their specification will thus vary substantially between different livelisystems and analyses and, depending on their essential properties, will be both contextually and socially defined (Kent and Dorward, 2012b). The ‘second tier system variables’ identified by Ostrom (2007) and others in their framework for analysing SES provide further options for specifying and categorising asset attributes.

Table 1. Asset attributes

Main Attribute	Contributing to which function(s)	Components
Productivity	Production, income,	Productivity (or throughput) under expected, average or 'normal' conditions; variability; sensitivity to and resilience under different conditions; probability of these different conditions occurring; appreciation of asset value
Utility	Income, consumption,	'Normal' utility or wellbeing; variability; sensitivity to and resilience under different conditions; probability of these different conditions occurring
Security	All, especially saving	Risk of theft, loss of control or access; susceptibility to pathogens or other 'natural' event. For debts: risks to collateral or collateral substitutes
Holding costs	Detracts from all	Maintenance and input costs (including time, claims, etc) borne by different stakeholders: under normal conditions; variability under different conditions; probability of different conditions
		Depreciation in time and in use: under normal conditions; variability under different conditions; probability of different conditions
Life	All	Expected period over which asset will be held: under normal conditions; variability under different conditions; probability of different conditions
		Asset value profile (seasonal, lifecycle changes)
Depreciation	All	Rate of loss of function / service, affected by use, investment, environment, etc
Convertibility	Sales income, savings, buffering, insurance	Exchange costs: under normal conditions; variability under different conditions; probability of different conditions
		Access: under normal conditions; variability under different conditions; probability of different conditions
		Lumpiness: related to unit value of sale and ease of sale
Complement-arity	Production, income	Effects on and of other assets and their functions
Ownership/ control	All	Private (individual, household); communal; public; gendered rights and responsibilities for disposal, acquisition, costs and returns
Divisibility	All	Minimum functional scale (may vary across services), variation of other attributes with scale
Dispersion/ concentration	All	Spatial & temporal distribution, could also be applied to ownership

Adapted from (Dorward et al., 2005)

Two further categorizations of assets and attributes are included in figure 1. The first recognizes that assets and attributes are subject to endogenous changes as well as changes effected by livelihood transitions (as described earlier). Endogenous changes arise as a result of mutation, innovation, and recombination (where mutation describes random changes generally arising in processes of replication, innovation describes intentional changes, and recombination describes new combinations of core characteristics, composition and structure of assets and their attributes). Mutation and innovation may act in combination or singly, and may affect material, informational or relational elements. These broad mechanisms of endogenous change are critical to livelisystems as they allow variation, the third of the three necessary processes of Darwinian evolution mentioned above.

The second further categorization of assets and attributes in figure 1 applies principally to assets rather than their attributes, and distinguishes between assets that are intrinsic and those that are extrinsic to (integral or not integral parts of) organisms in a livelisystem. Examples of extrinsic assets might include animals' nests and burrows, machinery, information technology systems, and, by definition, relational assets. This distinction may or may not be usefully applied to other livelisystem entities.

Consideration of extrinsic assets and relational assets raises questions about livelisystem boundaries and relations with external systems. Defining boundaries of open systems is commonly difficult and requires problem and context specific determination. Feedbacks between systems depend upon the extent of coupling and relative scales and numbers of interacting systems – hence their partial independence. It is helpful, however, to recognize different categories of change in external systems (for example 'normal' apparently random variation, shocks, cycles and trends) as these will have different impacts on livelisystems, and to recognize different types of flows between livelisystems and their environment, with material, informational and relational resources and waste flowing in and out, and a maintenance of negentropy by taking in resources with lower entropy than the 'waste' they emit or expel.

