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

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Dear John L Innes

We resubmit our revised paper entitled 'Shaping the role of 'fast' and 'slow' drivers of change in forest-shrubland socio-ecological systems' for the eventual publication on JEMA.

We carefully checked the references and made all necessary changes as requested by the reviewer.

Best regards

Agostino Ferrara

***Response to Reviewers**

Response to the reviewers' comments

Reviewer #2: The paper is greatly improved and I suggest it for publication. However, Author(s) should check some references because there are sometime some errors.

Thank you for the positive comment. We carefully checked the references and made all necessary changes.

*Highlights (for review)
Click here to view linked References

- We examined the role of fast and slow variables in forest-shrubland socio-ecological systems (SES);
- We applied a specific statistical approach based on multiway factor analysis to monitor the evolution of their interlinkages over time and space;
- A small set of critical determinants of changes in a representative SES was identified;
- We contribute to better supporting the management of complex forest and shrubland socio-ecological systems operating at multiple spatial and temporal scales.

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

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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.

Keywords: capitals; fast variables; forest; shrubland; slow variables; socio-ecological systems

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 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, focusing 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.

Matera Prefecture is affected by isolation, due to a poorly developed infrastructure network (both road and rail), which significantly hampers socio-economic development in the area. These factors, together with a lack of employment opportunities due to few industries other than agriculture, have led to a generally negative demographic trend with direct consequences on the age structure of the rural population, causing a gradual shift of individuals from younger age classes away from the area, leaving communities dominated by elderly and economically inactive individuals. Depopulation is more pronounced in the innermost area of the study site where demographic decline is related to lack of development opportunities due to a lack of a culture of enterprise (Kelly et al., 2015), climate and topography. Population has decreased in almost all municipalities in Matera Prefecture over the last fifty years with the exception of the town of Matera and some of the coastal municipalities, which benefit from tourism activities and therefore attract young people for work.

2.2. Data and variables

2.2.1. Assessing capitals

The three capitals used in this study are: natural capital, social capital and economic capital. Wilson (2012) draws on definitions developed by Costanza et al. (1997) amongst others to conceptualise natural capital as the availability of natural resources for human consumption. The components of natural capital also play a critical role in shaping socioeconomic development pathways (Chiesura and de Groot, 2003; Deutsch et al., 2003; Robinson and Lebron, 2010; Roseta-Palma et al., 2010; Imeson, 2012). In forests and shrubland environments natural capitals sustain, over time, the production of goods and services with particular regard to the natural and semi-natural components of the system (Pearce and Turner, 1990; Daily, 1997; De Groot et al., 2003; Azqueta and Soltelsek, 2007; Maass et al., 2005). The key components of natural capital used in this study are: climate, soil, water and vegetation. Single variables or composite indexes were used as proxies to estimate the amount and change over time in the components of the three capitals. The list of capital components and the related variables used in the analysis are shown in Table 1. Note that this list is tailored to the characteristic of this specific SES, its territorial dimension, the data availability and the illustrative purposes of the approach. A complete reference for variable use and selection can be found in Briassoulis (2015).

Economic capital is the key foundation of the financial and economic well-being of a society. In its broadest sense, economic capital refers not only to forms of mercantile transactions but also to the human attributes and actions associated with the use and generation of monetary capital (McKinnon, 1973; Bourdieu, 1983; Thampapillai and Uhlin, 1997; Bourdieu, 2008; Wilson, 2012). The key components of economic capital used in this study are: produced capital (value of the products and services produced in an area), financial capital (financial resources available that can be used for investments and consumption in an area), landesque capital (investments on the land to improve its productivity such as fire belts, etc.), physical capital (value of goods), technology (tools, machines, techniques or methods of organization) and plant and animal capital (i.e. species used for production).

Social capital is arguably the most complex set of 'capitals' under investigation and does not always lend it itself easily to quantification (Wilson, 2012). Most authors agree that social capital includes complex social and political processes, institutions, regulations and cultural factors, but also includes more 'fuzzy' ingredients such as the strength of human networks, the quality of communication between stakeholders or the role played by key individuals within a community (Ostrom, 1990; Berkes and Folke, 1998; Adger, 2000; Bryant, 2005; Parnwell, 2007; Cutter et al., 2008; Bunce et al., 2009; Wilson, 2012). Approaches such as the MFA demand quantitative data and it is not possible to define social capital in terms of quantitative data alone. This is a key limitation of this approach. However, it is important to note that the use of the MFA is proposed here as a tool to identify the most influential variables acting on the SES as a whole over a specific period of time, not to explain them *a priori*. As we highlight in the discussion, once identified, the role of these variables in driving change can then be unpacked, using a range of quantitative and qualitative data, to find explanations for their impact on the SES. The key components of social capital used in this study are: demographic (the structural population features of a socio-ecological system), human (the skills and knowledge available in a society), cultural (society's historical memory and experience, arts and traditions, ideological standpoints, habits and values), social (connectedness, trust, reciprocity and exchanges) and institutional (governance, organisational ability, institutions, trust in institutions and processes). Not all of these processes can be fully quantified, but proxy indicators have been used in previous studies that suggest that a relative weighting or numerical value can be assigned to some of these 'softer' social capital components (see in particular Cumming et al., 2005; Resilience Alliance, 2007; Cutter et al., 2008; Wilson, 2012, 2014).

2.2.2. Assessing critical functions

Natural, social and economic capitals can be considered as a stock of resources as well as components and products of the critical functions of socio-ecological systems which lead to ecosystem services that are of benefit to human society. In managing critical functions, human actions should, therefore, take into account their finite nature and ensure that the stocks of capitals that supply them are able to continue supporting a flow of ecosystem services into the future. The critical functions in forest and shrubland SES considered in this study include: (i) primary production, assessed through the spatial version of the process-based model 3-PGS (Coops and Waring 2001; Coops et al., 2005; Nolè et al., 2009, 2013); (ii) regulation of hydrological process, defined using the PESERA soil erosion model (Kirkby et al., 2004; Irvine and Kosmas, 2004) aimed at assessing surface rain water runoff rates under different environmental conditions, seen as the main component for assessing regulation of hydrological processes in a region; and (iii) biodiversity support and conservation, defined using spatio-temporal changes in the number and surface area of protected land related to political and institutional desires to support the critical function of biodiversity conservation (Onaindiaa et al., 2004; Luque and Vainikainen, 2008; Liu et al., 2011; Tynsong and Tiwari, 2011) and the Naturality Index as a summary measure of species richness, distribution and quality of natural and semi-natural environments (Costantini et al., 2006). The list of critical functions used in the analyses of this specific SES is shown in Table 1.

2.3. Multiway Factor Analysis

In order to explore diachronically the complex, non-linear and multidimensional relationship between capitals, critical functions and socio-ecological functions, a multivariate framework (MFA) was applied to a matrix composed of variables used to define capitals and critical functions on a municipal scale, separately for the three base years of study (1960, 1990 and 2010), thus obtaining two time periods for analysis (1960-1990 and 1990-2010). A multidimensional analysis working together with time and scale dimensions, such as the MFA, was preferred to other widely used techniques such as regression models, since our primary objective was to present a tool to explore SES complexity described 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 time scale and the spatial scale (local municipalities) selected in this study reflect the main issue of the paper.

The MFA is a generalization of Principal Component Analysis (PCA), the goal of which is to explore variables collected on the same set of observations and is based on ultra-metric distance (Duran and Odell, 1974). The general objectives of MFA are: (i) to analyse diachronically the relationship between different data sets; (ii) to combine these into a common matrix called 'compromise' which is then analysed via PCA to reveal the common structure between observations and finally; (iii) to project each of the original data sets into the compromise to analyse commonalities and discrepancies (Salvati and Sabbi, 2011). The weights used to compute the compromise matrix are chosen to make it representative of all possible data sets. The MFA allows us on the one hand, to evaluate if the position of observations (for example natural capital components and critical functions) is stable or changing (more or less rapidly) over time, and on the other hand it describes the conjoint path of capital components (and critical functions) and municipalities.

