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Research article

Shaping the role of 'fast' and 'slow' drivers of change in forest-shrubland socio-ecological systems

Agostino Ferrara [a,*], Claire Kelly [b], Geoff A. Wilson [b], Angelo Nolè [a], Giuseppe Mancino [a], Sofia Bajocco [c], Luca Salvati [c,**]

[a] School of Agricultural, Forest, Food and Environmental Sciences, University of Basilicata, 85100 Potenza, Italy
[b] School of Geography, Earth and Environmental Sciences, Plymouth University, United Kingdom
[c] Italian Council for Agricultural Research and Economics (CREA), Rome, Italy

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ABSTRACT

The temporal speeds and spatial scales at which ecosystem processes operate are often at odds with the scale and speed at which natural resources such as soil, water and vegetation are managed those. Scale mismatches often occur as a result of the time-lag between policy development, implementation and observable changes in natural capital in particular. In this study, we analyse some of the transformations that can occur in complex forest-shrubland socio-ecological systems undergoing biophysical and socioeconomic change. We use a Multiway Factor Analysis (MFA) applied to a representative set of variables to assess changes in components of natural, economic and social capitals over time. Our results indicate similarities among variables and spatial units (i.e. municipalities) which allows us to rank the variables used to describe the SES according to their rapidity of change. The novelty of the proposed framework lies in the fact that the assessment of rapidity-to-change, based on the MFA, takes into account the multivariate relationships among the system's variables, identifying the net rate of change for the whole system, and the relative impact that individual variables exert on the system itself. The aim of this study was to assess the influence of fast and slow variables on the evolution of socio-economic systems based on simplified multivariate procedures applicable to vastly different socio-economic contexts and conditions. This study also contributes to quantitative analysis methods for long-established socio-ecological systems, which may help in designing more effective, and sustainable land management strategies in environmentally sensitive areas.

1. Introduction

A socio-ecological system (SES) can be defined as a complex and integrated system in which mixed components of economic, social and environmental capitals interact across spatial scales (but within a geographically-bounded space) over a defined period of time. Socio-ecological systems provide ecosystem benefits to humans and are, in turn, modified by human actions (Berkes and Folke, 1998; Berkes et al., 2003). In this paper, we use the definition developed by the Resilience Alliance (2002) and adopted in the LEDDRA project (Briassoulis, 2010b, 2014, 2015), which identifies a SES as '*a coupled human-environment system; a multi-scale pattern of resource use around which humans have organized themselves in a particular social structure (distribution of people, resource management, consumption patterns, and associated norms and rules)*' (Briassoulis, 2010a: 1). There are, however, critical differences between economic, social and ecological components centred around human agency, power and collective action (Davidson, 2010; Wilson, 2012). The role of humans in responding to their environment, and changes within it, is an important element of the complexity of a SES which makes the task of analysing drivers of change particularly challenging (Davidson, 2010). The importance of spatial and temporal scales is also critical when interpreting drivers of change in a SES. The temporal speeds and spatial scales at which natural resources such as soil, water and vegetation are managed by humans, and the speed at which policy implementation occurs, are often at odds with the speeds and scales at which ecosystem processes actually operate (Zurlini et al., 2006; Reed

* Corresponding author.
** Corresponding author.
E-mail addresses: agostino.ferrara@unibas.it (A. Ferrara), bayes00@yahoo.it (L. Salvati).

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et al., 2011). Scale mismatches, therefore, often occur as a result of the time-lag between management actions and observable changes in natural capital, and poorly-designed policy and management processes (Cumming et al., 2006). One way to better understand how and why a SES functions and/or changes over time and space is to consider the roles of different capital components, its critical functions, the ecosystem services that it provides, and its spatial and temporal interlinkages.

The concept of 'capitals' is widely used in understanding how human society organizes itself and is particularly useful when considering how a SES is structured and works (Wilson, 2012). Capital is a stock resource, with value embedded within its ability to produce a flow of benefits (Berkes and Folke, 1998). Social, economic and natural capitals, and their constituent components, play a critical role in shaping socioeconomic development pathways and their importance in any given context is likely to change over different spatial and temporal scales of observation (Costanza et al., 1997; Chiesura and de Groot, 2003; Deutsch et al., 2003; Robinson and Lebron, 2010; Roseta-Palma et al., 2010; Imeson, 2012). For the purposes of the research reported here, a theoretical framework was developed using three broad capitals as the basis of analysis to assess SESs exposed to land degradation in the Mediterranean basin (Ferrara et al., 2010; Briassoulis, 2010b, 2014; Wilson, 2012): (i) economic capital, (ii) social/political/institutional/cultural capital and (iii) natural capital (McKinnon, 1973; Bourdieu, 1983; Thampapillai and Uhlin, 1997; Bourdieu, 2008; Dekker and Uslaner, 2001). The interplay between a subset of components of these capitals provides insights into human-environment decision-making processes and pathways, and their impacts on the SES under scrutiny (Wilson, 2014).