The categorizations in figure 1 should not be seen as rigid, tightly defined, separate and mutually exclusive. On the contrary, the boundaries between them will often be fuzzy and overlapping, both within and across hierarchies of scale. Thus the four categories of livelisystem transitions may be present together, and the same processes (take for example a switch from less intensive to more cropping systems in an socio-agro-ecological system or a species transition from crawling to running) might be seen as stepping up (of agricultural productivity or mobility respectively) or stepping out (from one crop to another or from one form of locomotion to another). Similarly asset services might be categorized differently in different types of analysis or at different scales of analysis (for example a service categorized as 'supporting' at a higher scale of analysis might be considered a 'provisioning' service at a lower scale of analysis). This is one way of addressing difficulties in defining and distinguishing between direct and indirect services and functions in the ecosystem services framework (Jax, 2010). These categorizations also need further development and definition within the context of the overall conceptualization. The concept and roles of 'relational assets', for example, while providing useful insights need better specification.

We conclude our introduction to the livelisystems framework by introducing illustrative potential characteristics of livelisystem, most importantly in terms of the nature of livelisystems behavior and of structural transformations and transformation processes. The introduction of these in red text leads to some unavoidable crowding of figure 1, but highlights important features that may or may not be present in different livelisystems. Specification of these demonstrates the richness and variety of the processes and systems that may be captured with a livelisystems framework. The centre of the figure lists critical ecological, social and SES features that can be captured by cross scale contextualized analysis of livelisystem transitions and their interactions with evolving assets and attributes. At the top of figure 1 a range of different types and dimensions of structural transformations are listed, while at the bottom of figure 1 is a list of different types of processes which may be involved in these transformations. Similarly lists of hierarchical scales of analysis are added on the right of the figure. It is important to note that these also define types and scales to which various livelisystem concepts (such as transitions, transformations, and asset functions and attributes) may be applied. As with our earlier discussion of asset functions and attributes, these lists are not intended to be either prescriptive or exhaustive (they do not set out a typology of transformations or processes which will apply to all livelisystems) but illustrate the richness of the potential range that may or may not be considered and may or may not be helpful when using the framework to analyse particular livelisystems.

APPLICATION AND DISCUSSION

The conceptual framework set out in the previous section can be applied in a number of ways. Paradoxically it's metatheoretical nature means that specific applications of the whole framework will be relatively rare: in providing a framework for bringing together understandings, analysis and investigations across SES it allows a holistic but more general integration of different parts, as called for by SchlÜTer et al. (2012).

Limited experience in broader use of the framework suggests that it can provide a valuable starting point for investigation of particular livelisystems by defining core research questions within an integrating structure (du Toit, pers. comm.). These core research questions could, for example, iteratively examine where livelisystem boundaries can be drawn, the main hierarchical and overlapping components, what resources and attributes provide what services, what livelisystem transitions are occurring, what options or possibilities there are for different livelisystem transitions, how asset attributes and livelisystem transitions are mediated by their location in the system, the vulnerability and resilience of livelisystems and of different elements in livelisystems and the causes of their vulnerability, what structural transformations and processes are unfolding and their drivers and feedback effects, and key relations with external systems and how may these be changing. These questions have been posed in ways that are applicable to both natural and social systems and subsystems. More specific question topics that might be appropriate to social systems might concern institutional or knowledge change or power, while topics more appropriate to ecological systems might for example concern trophic pathways or environmental change.

A specific example of the application of part of the framework is its use in investigating impacts of and responses to biodiversity change in the Western Ghats, India. This involved a fairly rapid study of the impacts of the invasive spread of *Lantana camera* and of human adaptation to this in a village in the Male Mahadeshwara Hills Forest Reserve, southern Karnataka where the *Lantana* invasion has caused a decline in availability of forest products (including grazing for cattle), obstruction of movement of humans and animals in the forest, and increased risk of encounters with wild animals. (See Kent and Dorward (2012b) and Kent and Dorward (2012a) for a fuller description of the study.)

Before engaging in fieldwork, the multi-disciplinary research team used the livelisystems framework to develop a specific conceptual framework for investigating both the impacts of the spread of Lantana on people's livelihoods and people's responses to this. As set out in figure 2, this focusses on examination of changes in asset properties, in attributes and in functions and use within people's livelihoods in response to biodiversity and other changes, with the shaping of decisions by knowledge and values, with changing livelihood outcomes and wellbeing, and with human adaptation. Figure 2 may not immediately appear to be related to figure 1. Closer inspection shows, however, the central but separate positions of asset properties and asset attributes. The focus on these provided 'boundary concepts' that linked disciplines (ecology, anthropology, and economics) and their respective attention to multiscale changes in ecosystem structures and processes, in values and knowledge, and in resource use and livelihood outcomes with critical separation of (ecological) asset properties from contextually determined and socially constructed and differentiated asset attributes. This focus also allowed the development of common 'boundary tools' linking researchers and local people: qualitative interviews considering the functions and attributes of forest assets for different groups of users and perceptions of how these had changed over time.