In other words, the analysis provides a tool to evaluate directly the net amount of change of each variable (by comparing each of them on the same plane and with the same metric) and also allows us to identify, indirectly, the rate and direction of change. This is possible by analysing changes over time in the loadings along each component. Based on the correlation of each indicator to the selected components, it is possible to identify the key variables associated with each component and thus label each component accordingly. MFA components, thus, identify a few relevant dimensions of analysis selected from a large set of input variables. Changes in loadings observed along the components may indicate the direction of change of each variable along these dimensions. This information is derived from the analysis of the MFA integrated output. The simplicity of carrying out the analysis and the existence of relevant information for local stakeholders and practitioners enabled us to use this methodology.

The MFA allows for a normalized geometrical representation of factor loadings and scores over time and space. Changes in the input variables are considered net changes along the relevant components extracted, since the analysis removed the effect of partial correlation with the other variables. This also provides indirect but relevant information on patterns of change (of both variables and spatial units) over time by using different time periods considered as characteristic 'states' of the system. The selection of time periods representative of different environmental and socio-economic 'states' of the SES completes the rationale for the analyses.

Changes in the capital components were described by projecting them into the same factorial plane formed by the MFA axes, selected according to their eigenvalues. Factors with absolute eigenvalue > 3 have been selected as significant multivariate analysis dimensions (Coppi and Bolasco 1989). Points (such as natural capitals and critical functions) with similar location in the Principal Component plane indicate a strong spatial relation (Lavit et al., 1994). The MFA was applied to the variables reported in Table 1 and the dataset was standardized prior to statistical analysis. Finally, the MFA was used to identify slow and fast variables according to the proposed framework. The relationship between trends in variables was analysed using factor loading and score plots. Arrows were used to connect the position of each variable over time. The length of each arrow was considered a valuable proxy for more rapid changes in the single variable analysed from a multivariate point of view (Salvati, 2014).

3. Results

The percentage of explained variance for the first MFA axis amounts to 20.7% of the total variance for the year 1960 (the start of the first of the two study periods). The second factor explained 12.2% of the total variance. Variable loadings on the selected factors by year are reported in Table 2. Starting from the data shown in Table 2, the position of each variable in the factorial plane can be plotted and changes assessed over time and space. Factors 1 and 2 are illustrated together in Figs 2 and 3 respectively for the two periods examined (1960-1990 and 1990-2010). As can be seen in Table 2 and in Figs 2 and 3, environmental capital (as an average of the vector length of the variables belonging to each theme) shows the slowest change in the factorial plane for both time periods (0.65 for 1960-1990 and 0.47 for 1990-2010). Social capital shows the fastest change in the first period (1.33 for 1960-1990 and 1.02 for 1990-2010) while economic capital is fast yet stable between the two time periods (1.06 and 1.04 respectively), though with significant variations in individual variables. With regards to critical functions, a substantial increase was found for biodiversity support and conservation. The increase in primary production of forests corroborates evidence in previous studies (Mancino et al., 2014). In contrast, changes in regulation of hydrological processes are relatively stable over time.

Monitoring actions are needed when managing critical functions with high spatial variability, such as regulation of hydrological processes, and based on differentiated factors, such as soil erosion in areas prone to degradation and land abandonment in Calanchi badlands, which in part is counterbalanced by natural re-colonization or the effects of forest areas on water quality (Mancino et al., 2009, 2014). This aspect is indirectly confirmed by the different pattern of the variables +Soil-ES-F and +Water-CS-F in Figs 2 and 3, both of which indicate improvement in soil protection and water content of forest soils. By comparing the two study periods (1960-1990, 1990-2010) it is also possible to show the shift over time in each variable using arrow length (Fig. 4). As Figs 2, 3 and 4 show, the variables with the greatest variation over time between the two periods are (i) the percentage of farms 5-10 ha (which rapidly changes in the first period and then slows considerably in the second period) and (ii) the density of machinery per farm (showing the reverse trend). Conversely, other variables showed a stable position in the MFA plane, indicating the same levels of variation between periods (especially for road connectivity; the percentage of the population with low levels of education and participation/activity rate).

MFA allows us to determine the position of each municipality in the factorial plain and to correlate that position with changes in the variables describing the complexity of the system. Factor loadings for the municipalities in the study site are shown in Table 3 and the corresponding position of each municipality in the factorial plain is reported in Fig. 5. By analysing the relative position of variables and municipalities in the factorial plains, it is possible to identify specific groups of municipalities characterised by similarities. These groups clearly reflect the spatial complexity present in the Matera SES, highlighting both the coastal-inland gradient and the urban-rural axis (Fig. 6).

4. Discussion

Comparative analysis of the critical environmental and socio-economic variables that characterise the Matera SES in the time period between 1960 and 2010 highlights a pattern of general stability for most variables. By considering the overarching differences between the three capitals over time and space, natural capital is characterised by slow changes in both time periods, whilst economic and social capital show similar dynamics but with faster changes in some of their components, influenced by rapid positive changes in the quality of life for inhabitants of coastal and urban areas, and by changes in socio-economic components such as education, gender equality and income from tourism. Changes in industrial infrastructure are responsible for variations in economic capital at the municipal scale.

With regard to natural capital components, there is a slight decrease in climate severity. This trend is positively connected to changes in vegetation capital components including forest re-colonization and biodiversity conservation. As expected, the component with the slowest changes in both time intervals was soil capital. Trends in critical functions are positively correlated with changes in climate and vegetation components. In particular, a key role is played by vegetation re-colonization processes, and by changes in the dominant forest typology, impacting on biodiversity and possibly influencing its conservation status. In this sense, recent reductions in the use of forests for timber extraction and agro-forestry have increased the capacity of forests to protect soils.

Economic capital showed a number of changes during the two study periods, in particular linked to the labour market (driven by ongoing decreases in the number of primary sector workers and the increase in the number of tertiary sector workers) due to ongoing urbanization around the main city of Matera. Other important changes during the first time interval included changes in the number of workers in the silviculture and tourism sectors in some municipalities. Relevant changes also occurred in the technological capital component, with overall improvement in the stock of agricultural machinery concurrent with farm modernisation processes in this part of Italy. Farm size also shows an interesting trend over time with increasing differences between coastal and inland areas caused by land abandonment in upland municipalities, particularly apparent during the first time interval. Physical capital was the component that showed the least change together with individual variables such as the number of workers at the municipal scale, and the proportion of workers in the industrial sector.

Changes in social capital components were more evident during the latter time interval. Improvements in the level of education increased rapidly with potentially positive impacts on the ability to respond effectively to changes in other SES components. Changes in the demographic component were also relevant here, in particular uneven internal migration from rural mountain areas to the coast, and to larger towns such as Matera, driven by economic opportunities in the tertiary sector outlined above. Other important processes included population ageing, reaching critical values in some municipalities, and a rapid increase in the proportion of foreign workers in coastal and peri-urban areas. Institutional and cultural components of social capital showed distinct trends in the two study periods. During 1990-2010, institutional capital components underwent significant change with the transfer of statutory responsibilities and institutional competences from central government to the regions. It was during this time that most of the policies related to forest, environment, soil management and water protection were strengthened and implemented more effectively than they had been in the past, which had a substantial impact on many other capital components and, therefore, on the SES as a whole. However, population ageing in the area has counteracted any positive trends in the medium-term.

These findings highlight the contrasting role of the 'control' variables, or variables that humans can manipulate (even indirectly) to produce changes in the socio-ecological system (Walker et al., 2012). Based on this, it is important to note in Fig. 4 the importance of education levels in improving the effectiveness of environmental policy development and implementation and in increasing the quality of land and farm management (increases are seen in the density of agricultural machinery per farm, or in the implementation of Forest Management Plans for municipality forests as reported in Kelly et al., 2015).

With regard to the interlinkages between capitals and critical functions, it is interesting to note how the statistical analysis has shed light on the relationship among the system's components, highlighting how the strong increase in support for biodiversity and conservation (Bio-Nat-ind, Bio-Pielou, Bio-Prot-Areas in Fig. 3 and Table 2) is linked to a similar increase in education levels

(#Perc-H-Sch, #Perc-Elem, #Perc-Out-E, #Perc-Grad). For example, the introduction of Forestry and Environmental Sciences courses by the University of Basilicata led to an increase in the number of locally available skilled graduates, which had significant and positive impacts on several components of the SES, including increases in environmental awareness in general. As previous research in the area has emphasised, indirect positive effects included improvements in the level of environmental management skills and knowledge, which supported improved management of natural capital components, and subsequent improvements in other capital components, in terms of policy implementation, effectiveness and governance at the local scale (see Kelly et al., 2015; Wilson et al., 2015).