The ability of a SES to persist through time, however, should not only be considered as a result of the balance between economic, social and natural resources but also as the result of the effective functioning of the systems that regulate biophysical functions and interactions (MEA, 2005). Conserving ecosystem services and maintaining critical functions (Onaindiaa et al., 2004; MEA, 2005; Chauhan et al., 2010; Liu et al., 2011; Tynsong and Tiwari, 2011) are essential to enable a SES to continue to function well into the future.

Spatial and temporal interdependencies also need to be analysed from the point-of-view of the speed of change in elementary system drivers. To disentangle cause and effect on local and regional processes is a particularly challenging task because they are subject to the effects of processes evolving slowly over time. Changes in a SES are strongly scale- and time-related and are driven by a range of interrelated processes operating at higher and lower spatial scales, and at different speeds - which interact to produce cumulative and sometimes unanticipated impacts (Gunderson and Holling, 2002; McAllister et al., 2006; Leuteritz and Ekbia, 2008; Garmestani et al., 2009).

The critical determinants of socio-ecological system dynamics can be identified through a limited number of 'slow' variables. 'Fast' variables tend to be sensitive to disturbance from short-term events and are, therefore, less useful in characterising the long-term state of the system (Adger et al., 2005; Abidi-Habib and Lawrence, 2007). Stafford-Smith and Reynolds (2002), for example, identify a restricted set of critical variables, focussing on understanding the causes rather than the effects of change in a SES. Within the Dahlem Desertification Paradigm (DDP), Stafford-Smith and Reynolds (2002:409) argue that it is important to '*identify and manage for the small set of slow variables that drive fast variables*' to enable adaptive and responsive policies to be developed at any given (spatial and temporal) scale, and for any given SES. In this paper we, therefore, focus on the dynamics of a complex agro-forest system by identifying the variables that have contributed to the most important changes in the system.

Based on this premise, this study proposes a multi-way statistical approach to identify the key fast and slow variables in a particular SES, to monitor their inter-linkages over time and space, and to identify a set of critical determinants of change as a contribution to understanding resilience in these types of agro-forest systems. Our study analyses changes in a forest and shrubland socio-ecological system (Matera province, southern Italy) over the last 50 years (1960–2010) by assessing the key variables of the system (capital components and critical functions) and their spatio-temporal evolution. The SES analysed here is a representative example of a complex semi-natural environment experiencing increased anthropogenic and biophysical pressures (e.g. Mancino et al., 2014). A multidimensional analysis, which combines dimensions of time and scale, such as the MFA, was chosen over other techniques, such as regression models as our primary objective was to develop a tool to explore complexity through a large set of environmental, social and economic indicators integrated on the same computational platform using geographic information system technologies and multivariate statistics.

The methodology proposed here is open to change/additions in input variables according to the complexity of the context and the availability of indicators at the desired scale and resolution. While our study refers to an agro-forest SES, the choice of variables can be adapted for a SES with different socio-economic characteristics, or at a different spatial scale. Clearly, the selection of critical functions and the focus on specific drivers of change can be tailored to the characteristics of the SES being studied. The methodology proposed here is, therefore, adaptable to context but also to geographical and temporal scale as well as to the resolution of available data. Results of our study may contribute to better supporting the management of complex forest and shrubland socio-ecological systems operating at multiple spatial and temporal scales.

2. Methods

2.1. The study site

The study site, located in Basilicata, southern Italy (Fig. 1), is a functional and integrated forest/shrubland socio-ecological system with the characteristics of many Mediterranean areas, including severe climate and spatially variable environmental and socioeconomic conditions. It is bounded by the administrative limits of Matera prefecture, and covers an area of 3434 km^2, administered by 31 municipal councils (Fig. 1). Municipal boundaries were chosen as the relevant spatial unit of analysis to achieve full integration between environmental and socioeconomic indicators at an appropriately detailed geographical scale. Municipalities in the study area are also representative of local (mainly rural) communities with distinct social traits and economic structures.

The main socio-ecological characteristics of the system are severe climatic conditions with long, dry periods and high temperatures during summer, associated with decreasing average annual rainfall over recent decades that has negatively impacted the ecophysiological efficiency of the forests and their phytosanitary status, leading in most cases to a decline in productivity. Productivity decline is also coupled with the high frequency of forest fires, which mainly affect macchia and pine plantations, and overgrazing which causes negative impacts on vegetation growth. From a geomorphological point of view, the area includes a wide plain with a flat coastal strip, and a wide alluvial plain derived from fluvial deposits. Moving inland there are a series of hills formed by extensive deep sea deposits of blue-grey clay, where the steepest slopes are characterized by linear forms of erosion, called 'Calanchi badlands', and typical forms of accelerated erosion are seen in the Apennines which are strongly affected by erosion and landslides.