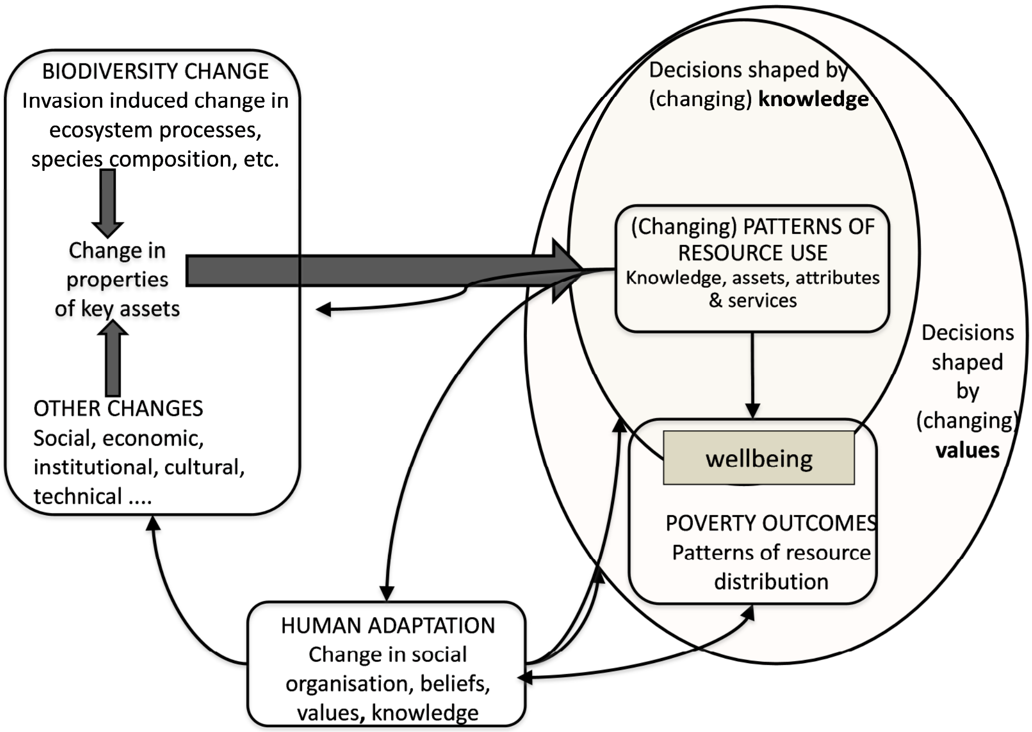

Figure 2. Conceptual framework: human adaptation to biodiversity change
Kent and Dorward (2012b)

Table 2 provides a general, aggregate summary of assets and their functions in livelihoods, distinguishing between those managed and held by households and by or within the wider community. This locates the contributions of the forest to the wider set of asset functions as people draw on forest resources as part of diverse livelihood strategies which incorporate crop production, livestock raising, and extraction of forest products for income and subsistence alongside labor migration, use of savings and credit services from Self Help Groups, and consumption of Public Distribution System (PDS) grain. However the table does not show differentiation in livelihood access to and use of assets by the two ethnic communities that live in the village (the Lingayat and Soliga) and by men and women within these communities.

Since households' have little power to control the spread and impact of *Lantana* , consideration of asset properties and differentiated attributes and functions allowed analysis of their adaptation to changes in the forest in terms of their finding substitutes for the functions previously derived from the forest. The capacity for such adaptation was found to vary considerably between households and individuals as a result of variations in access to non-forest assets. This was most apparent with regard to households' ability to substitute forest-derived income with wages from migrant work. Here extended households containing both adult sons (able to take turns to leave for migrant labor) and parents (able to maintain the farm and/or look after cattle) have adapted to the effects of the loss of forest grazing with increased periodic migrant labor and earnings. This has facilitated investments in house building and in agriculture. However, extended households are more common in the Lingayat community and by comparison the more nuclear Soliga households tend to be in a more precarious position in adapting to loss of forest assets.