By analysing the results in terms of whole system changes (Figs 2, 3 and 4) it is also possible to see how the system has re-organised between the two time intervals, in terms of positive and negative responses to internal and external drivers (Walker et al., 2012). For example, the positive internal increase in education levels is evident (i.e. increase in environmental and ecological awareness which led to an increase in the areas under protection) as is the negative internal impact of population dynamics (i.e. general outmigration and rural outmigration from inland to coastal and urban areas with an associated increase in the elderly index in inland areas, as shown in Figs 4 and 5) or the external influence of the establishment of the University of Basilicata, a public university offering specific tertiary-level courses on the environment, agronomy and forest science (Kelly et al., 2015).

The spatial analysis illustrated in Figs 5 and 6 also shows how the socio-economic structure of the system varies across the area. In both time intervals, demographic changes influenced the characteristics of the SES, reflecting a socio-economic coastal-inland gradient. A special mention should be made regarding the demographic structure of the area, which was dependent not only on natural population growth but also on migration rates including, in recent years, rural-to-urban migration with impacts on south-north migration within Italy. The poor state of transport connections, changes in the percentage of workers in the main sectors of agriculture, industry and services (i.e. the increase of workers in silviculture coupled with a decrease of workers in industry in Fig. 4) together with a strong decrease in population density and growth rate are the variables most correlated with this processes, as the MFA highlights.

5. Conclusions

In socio-ecological systems, speed of change in variables has a significant impact on relationships between variables and shapes other system characteristics such as robustness, diversity, connectedness, flexibility and, ultimately, on the resilience of the whole system (Briassoulis, 2010b; Resilience Alliance, 2011; Walker et al., 2012). The state of the system is the result of socio-economically driven changes in terms of population dynamics and cross scale interactions (i.e. institutional factors, changes in labour markets, educational levels, etc.) that directly and indirectly affect changes in natural capital components and, thus, affect the balance (resilience) of the system (Bennett et al., 2005; Meadows, 2008; Salvati et al. 2013). In addition, feedback mechanisms operating at slower speeds are seen to induce change in the system which lag behind the faster-rate changes, but onto which policy decisions are ultimately overlaid (Walker and Salt, 2006).

The methodology used in this study offers a valuable framework to identify and subsequently interpret some of the most relevant variations observed in complex socio-ecological systems undergoing mixed biophysical and socio-economic changes. By using a representative set of variables integrating natural, economic and social capitals and critical functions, the impact of changes in a complex southern Italian forest system experiencing increasing human pressure was assessed (Walker et al., 2012). It is interesting to note that the proposed methods allow us to identify the role of slow variables (variables that show moderate rates of change, such as soil capital, primary production etc.) as well as variables that undergo slow changes over time albeit at a higher spatial scale (i.e. density of LSU on the total ASA municipal surface area or the activity rate). The proposed framework has also allowed us to identify similarities amongst variables and spatial units (i.e. municipalities) and allowed the ranking of variables used to describe the SES according to their speed of change and impact on the system. In particular, the approach used here has allowed us to examine the role of variables linked to both the natural system (in our case a forest-dominated SES with all its biological and ecological processes) and human systems (i.e. social, economic, political, institutional and governance-related factors at various scales ranging from communities to municipalities). Building on previous SES and resilience studies (e.g. Adger, 2000; Holling, 2001; Walker and Salt, 2006; Cutter et al., 2008; Wilson, 2012; Imeson, 2012), this has allowed us to paint a detailed picture of the multiple interlinked variables that affect a complex SES dominated by multiple stakeholder interests. The originality of this study lies, therefore, in the ability of the proposed approach to identify the main determinants of a socio-ecological system not only in terms of rapidity of change but also in terms of impact on the system undergoing change. Our results also confirm the ability of the framework to identify trends in terms of spatial distribution, and to shed light on the hidden relationships that exist between the temporal and spatial characteristics of the components of the socio-ecological system (Hein, et al., 2006.).

In other words, the novelty of the proposed framework lies in the fact that the assessment of rapidity-to-change, based on the length of MFA vectors, takes into account the multivariate relationship among the system's variables, identifying the net rate of change for the whole system, and the relative impact that single human and natural variables exert on the system itself. Our study is, therefore, a contribution to the quantitative analysis of long-established socio-ecological systems and may be useful for designing more effective and sustainable land management strategies in similarly sensitive areas. The results reported here are in agreement with studies on the complex topography and social geography found in the area and depict a system which is moving towards new equilibrium conditions represented by different capital values which are reflected in a different set of critical functions (Povellato and Ferraretto, 2005; Mancino et al., 2014; Kelly et al., 2015).

The methodology proposed in this study was intended to be flexible to allow it to be tailored to changes in the input indicators based on the complexity of the context evaluated, and the availability of appropriate data. Variable lists can, thus, be enriched according to the intrinsic characteristics of the SES investigated. This methodology can also be adapted to different formulations of SES critical functions. The geographical and temporal scales and spatial resolution of data selected will depend on the typology and data availability of the SES.

Based on the above, we suggest that future studies on socio-ecological systems should integrate qualitative analyses (story lines, narratives, interviews with local stakeholders), with robust quantitative techniques, like the one used in this study, to support a better and more holistic understanding of the complexity of complex socio-ecological systems.

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Table 1. List of the variables with the abbreviation codes.

Variable	Code
Natural capital (light grey in the figures 2 and 3)	
Climate Quality Index, CQI	+CQI
Soil capital, ES	+Soil-ES
Soil capital for the forested areas, ES	+Soil-ES-F
Vegetation Quality Index, VQI	+VQI
Vegetation Quality Index for the forested areas, VQI	+VQI-F
Water content in the soil - Soil moisture ratio, $r\theta$	+Water-CS
Water content in forest soil - Soil moisture ratio for the forested areas, $r\theta$	+Water-CS-F
Social capital (grey in the figures 2 and 3)	
Population density, n/km2	#Pop-Dens
Population growth rate, %	#Pop-Gr-Rate
Dependency ratio	#Dep-Ratio
Elderly index	#Eld-Index
Density of foreign citizenships, n/km^2	#Dens-F-Cit
Percentage of high school graduated, %	#Perc-H-Sch
Percentage of persons with Elementary degree, %	#Perc-Elem
Percentage of out-of-education persons, %	#Perc-Out-E
Percentage of University graduated, %	#Perc-Grad
Density of buildings on the total municipal surface area, n/km^2 †	#Dens-Build
Percentage of dwellings with toilet, % †	#Perc-Dwell
Economic Capital (dark grey in the figures 2 and 3)	
Density of enterprise local unit of production, n/km^2	@Dens-Ent-LU
Density of workers in local unit of production, n/km^2	@Dens-Wo-LU
Density of workers in tourism sector, n_tour/tot_workers	@Dens-Wo-Tour
Density of workers in silviculture sector, n_selv/tot_workers	@Dens-Wo-Silv
Percentage of workers in agriculture, %	@Perc-Wo-Agr
Percentage of workers in the industrial sector, %	@Perc-Wo-Ind
Percentage of workers in services, %	@Perc-Wo-Serv
Activity rate	@Activity-Rate
Occupancy rate	@Occup-Rate
Unemployment rate	@Unemp-Rate
Agricultural Surface Area per farm, km^2	@ASA-Farm
Farms on the total municipality area, n/km^2	@Farms-Mun
Percentage of farms with ASA < 1 ha, %	@Perc-Farm<1
Percentage of farms with ASA 5-10 ha, %	@Perc-Farm-5-10
Percentage of farms with ASA >50 ha, %	@Perc-Farm>50
Density of agricultural machinery per farm, n/n_farms	@Dens-Mac-Farm
Mean distances from neighbor cities, corrected to the quality of maintenance, km	@Road-conn
Density of bovins on the total ASA municipal surface area, n/km2	@Dens-Bov-ASA
Density of LSU on the total ASA municipal surface area, n/km2	@Dens-LSU-ASA
Surface of rural woodlands on the total ASA municipal surface area, km2	@Rural-Wo-ASA
Forest capital index	@Forest-Cap
Critical functions (black in the figures 2 and 3)	
Mean annual forest biomass increment, dry matter, t ha^{-1} year^{-1}	Prim-Prod-F
Regulation of hydrological process on forest areas, runoff on precipitation from Pesera model, %	Reg-Hydr
Naturality index on forest areas, index	Bio-Nat-ind
Pielou Evenness index	Bio-Pielou
Percent of surface of protected areas on the municipality forest surface, %	Bio-Prot-Areas

† As related to the quality of life

Table 2. Factor loadings and vector length for the considered period.

Variables	1960		1990		2010		Vector length	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	1960-1990	1990-2010
+CQI	5.14	-0.43	5.46	-0.76	4.97	-2.08	0.46	1.41
+Soil-ES	4.95	0.62	4.95	0.62	4.95	0.62	0.00	0.00
+Soil-ES-F	4.69	0.19	5.05	-0.20	5.06	-0.25	0.53	0.06
+VQI	2.61	-0.66	2.97	0.00	3.16	-0.05	0.75	0.20
+VQI-F	2.51	-0.68	2.96	0.06	3.14	-0.04	0.87	0.21
+Water-CS	-0.71	-0.35	-2.04	-0.88	-1.52	-1.44	1.44	0.77
+Water-CS-F	-1.21	0.02	-1.67	-0.22	-1.06	-0.04	0.52	0.64
							mean 0.65	*mean 0.47*
#Pop-Dens	0.61	2.53	1.78	2.93	1.93	2.91	1.24	0.15
#Pop-Gr-Rate	1.61	1.68	2.98	1.53	3.60	1.77	1.38	0.66
#Dep-Ratio	-2.49	0.61	-2.90	-1.15	-4.38	-1.08	1.80	1.49
#Eld-Index	-2.94	-2.02	-4.16	-1.02	-4.70	-1.02	1.57	0.54
#Dens-F-Cit	0.24	-0.49	0.49	1.88	1.69	3.40	2.40	1.93
#Perc-H-Sch	1.42	1.00	1.51	1.36	2.70	0.21	0.37	1.65
#Perc-Elem	2.30	-0.17	0.85	-1.00	-2.41	-0.84	1.68	3.27
#Perc-Out-E	-4.59	-1.05	-4.90	-0.73	-4.51	-0.77	0.44	0.39
#Perc-Grad	0.58	0.67	1.01	1.84	0.84	1.15	1.25	0.71
#Dens-Build	0.45	3.33	1.49	3.22	1.59	3.28	1.04	0.11
#Perc-Dwell	0.01	0.64	1.46	0.32	1.64	0.58	1.49	0.31
							mean 1.33	*mean 1.02*
@Dens-Ent-LU	0.20	2.48	1.04	3.08	1.66	2.83	1.04	0.67
@Dens-Wo-LU	1.40	2.55	1.47	2.31	1.66	2.29	0.25	0.19
@Dens-Wo-Tour	-1.73	-1.23	-2.79	1.09	-1.54	2.22	2.54	1.69
@Dens-Wo-Silv	-1.02	0.07	-1.58	-1.02	0.28	1.30	1.22	2.97
@Perc-Wo-Agr	-2.08	0.14	-3.06	0.31	-3.04	1.15	1.00	0.85
@Perc-Wo-Ind	1.37	-2.93	2.21	-3.79	2.50	-3.93	1.20	0.32
@Perc-Wo-Serv	0.91	1.18	1.06	1.66	0.55	0.98	0.50	0.85
@Activity-Rate	0.59	0.08	0.38	1.54	1.80	1.69	1.47	1.43
@Occup-Rate	0.27	0.15	0.89	1.01	0.59	2.47	1.06	1.49
@Unemp-Rate	0.69	-1.06	1.22	-1.31	1.80	-2.20	0.58	1.07
@ASA-Farm	0.29	-3.69	-0.52	-4.14	-0.65	-3.35	0.93	0.80
@Farms-Mun	-0.77	2.34	0.71	3.17	1.21	3.42	1.70	0.56
@Perc-Farm<1	-1.43	0.55	0.71	-0.26	-0.07	-1.29	2.29	1.30
@Perc-Farm-5-10	2.26	0.51	0.75	1.57	0.80	1.66	1.85	0.11
@Perc-Farm>50	0.89	-4.12	0.20	-4.92	0.33	-4.21	1.06	0.73
@Dens-Mac-Farm	1.96	1.60	1.85	1.71	1.22	-2.77	0.16	4.52
@Road-conn	-1.55	0.56	-1.58	0.71	-1.69	0.59	0.14	0.16
@Dens-Bov-ASA	-2.90	2.46	-3.29	2.96	-2.56	3.06	0.63	0.73
@Dens-LSU-ASA	-4.08	1.96	-4.82	2.22	-4.03	2.00	0.78	0.82
@Rural-Wo-ASA	-3.05	0.68	-3.26	-1.32	-3.54	-0.33	2.01	1.03
@Forest-Cap	-1.30	3.18	-0.63	3.41	-1.10	3.19	0.70	0.52
							mean 1.10	*mean 1.09*
Prim-Prod-F	-0.49	-0.76	-0.44	-0.63	-0.14	-0.67	0.14	0.30
Reg-Hydr	-2.67	-3.22	-2.63	-2.94	-2.76	-2.68	0.28	0.29
Bio-Nat-ind	0.35	-0.36	0.38	-1.19	-0.07	-1.37	0.83	0.48
Bio-Pielou	2.01	0.98	1.83	0.12	1.60	-0.19	0.88	0.38
Bio-Prot-Areas	-0.16	-0.10	0.87	0.69	-2.54	0.97	1.30	3.42
							mean 0.69	*mean 0.97*

Table 3. Factor loadings for the considered period.

Municipality	Factor 1	Factor 2
Accettura	-0.58	0.06
Aliano	-0.44	-0.40
Bernalda	0.66	0.36
Calciano	-0.51	0.16
Cirigliano	-0.69	0.00
Colobraro	-0.34	-0.37
Craco	0.20	-0.53
Ferrandina	0.36	-0.56
Garaguso	-0.27	0.00
Gorgoglione	-0.67	0.06
Grassano	0.35	0.17
Grottole	0.52	-0.58
Irsina	0.41	-0.27
Matera	0.50	0.20
Miglionico	0.57	-0.27
Montalbano Jonico	0.52	-0.01
Montescaglioso	0.59	0.12
Nova Siri	0.07	0.51
Oliveto Lucano	-0.70	0.10
Pisticci	0.71	0.09
Policoro	0.36	0.66
Pomarico	0.31	-0.55
Rotondella	-0.23	0.28
Salandra	0.00	-0.57
San Giorgio Lucano	-0.58	0.02
San Mauro Forte	-0.23	-0.50
Scanzano Jonico	0.30	0.58
Stigliano	-0.27	-0.26
Tricarico	-0.29	0.14
Tursi	-0.01	-0.18
Valsinni	-0.49	0.14

Fig. 1. Location of the study site (Matera prefecture, southern Italy)