Table 2. Household and community / local assets levels fulfilling asset functions

Asset function categories	Household level	Community and local level
Consumption	Grain stores; PDS ration; houses	Forest products: foods (fruits, tubers, greens, game); fuelwood; timber; bamboo;
Social/ cultural functions	livestock; houses; labor	Forest; temples/shrines;
Productive/transformative functions	Farmland; livestock; ploughs; labor; houses	Forest; labor; school;
Exchange functions	Farm products (maize, ragi); labor; livestock	Forest products (broomstick, forest fruits, bamboo, firewood).
Savings functions	Livestock; SHG savings; bank savings; jewelry	
Protective functions	Livestock; bank savings; jewelry; insurance;	SHG credit; forest products; money lenders; PDS
Regulating functions		Forest, other environmental assets
Supporting functions		Forest, other environmental assets; health services; water pump, roads, transport.

Kent and Dorward (2012b)

Differences between the two communities are also found in the use of bamboo for basket making and in the collection of *Phoenix* or broom (an understory palm). Both activities provide a source of cash income and are potentially open to all, but the former is more prevalent among men in Soliga households and the latter more important for women in Lingayat households. Soliga mens' engagement with basket making appears to be related to its compatibility with migrant labor and to possibilities for accessing credit and consumption smoothing through advance payment from traders. Lingayat women, on the other hand, value the collection of broom, as it's compatibility with domestic tasks make it one of the few income earning options available to them. It also provides income for the regular savings required for membership of micro finance Self Help Groups. Any *Lantana* induced decline in access to or availability of bamboo and broom collection may then have differential impact on men and women and on Lingayat and Soliga households.

This case demonstrates the usefulness of a focus on assets (and their properties, functions and attributes) as 'boundary concepts' for researchers from different disciplines, in supporting the development of 'boundary tools', in setting these within a wider context of social and economic change (not explicitly discussed here), and in providing valuable insights into differential responses and vulnerabilities to biodiversity change in a multiscale SES analysis. The findings suggest that policy responses supporting adaptation need to pay particular attention to different groups' portfolios of asset functions, the attributes of these assets within particular social, institutional, economic and biophysical contexts, and the way that these are affected by biodiversity and other changes.

Beyond suggesting a general structured approach to investigation of specific biological and social systems, the framework also raises questions about and provides insights into specific topics and processes. This may be illustrated with regard to a major challenge with economic policy and practice: conceptualization of the multi-scale, multi-dimensional dynamics of structural change. The conceptualization of hanging in, stepping up, and stepping out transitions addresses this and indeed emerged from consideration of changes in peoples' livelihoods and in wider economies (Dorward, 2009; Dorward et al., 2009). A key insight highlighted by this is the need in socio-economic policy for coordinated change at different scales of analysis, in demand and supply across a range of complementary activities, services, and investments – across technical, institutional, human, physical, and natural capital.

Core evolutionary processes involve similar multi-scale, complementary and interacting 'co-evolutionary' change across different genes, cells, organisms, species and ecosystems (there are, for example, interesting biological evolution and socio-economic change parallels in the importance of and links between 'hanging in', 'stepping out' and some spatial movements). Social and biological evolutionary processes may be distinguished from each other by the greater importance of culture in social processes, but these interact in gene-culture evolution in human systems, while the importance of social learning and stable trans-generational culture in non-human species is increasingly recognized (Laland and Boogert, 2010). There are also parallels and continuities as regards changes in the relative importance of intrinsic and extrinsic assets and of material, informational and relational capital, and of their interaction. These differences may be seen as key elements of socio-economic development - for example it appears that systems within more developed societies tend to be characterized by greater reliance on extrinsic informational assets. It may, indeed, be possible to trace a global SES evolutionary pathway in terms of the interactions between and relative importance of extrinsic, informational and relational assets. Alternatively, at a more micro level, the framework has the potential to take forward work on asset based poverty and poverty measures (Carter and Barrett, 2006; Liverpool-Tasie and Winter-Nelson, 2011) through its emphasis on a wide set of assets, the different functions they perform, and their related and contextualized attributes.