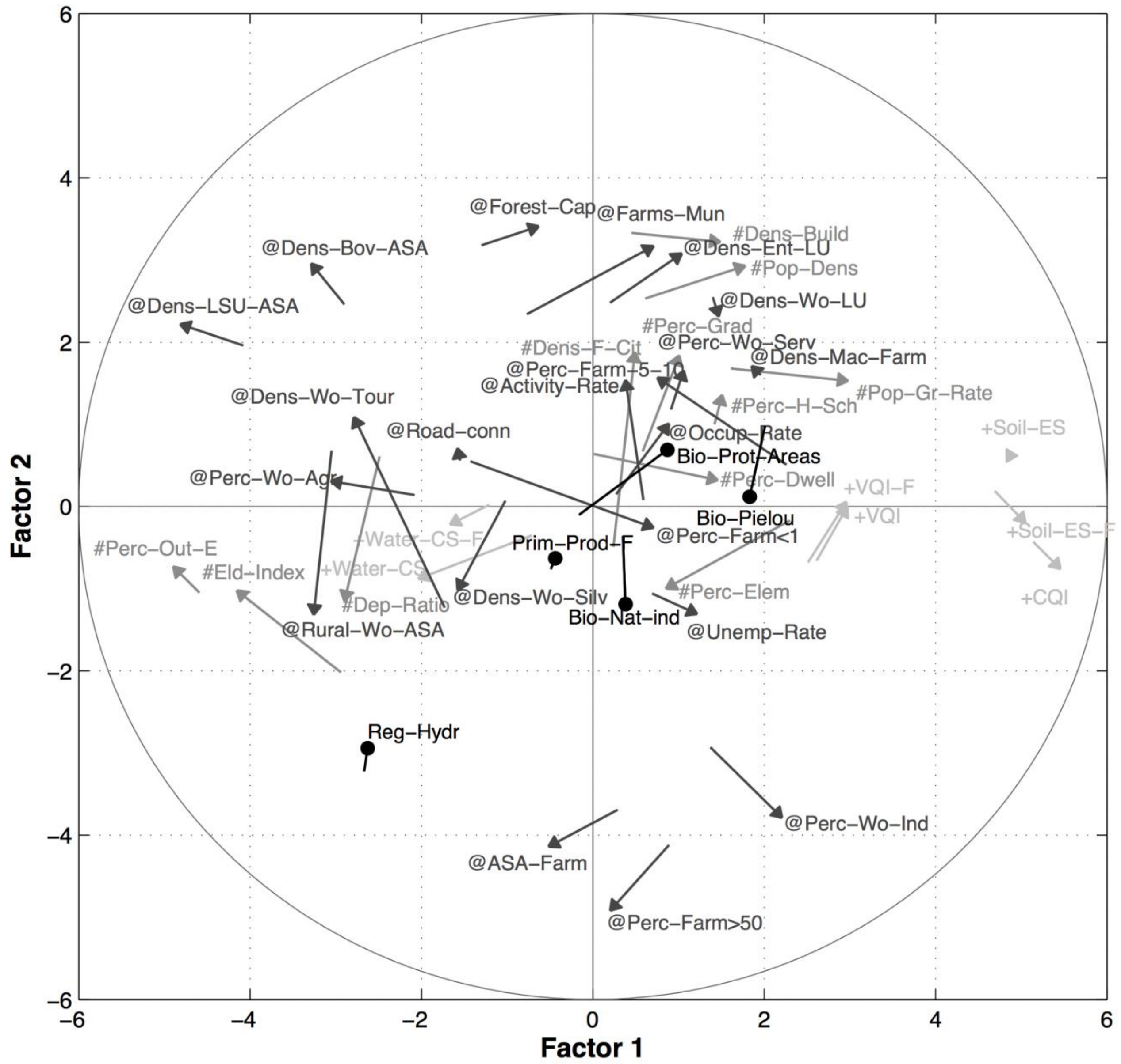

Fig. 2. Factor score plot for the first period (1960-1990). Refer to Table 1 for the codes.

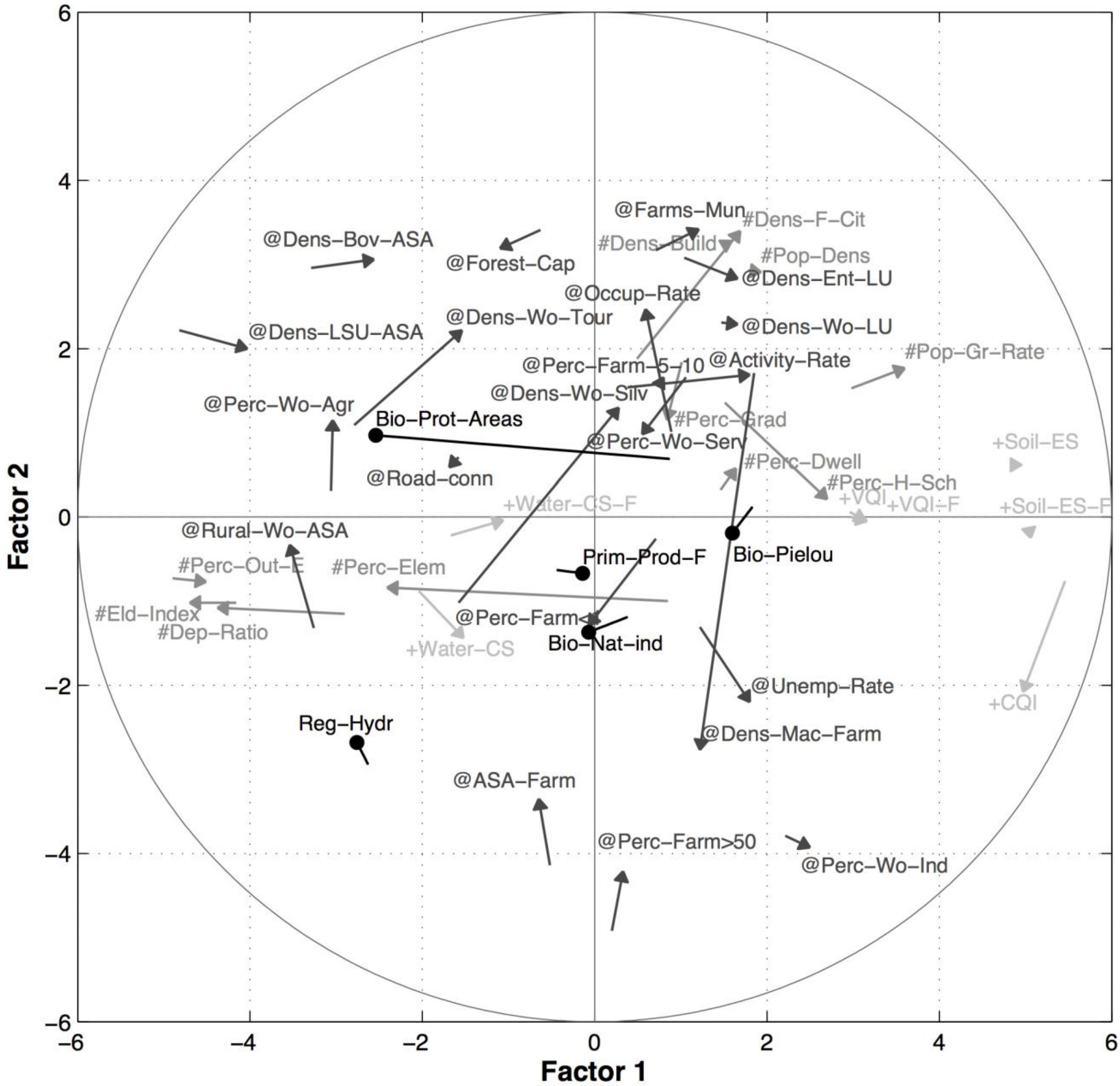

Fig. 3. Factor score plot for the second period (1990-2010). Refer to Table 1 for the codes.

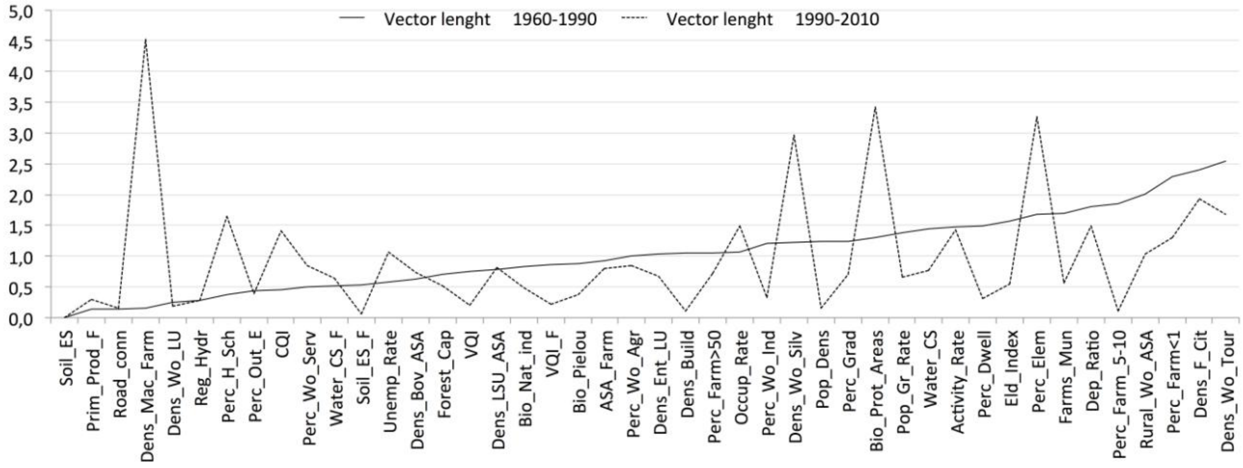

Fig.4. Vector length between two points in the factorial spaces over time of each variable (changes increase with the vector length).