The increasing importance of relational capital as systems develop suggests potential insights from cross disciplinary investigation of the concept of 'niche construction'. Laland and Boogert (2010) note the importance of niche construction in human societies and their interactions with the natural environment. In the livelisystems framework this raises questions about system boundaries between and definitions of relational assets and external systems, and about the role of power in defining boundaries and relations (as well as in innovation and selection processes). Concepts of 'roving and stationary bandits' may have widespread value and validity across their original application in political and economic development (Olson, 1993) to natural resource management (Ostrom, 2007) and wider predator-prey and parasitic relations.

CONCLUSIONS

The desirable specifications set out earlier for a trans-disciplinary and valid theoretical framework provide a bench mark against which the livelisystems framework may be evaluated – and it appears to perform relatively well. Its structure is explicitly multi-scale and dynamic, with multiple components and subsystems that provide potential for emergent and embedded properties, for multiple structural transformations, and for a variety of disciplinary perspectives and investigational approaches. Its cross disciplinary roots, concepts and language (drawing on livelihood and other development studies and economics concepts, ecosystem service categorizations, and living systems, panarchy, niche construction, CHANS and extended evolutionary theories) are an explicit strength which, with its system components, allow mediation and integration between perspectives and investigational approaches from different disciplines. In this it is not inherently anthropocentric or biocentric, but capable of application in both contexts. It also has the potential to provide a metatheoretical framework for contributions to individual disciplines and to stimulate conceptual development and research within disciplines and at their interface with other disciplines. Its cross disciplinary roots and multi-scale structure should make it methodologically flexible and inclusive, as subsystems can be defined and investigated in a variety of ways. In this it should be seen as complementing and sometimes providing a context for rather than competing with a number of the approaches and frameworks reviewed earlier. There may, for example, be particular opportunities for the use of nested agent based models to describe multiple and multi-scale interactions between systems' different subsystems and components.

We conclude by suggesting two ways in which the framework can and should be taken forward – further conceptual development and wider application. First, there is a need for further conceptual development. Perhaps the most obvious weaknesses in the exposition in this paper are the need for a clearer conceptualization of relational assets (with specific regard to theories of niche construction, the definition of system boundaries, and conceptualizations of power, as touched on earlier) and the need for development of a more holistic set of asset attributes concerned with regulating, supporting, and cultural functions.

Conceptual advances on these and other topics will both benefit from and contribute to wider application of the framework. There is a wide range of systems where the concrete application of the framework could potentially improve both understanding and management of or responses to change. These might include climate, food or agri-health systems (at local and wider, up to global scales), specific resource, conservation or eco- systems, and particular species in different contexts. There are also opportunities for more theoretical applications. As an example, these might investigate the hypothesis that more 'advanced' evolution and development involve increasing relative importance of relational and extrinsic assets and of change through teleological selection and innovation. This hypothesis raises questions about the need for and nature of new 'anthropocenic processes' of livelisystem evolution and development in an increasingly globally organized and environmentally challenged society.

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Appendix. A review of SES frameworks and modelling approaches

A range of different cross-disciplinary frameworks and models have been developed and applied for diagnosing problems and developing and implementing solutions in SES. In this section we briefly review a range of different approaches used in these frameworks and models. We start from simpler frameworks but note that although these are accessible and useful in drawing attention to interactions between social and ecological or biophysical variables and processes, they find it difficult to give sufficiently symmetrical consideration to these interactions. We argue that more fundamental theoretical integration across social and biophysical processes is required, and then discuss alternative approaches to this.