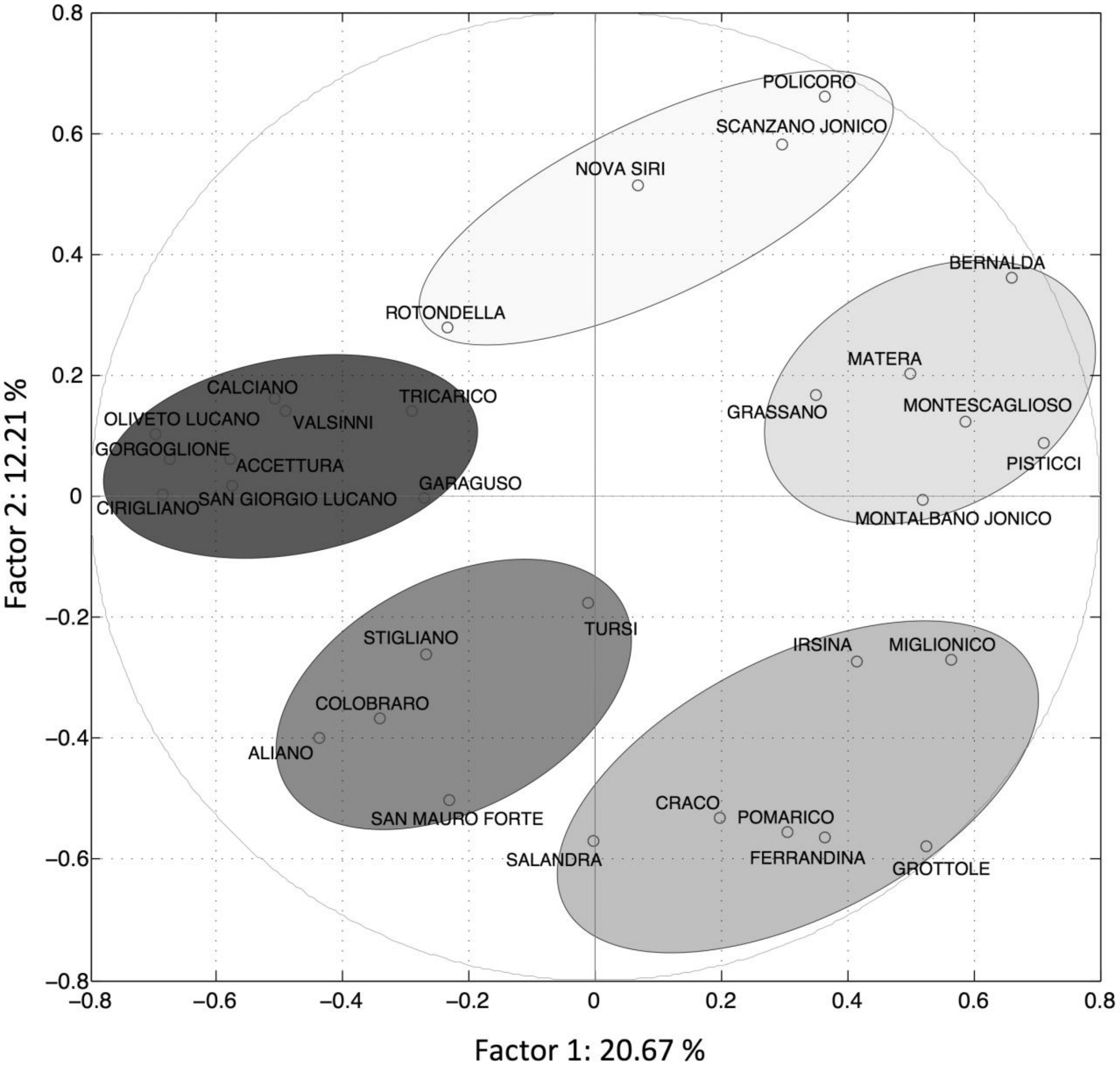

Fig. 5. Factor loading plot (expressing the position of the municipalities in the factorial plain)

Fig. 6. Spatial distribution of the municipality clusters.

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

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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.

Keywords: capitals; fast variables; forest; shrubland; slow variables; socio-ecological systems

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~~3; Glaser et al., 2008~~). 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 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 (~~GLOBE, 2010; ~~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,~~et al.,~~ 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, focusing 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.

Matera Prefecture is affected by isolation, due to a poorly developed infrastructure network (both road and rail), which significantly hampers socio-economic development in the area. These factors, together with a lack of employment opportunities due to few industries other than agriculture, have led to a generally negative demographic trend with direct consequences on the age structure of the rural population, causing a gradual shift of individuals from younger age classes away from the area, leaving communities dominated by elderly and economically inactive individuals. Depopulation is more pronounced in the innermost area of the study site where demographic decline is related to lack of development opportunities due to a lack of a culture of enterprise (Kelly et al., 2015), climate and topography. Population has decreased in almost all municipalities in Matera Prefecture over the last fifty years with the exception of the town of Matera and some of the coastal municipalities, which benefit from tourism activities and therefore attract young people for work.

2.2. Data and variables

2.2.1. Assessing capitals

The three capitals used in this study are: natural capital, social capital and economic capital. Wilson (2012) draws on definitions developed by Costanza et al. (1997) amongst others to conceptualise natural capital as the availability of natural resources for human consumption. The components of natural capital also play a critical role in shaping socioeconomic development pathways (Chiesura and de Groot, 2003; Deutsch et al., 2003; Robinson and Lebron, 2010; Roseta-Palma et al., 2010; Imeson, 2012). In forests and shrubland environments natural capitals sustain, over time, the production of goods and services with particular regard to the natural and semi-natural components of the system (Pearce and Turner, 1990; Daily, 1997; De Groot et al., 2003; Azqueta and Soltelsek, 2007; Maass et al., 2005). The key components of natural capital used in this study are: climate, soil, water and vegetation. Single variables or composite indexes were used as proxies to estimate the amount and change over time in the components of the three capitals. The list of capital components and the related variables used in the analysis are shown in Table 1. Note that this list is tailored to the characteristic of this specific SES, its territorial dimension, the data availability and the illustrative purposes of the approach. A complete reference for variable use and selection can be found in Briassoulis (2015).

Economic capital is the key foundation of the financial and economic well-being of a society. In its broadest sense, economic capital refers not only to forms of mercantile transactions but also to the human attributes and actions associated with the use and generation of monetary capital (McKinnon, 1973; Bourdieu, 1983; Thampapillai and Uhlin, 1997; Bourdieu, 2008; Wilson, 2012). The key components of economic capital used in this study are: produced capital (value of the products and services produced in an area), financial capital (financial resources available that can be used for investments and consumption in an area), landesque capital (investments on the land to improve its productivity such as fire belts, etc.), physical capital (value of goods), technology (tools, machines, techniques or methods of organization) and plant and animal capital (i.e. species used for production).

Social capital is arguably the most complex set of 'capitals' under investigation and does not always lend it itself easily to quantification (Wilson, 2012). Most authors agree that social capital includes complex social and political processes, institutions, regulations and cultural factors, but also includes more 'fuzzy' ingredients such as the strength of human networks, the quality of communication between stakeholders or the role played by key individuals within a community (Ostrom, 1990; Berkes and Folke, 1998; Adger, 2000; Bryant, 2005; Parnwell, 2007; Cutter et al., 2008; Bunce et al., 2009; Wilson, 2012). Approaches such as the MFA demand quantitative data and it is not possible to define social capital in terms of quantitative data alone. This is a key limitation of this approach. However, it is important to note that the use of the MFA is proposed here as a tool to identify the most influential variables acting on the SES as a whole over a specific period of time, not to explain them *a priori*. As we highlight in the discussion, once identified, the role of these variables in driving change can then be unpacked, using a range of quantitative and qualitative data, to find explanations for their impact on the SES. The key components of social capital used in this study are: demographic (the structural population features of a socio-ecological system), human (the skills and knowledge available in a society), cultural (society's historical memory and experience, arts and traditions, ideological standpoints, habits and values), social (connectedness, trust, reciprocity and exchanges) and institutional (governance, organisational ability, institutions, trust in institutions and processes). Not all of these processes can be fully quantified, but proxy indicators have been used in previous studies that suggest that a relative weighting or numerical value can be assigned to some of these 'softer' social capital components (see in particular Cumming et al., 2005; Resilience Alliance, 2007; Cutter et al., 2008; Wilson, 2012, 2014).