We begin by recognising that the terms 'framework', 'model' and 'theory' are used, and indeed combined (for example theoretical model or theoretical framework'), in different ways. Following Ostrom (2009) and McGinnis (2011) we consider 'frameworks' to identify categories and sets of variables relevant for study, with limited specification of the nature of relationships between them, and 'theories' to set out and evaluate general causal relationships between categories and sets of variables. 'Models' specify these relationships in particular circumstances. The relationships between and choices of theories, models and frameworks in any analysis are determined by context, by the purposes of analysis, and by analysts' disciplinary interests (SchlÜTer et al., 2012)

The first framework we consider has gained wide and enduring traction, the EcoSystem Services (ESS) framework. Building on early work by Costanza and Daly (1992) and Perrings et al. (1992), the Millennium Ecosystem Assessment Millennium Ecosystem Assessment (2005) set out a formal EcoSystem Services framework to demonstrate the importance of ecosystems and ecosystems threats. Although it has strong roots in ecology, it is criticized for its limited conceptualization of ecosystems primarily as stock- flow systems, its application to partial rather than general equilibrium analysis, and its facilitation of the commoditization of ecosystem services (Gómez-Baggethun et al., 2010; Norgaard, 2010). However, beyond its conceptualization of human drivers and ecosystem stocks and flows, and the opportunity it provides for valuing flows and hence the stocks they are derived from, it has limited theoretical content as regards socio-economic influences on and responses to change.

A framework whose terminology relates closely to the ESS Framework (with 'drivers' and 'pressures' equivalent to the ESS 'indirect' and 'direct' drivers (Fisher et al., 2012), is the Drivers-Pressures-State-Impact-Response (DPSIR) which has been further developed into the Framework for Ecosystem Service Provision (FESP) (Rounsevell et al., 2010). Although in many ways similar to the MEA ESS framework, these frameworks place more explicit emphasis on the possibility of adaptation by ecosystem service providers (key ecosystem elements or communities providing specific services) and, in the case of FESP, on responses by ecosystem beneficiaries. However such feedbacks are also allowed for in research frameworks that explicitly seek to operationalize the MEA, for example Collins (2007).

An earlier more social science oriented framework with little emphasis on ecological elements was the 'sustainable livelihoods approach' (Carney, 1998; Chambers and Conway, 1992). This was originally a checklist of issues to consider in analysing sustainable rural livelihood constraints, opportunities and interventions. As an analytical or development aid it has value, but is subject to criticism that even on socio-economic issues it omits key issues, such as markets, institutions and politics (Dorward et al., 2003) and lacks theory regarding processes and pathways of change and detailed linkages across different scales (Scoones, 2009). It also lacks any specification of linkages across the natural and social sciences.

These frameworks are useful in setting out checklists of the elements of SES that need to be considered. Their weaknesses arise from (a) the elements that they omit, (b) the limits of the system behavior theories (or lack of theory) underpinning them, and (c) implementation difficulties in obtaining reliable information linking the behavior of different elements (arising from both theoretical and data difficulties). A key weakness is that although both social and ecological elements may be in included in the framework, we seldom find both social and ecological theory underpinning them (a possible exception is the application of the ESS framework to design schemes for payments for ecosystem services – although this raises fundamental objections about the inadequacy of considering social relations only in market exchanges and about insufficient consideration of possible indirect effects and feedbacks (see for example (Maestre Andrés et al., 2012; McAfee and Shapiro, 2010; Muradian and Rival, 2012; Norgaard, 2010)).

Frameworks drawn from both social and ecological theory are more analytically challenging to implement. Ostrom and others have developed a valuable framework for identifying and organizing relevant variables that affect self-organization by resource users in SESs (Anderies et al., 2004; Ostrom, 2005, 2007, 2009). These variables describe features of resource units, resource users and resource and governance systems, the core subsystems for analysis of SESs, and are identified and brought together to allow integration of knowledge from biophysical and social science studies for use in data collection, fieldwork, and analysis of SES sustainability. Anderies et al. (2004) noted with early work with this framework that the original design principles did not explicitly address ecological dynamics: attention was needed to 'mechanisms related to the match between the spatial and temporal dynamics of ecological and social systems'.