2.2.2. Assessing critical functions

Natural, social and economic capitals can be considered as a stock of resources as well as components and products of the critical functions of socio-ecological systems which lead to ecosystem services that are of benefit to human society. In managing critical functions, human actions should, therefore, take into account their finite nature and ensure that the stocks of capitals that supply them are able to continue supporting a flow of ecosystem services into the future. The critical functions in forest and shrubland SES considered in this study include: (i) primary production, assessed through the spatial version of the process-based model 3-PGS (Coops and Waring 2001~~et al., 1998~~; Coops et al., 2005; Nolè et al., 2009, 2013); (ii) regulation of hydrological process, defined using the PESERA soil erosion model (Kirkby et al., 2004; Irvine and Kosmas, 2004) aimed at assessing surface rain water runoff rates under different environmental conditions, seen as the main component for assessing regulation of hydrological processes in a region; and (iii) biodiversity support and conservation, defined using spatio-temporal changes in the number and surface area of protected land related to political and institutional desires to support the critical function of biodiversity conservation (Onaindiaa et al., 2004; Luque and Vainikainen, 2008; Liu et al., 2011; Tynsong and Tiwari~~ et al.~~, 2011) and the Naturality Index as a summary measure of species richness, distribution and quality of natural and semi-natural environments (Costantini et al., 2006). The list of critical functions used in the analyses of this specific SES is shown in Table 1.

2.3. Multiway Factor Analysis

In order to explore diachronically the complex, non-linear and multidimensional relationship between capitals, critical functions and socio-ecological functions, a multivariate framework (MFA) was applied to a matrix composed of variables used to define capitals and critical functions on a municipal scale, separately for the three base years of study (1960, 1990 and 2010), thus obtaining two time periods for analysis (1960-1990 and 1990-2010). A multidimensional analysis working together with time and scale dimensions, such as the MFA, was preferred to other widely used techniques such as regression models, since our primary objective was to present a tool to explore SES complexity described 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 time scale and the spatial scale (local municipalities) selected in this study reflect the main issue of the paper.

The MFA is a generalization of Principal Component Analysis (PCA), the goal of which is to explore variables collected on the same set of observations and is based on ultra-metric distance (Duran and Odell, 1974). The general objectives of MFA are: (i) to analyse diachronically the relationship between different data sets; (ii) to combine these into a common matrix called 'compromise' which is then analysed via PCA to reveal the common structure between observations and finally; (iii) to project each of the original data sets into the compromise to analyse commonalities and discrepancies (Salvati and Sabbi, 2011). The weights used to compute the compromise matrix are chosen to make it representative of all possible data sets. The MFA allows us on the one hand, to evaluate if the position of observations (for example natural capital components and critical functions) is stable or changing (more or less rapidly) over time, and on the other hand it describes the conjoint path of capital components (and critical functions) and municipalities.

In other words, the analysis provides a tool to evaluate directly the net amount of change of each variable (by comparing each of them on the same plane and with the same metric) and also allows us to identify, indirectly, the rate and direction of change. This is possible by analysing changes over time in the loadings along each component. Based on the correlation of each indicator to the selected components, it is possible to identify the key variables associated with each component and thus label each component accordingly. MFA components, thus, identify a few relevant dimensions of analysis selected from a large set of input variables. Changes in loadings observed along the components may indicate the direction of change of each variable along these dimensions. This information is derived from the analysis of the MFA integrated output. The simplicity of carrying out the analysis and the existence of relevant information for local stakeholders and practitioners enabled us to use this methodology.

The MFA allows for a normalized geometrical representation of factor loadings and scores over time and space. Changes in the input variables are considered net changes along the relevant components extracted, since the analysis removed the effect of partial correlation with the other variables. This also provides indirect but relevant information on patterns of change (of both variables and spatial units) over time by using different time periods considered as characteristic 'states' of the system. The selection of time periods representative of different environmental and socio-economic 'states' of the SES completes the rationale for the analyses.

Changes in the capital components were described by projecting them into the same factorial plane formed by the MFA axes, selected according to their eigenvalues. Factors with absolute eigenvalue > 3 have been selected as significant multivariate analysis dimensions (Coppi and Bolasco 1989). Points (such as natural capitals and critical functions) with similar location in the Principal Component plane indicate a strong spatial relation (Lavit et al., 1994). The MFA was applied to the variables reported in Table 1 and the dataset was standardized prior to statistical analysis. Finally, the MFA was used to identify slow and fast variables according to the proposed framework. The relationship between trends in variables was analysed using factor loading and score plots. Arrows were used to connect the position of each variable over time. The length of each arrow was considered a valuable proxy for more rapid changes in the single variable analysed from a multivariate point of view (Salvati, 2014).

3. Results

The percentage of explained variance for the first MFA axis amounts to 20.7% of the total variance for the year 1960 (the start of the first of the two study periods). The second factor explained 12.2% of the total variance. Variable loadings on the selected factors by year are reported in Table 2. Starting from the data shown in Table 2, the position of each variable in the factorial plane can be plotted and changes assessed over time and space. Factors 1 and 2 are illustrated together in Figs 2 and 3 respectively for the two periods examined (1960-1990 and 1990-2010). As can be seen in Table 2 and in Figs 2 and 3, environmental capital (as an average of the vector length of the variables belonging to each theme) shows the slowest change in the factorial plane for both time periods (0.65 for 1960-1990 and 0.47 for 1990-2010). Social capital shows the fastest change in the first period (1.33 for 1960-1990 and 1.02 for 1990-2010) while economic capital is fast yet stable between the two time periods (1.06 and 1.04 respectively), though with significant variations in individual variables. With regards to critical functions, a substantial increase was found for biodiversity support and conservation. The increase in primary production of forests corroborates evidence in previous studies (Mancino et al., 2014). In contrast, changes in regulation of hydrological processes are relatively stable over time.

Monitoring actions are needed when managing critical functions with high spatial variability, such as regulation of hydrological processes, and based on differentiated factors, such as soil erosion in areas prone to degradation and land abandonment in Calanchi badlands, which in part is counterbalanced by natural re-colonization or the effects of forest areas on water quality (Mancino et al., 2009, 2014~~3~~). This aspect is indirectly confirmed by the different pattern of the variables +Soil-ES-F and +Water-CS-F in Figs 2 and 3, both of which indicate improvement in soil protection and water content of forest soils. By comparing the two study periods (1960-1990, 1990-2010) it is also possible to show the shift over time in each variable using arrow length (Fig. 4). As Figs 2, 3 and 4 show, the variables with the greatest variation over time between the two periods are (i) the percentage of farms 5-10 ha (which rapidly changes in the first period and then slows considerably in the second period) and (ii) the density of machinery per farm (showing the reverse trend). Conversely, other variables showed a stable position in the MFA plane, indicating the same levels of variation between periods (especially for road connectivity; the percentage of the population with low levels of education and participation/activity rate).

MFA allows us to determine the position of each municipality in the factorial plain and to correlate that position with changes in the variables describing the complexity of the system. Factor loadings for the municipalities in the study site are shown in Table 3 and the corresponding position of each municipality in the factorial plain is reported in Fig. 5. By analysing the relative position of variables and municipalities in the factorial plains, it is possible to identify specific groups of municipalities characterised by similarities. These groups clearly reflect the spatial complexity present in the Matera SES, highlighting both the coastal-inland gradient and the urban-rural axis (Fig. 6).

4. Discussion

Comparative analysis of the critical environmental and socio-economic variables that characterise the Matera SES in the time period between 1960 and 2010 highlights a pattern of general stability for most variables. By considering the overarching differences between the three capitals over time and space, natural capital is characterised by slow changes in both time periods, whilst economic and social capital show similar dynamics but with faster changes in some of their components, influenced by rapid positive changes in the quality of life for inhabitants of coastal and urban areas, and by changes in socio-economic components such as education, gender equality and income from tourism. Changes in industrial infrastructure are responsible for variations in economic capital at the municipal scale.

With regard to natural capital components, there is a slight decrease in climate severity. This trend is positively connected to changes in vegetation capital components including forest re-colonization and biodiversity conservation. As expected, the component with the slowest changes in both time intervals was soil capital. Trends in critical functions are positively correlated with changes in climate and vegetation components. In particular, a key role is played by vegetation re-colonization processes, and by changes in the dominant forest typology, impacting on biodiversity and possibly influencing its conservation status. In this sense, recent reductions in the use of forests for timber extraction and agro-forestry have increased the capacity of forests to protect soils.