This match, perhaps the core problem in cross disciplinary integration in SES, is the subject of a review by Milner-Gulland of the implications of work on the interactions between human behavior and ecological systems for predictive systems ecology (Milner-Gulland, 2012). She reports considerable work examining one way impacts – of humans on ecosystems or of ecosystems on humans - but much less work that examines dynamic two way interactions. Where such work has been done, it has been very valuable in showing the important effects of these interactions (for example Holdo et al. (2010))– but tends to involve detailed and system specific modelling and modelling tools, rather than general theory. Agent based modelling can, however, provide a common tool and methodological framework for such modelling. It is interesting that coming at the problem from more of a conservation perspective, Milner-Gulland reaches symmetrical conclusions to those of Anderies et al. (2004) reported above, observing that 'indirect effects of conservation interventions on biodiversity, modulated through human decision-making, are poorly studied' and calling for 'an inter-disciplinary approach .. to quantify these interactions, with an understanding of human decision-making at its core'. Janssen et al. (2006)) and Bodin and Tengö (2012)) raise similar difficulties with SES frameworks' difficulties in coherent integration of social and natural sciences and in the critical ability to describe structural change. They use and advocate network theory and analysis as one approach that can address these difficulties in some situations. Like agent based modelling this is applied in both social and ecological science and provides common analytical concepts and tools. Social and natural scientists engaged in cross-disciplinary work on SESs therefore recognize the need for integration of 'dynamics of ecological and social systems', but have had limited success and have limited tools to achieve this. Ideally attempts to 'bolt together' disciplinary understandings and methods around common methodological approaches and tools would be complemented by more fundamental integration in terms of metatheoretical understanding b). This involves a move from 'mutual identification and cooperation' to 'fundamental transformation' in such work (MacMynowski, 2007) and from interdisciplinary to transdisciplinary modes of work with 'epistemological pluralism' (MacMynowski, 2007).

A core explanation for difficulties with SES frameworks and theory is likely to be the way that different disciplines operate with different conceptual frameworks regarding basic processes of change (Gintis, 2007; Hodgson and Knudsen, 2010). This is undesirable from at least three perspectives. First, different disciplines may not only have different concerns and perspectives (which is valuable), but also incompatible models (Gintis, 2007), with analysis of different variables and processes leading to incompatible analyses and difficulties in mutual comprehension. Second, even if models are not incompatible, it may be that a framework in one discipline has great analytical power in another discipline, and failure to use that framework within the second discipline is therefore missing opportunities for expanding analytical opportunities in that discipline (this is a major thrust of arguments by Hodgson and Knudsen (2010) for the adoption of generalized Darwinism across the social sciences). Third, and drawing on the first two points, work across disciplines, a fundamental requirement for work on socio-ecological systems, becomes significantly more challenging if the two disciplines do not share a common metatheoretical framework to unite and interface their different work and perspectives on different topics (Hodgson and Knudsen, 2010). To address these challenges Mollinga calls for three types of 'boundary work': the development of boundary concepts (cross disciplinary terminology and multi-dimensional thinking), tools (analytical models and assessment frameworks), and settings (institutional arrangements for inter-disciplinary work) (Mollinga, 2010). This first need is echoed by Schluter et al. who recognize considerable achievements in SES modelling but note 'the need for a common analytical framework for SES' (SchlÜTer et al. (2012), p251).

Interest in evolution has been a dominant theme in work on the development of such metatheoretical frameworks. Hodgson has been a strong proponent for the adoption of 'generalized Darwinism' as a uniting metatheoretical framework for the social sciences (see for example Hodgson and Knudsen (2010)). Hodgson and co-authors develop this in substantial depth and detail, dealing with a variety of objections to the application of Darwinian evolution to the social sciences and addressing specific difficulties with the development of principles for the analysis of evolution in social systems. Gintis (2007) proposes 'evolutionary theory, covering both genetic and cultural evolution, as the integrating principle of behavioral science 'in a 'framework for the unification of the behavioral sciences'. In both of these cases evolutionary theory is being proposed as a

unifying theory for the social sciences (Gintis includes biology within an initial list of behavioral sciences, but it is clear that his interest is in human behavior).
Norgaard has proposed 'coevolutionary' theory as a way of linking analysis of social and ecological change initially as 'an appeal for theoretical pluralism' (Norgaard, 1984) but more recently as a framework for explanation of sociocultural evolution in social sciences and for linking this to the biological sciences (Gual and Norgaard, 2010). Although this has faced a number of criticisms (for example regarding the role of group selection and processes of variation, selection and inheritance) many of these criticisms arise because evolutionary concepts are being lifted out of a narrower biological context (concerned with biological processes, mechanisms and variables) to fit in a wider context (concerned with social processes, mechanisms and variables) and in this does not distinguish, for example, between co-dynamics and Darwinian co-evolution (Kallis, 2007; Winder et al., 2005). Co-evolutionary theory is also proposed for the conceptualization and understanding of uncertainty inherent in economic development processes, involving the co-evolution of technical and institutional change (Nelson, 2011). Rammel et al. (2007) explicitly draw on ideas from complex adaptive systems theory, evolutionary theory and evolutionary economics to develop a co-evolutionary perspective on natural resource management.

Waring and Richerson (2011) argue that Norgaard's framework could provide a basis for a unified framework for SES analysis, and propose that with the addition of three traditions of mathematical theory (the Lotka–Volterra interactions of ecological theory, niche construction models of population genetics, and gene–culture coevolution theory) this could form the basis for an operational 'theory of socio-ecological coevolution' with coupled models of environmental change and human behavior. Gene-culture coevolution also features in Gintis' unifying theory (Gintis, 2007) while Laland and Boogert (2010) propose niche construction – both gene-based and cultural niche construction - as a dominant process in SESs dynamics. Niche construction provides the basis for the 'extended evolutionary theory' proposed by Odling-Smee et al. (2003), while Jablonka and Lamb (2005) put forward a related but different 'extended evolutionary theory' in their exposition of 'evolution in four dimensions' (the four dimensions being genetic, epigenetic, behavioral, and symbolic variation, selection and inheritance).

Other metatheoretical frameworks approach SESs in very different ways. Living systems theory, developed by Miller (Miller, 1978; Miller and Miller, 1992) adopts a systems approach in a formal description of hierarchical arrangements of nested and integrated biological and social systems arranged, from single celled organisms to supranational social systems, with formal functional sets of critical subsystems. Living systems theory has had limited application to SESs. Panarchy, another metatheoretical framework, focuses on linked, hierarchically arranged adaptive cycles representing cross-scale dynamic interactions and the interplay between change and persistence in a system (Holling et al., 2002).

While these frameworks provide ways of conceptualising the spatial and temporal dynamics of ecological and social systems, Gintis (2007) and Waring and Richerson (2011) also include methodological approaches or tools in the operational proposals for their frameworks – respectively the use of evolutionary game theory and the coupling of specific mathematical modelling approaches. As discussed earlier, network theory and agent based models provide two other, closely related methodological approaches to conceptualising and modelling agents in social and ecological systems (Hird, 2010; Rounsevell et al., 2012) – with increasing use of both approaches in both social and biological sciences. Modelling of adaptive cycles has both theoretical and methodological significance in panarchy, but potential for wider application (Widlok et al., 2012) and for links to agent based modelling.

Coupled Human and Natural Systems or CHANS (Liu et al., 2007) has been developed as an approach with both theoretical and methodological elements that 'aims to reveal the underlying rules and emergent properties of (SES), and the patterns and processes that link human and natural systems', emphasising 'the potentially unpredictable effects of humans, their organizations and practices on the environment, as well as the effects of environmental changes on human populations, institutions, and behaviors' and promoting 'the integration of agency and multi-scale interaction multiple organizational, spatial and temporal scales' (Hummel et al., 2012). However Hummel et al. (2012) argue that CHANS needs to develop general principles which themselves would need a 'comprehensive theoretical framework' integrating different natural and social science perspectives.

Our review of different cross-disciplinary frameworks for understanding and modelling SES therefore leads from simpler interdisciplinary approaches with 'mutual identification and cooperation' to the need for transdisciplinarity with a 'fundamental transformation' involving 'epistemological pluralism' (MacMynowski, 2007). Evolutionary and co-evolutionary theories are suggested by a number of authors as a providing a possible basis for such an epistemologically pluralist transdisciplinarity. These then need to be integrated with multi-scale systems theories and approaches.

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