Economic capital showed a number of changes during the two study periods, in particular linked to the labour market (driven by ongoing decreases in the number of primary sector workers and the increase in the number of tertiary sector workers) due to ongoing urbanization around the main city of Matera. Other important changes during the first time interval included changes in the number of workers in the silviculture and tourism sectors in some municipalities. Relevant changes also occurred in the technological capital component, with overall improvement in the stock of agricultural machinery concurrent with farm modernisation processes in this part of Italy. Farm size also shows an interesting trend over time with increasing differences between coastal and inland areas caused by land abandonment in upland municipalities, particularly apparent during the first time interval. Physical capital was the component that showed the least change together with individual variables such as the number of workers at the municipal scale, and the proportion of workers in the industrial sector.

Changes in social capital components were more evident during the latter time interval. Improvements in the level of education increased rapidly with potentially positive impacts on the ability to respond effectively to changes in other SES components. Changes in the demographic component were also relevant here, in particular uneven internal migration from rural mountain areas to the coast, and to larger towns such as Matera, driven by economic opportunities in the tertiary sector outlined above. Other important processes included population ageing, reaching critical values in some municipalities, and a rapid increase in the proportion of foreign workers in coastal and peri-urban areas. Institutional and cultural components of social capital showed distinct trends in the two study periods. During 1990-2010, institutional capital components underwent significant change with the transfer of statutory responsibilities and institutional competences from central government to the regions. It was during this time that most of the policies related to forest, environment, soil management and water protection were strengthened and implemented more effectively than they had been in the past, which had a substantial impact on many other capital components and, therefore, on the SES as a whole. However, population ageing in the area has counteracted any positive trends in the medium-term.

These findings highlight the contrasting role of the ‘control’ variables, or variables that humans can manipulate (even indirectly) to produce changes in the socio-ecological system (Walker et al., 2012). Based on this, it is important to note in Fig. 4 the importance of education levels in improving the effectiveness of environmental policy development and implementation and in increasing the quality of land and farm management (increases are seen in the density of agricultural machinery per farm, or in the implementation of Forest Management Plans for municipality forests as reported in Kelly et al., 2015).

With regard to the interlinkages between capitals and critical functions, it is interesting to note how the statistical analysis has shed light on the relationship among the system's components, highlighting how the strong increase in support for biodiversity and conservation (Bio-Nat-ind, Bio-Pielou, Bio-Prot-Areas in Fig. 3 and Table 2) is linked to a similar increase in education levels

(#Perc-H-Sch, #Perc-Elem, #Perc-Out-E, #Perc-Grad). For example, the introduction of Forestry and Environmental Sciences courses by the University of Basilicata led to an increase in the number of locally available skilled graduates, which had significant and positive impacts on several components of the SES, including increases in environmental awareness in general. As previous research in the area has emphasised, indirect positive effects included improvements in the level of environmental management skills and knowledge, which supported improved management of natural capital components, and subsequent improvements in other capital components, in terms of policy implementation, effectiveness and governance at the local scale (see Kelly et al., 2015; Wilson et al., 2015).

By analysing the results in terms of whole system changes (Figs 2, 3 and 4) it is also possible to see how the system has re-organised between the two time intervals, in terms of positive and negative responses to internal and external drivers (Walker et al., 2012). For example, the positive internal increase in education levels is evident (i.e. increase in environmental and ecological awareness which led to an increase in the areas under protection) as is the negative internal impact of population dynamics (i.e. general outmigration and rural outmigration from inland to coastal and urban areas with an associated increase in the elderly index in inland areas, as shown in Figs 4 and 5) or the external influence of the establishment of the University of Basilicata, a public university offering specific tertiary-level courses on the environment, agronomy and forest science (Kelly et al., 2015).

The spatial analysis illustrated in Figs 5 and 6 also shows how the socio-economic structure of the system varies across the area. In both time intervals, demographic changes influenced the characteristics of the SES, reflecting a socio-economic coastal-inland gradient. A special mention should be made regarding the demographic structure of the area, which was dependent not only on natural population growth but also on migration rates including, in recent years, rural-to-urban migration with impacts on south-north migration within Italy. The poor state of transport connections, changes in the percentage of workers in the main sectors of agriculture, industry and services (i.e. the increase of workers in silviculture coupled with a decrease of workers in industry in Fig. 4) together with a strong decrease in population density and growth rate are the variables most correlated with this processes, as the MFA highlights.

5. Conclusions

In socio-ecological systems, speed of change in variables has a significant impact on relationships between variables and shapes other system characteristics such as robustness, diversity, connectedness, flexibility and, ultimately, on the resilience of the whole system (Briassoulis, 2010b; Resilience Alliance, 2011; Walker et al., 2012). The state of the system is the result of socio-economically driven changes in terms of population dynamics and cross scale interactions (i.e. institutional factors, changes in labour markets, educational levels, etc.) that directly and indirectly affect changes in natural capital components and, thus, affect the balance (resilience) of the system (Bennett et al., 2005; Meadows, 2008; Salvati et al. 2013). In addition, feedback mechanisms operating at slower speeds are seen to induce change in the system which lag behind the faster-rate changes, but onto which policy decisions are ultimately overlaid (Walker and Salt, 2006).

The methodology used in this study offers a valuable framework to identify and subsequently interpret some of the most relevant variations observed in complex socio-ecological systems undergoing mixed biophysical and socio-economic changes. By using a representative set of variables integrating natural, economic and social capitals and critical functions, the impact of changes in a complex southern Italian forest system experiencing increasing human pressure was assessed (Walker et al., 2012). It is interesting to note that the proposed methods allow us to identify the role of slow variables (variables that show moderate rates of change, such as soil capital, primary production etc.) as well as variables that undergo slow changes over time albeit at a higher spatial scale (i.e. density of LSU on the total ASA municipal surface area or the activity rate). The proposed framework has also allowed us to identify similarities amongst variables and spatial units (i.e. municipalities) and allowed the ranking of variables used to describe the SES according to their speed of change and impact on the system. In particular, the approach used here has allowed us to examine the role of variables linked to both the natural system (in our case a forest-dominated SES with all its biological and ecological processes) and human systems (i.e. social, economic, political, institutional and governance-related factors at various scales ranging from communities to municipalities). Building on previous SES and resilience studies (e.g. Adger, 2000; Holling, 2001; Walker and Salt, 2006; Cutter et al., 2008; Wilson, 2012; Imeson, 2012), this has allowed us to paint a detailed picture of the multiple interlinked variables that affect a complex SES dominated by multiple stakeholder interests. The originality of this study lies, therefore, in the ability of the proposed approach to identify the main determinants of a socio-ecological system not only in terms of rapidity of change but also in terms of impact on the system undergoing change. Our results also confirm the ability of the framework to identify trends in terms of spatial distribution, and to shed light on the hidden relationships that exist between the temporal and spatial characteristics of the components of the socio-ecological system (Hein, et al., 2006.).

In other words, the novelty of the proposed framework lies in the fact that the assessment of rapidity-to-change, based on the length of MFA vectors, takes into account the multivariate relationship among the system's variables, identifying the net rate of change for the whole system, and the relative impact that single human and natural variables exert on the system itself. Our study is, therefore, a contribution to the quantitative analysis of long-established socio-ecological systems and may be useful for designing more effective and sustainable land management strategies in similarly sensitive areas. The results reported here are in agreement with studies on the complex topography and social geography found in the area and depict a system which is moving towards new equilibrium conditions represented by different capital values which are reflected in a different set of critical functions (Povellato and Ferraretto, 2005; Mancino et al., 2014; Kelly et al., 2015).

The methodology proposed in this study was intended to be flexible to allow it to be tailored to changes in the input indicators based on the complexity of the context evaluated, and the availability of appropriate data. Variable lists can, thus, be enriched according to the intrinsic characteristics of the SES investigated. This methodology can also be adapted to different formulations of SES critical functions. The geographical and temporal scales and spatial resolution of data selected will depend on the typology and data availability of the SES.

Based on the above, we suggest that future studies on socio-ecological systems should integrate qualitative analyses (story lines, narratives, interviews with local stakeholders), with robust quantitative techniques, like the one used in this study, to support a better and more holistic understanding of the complexity of complex socio-ecological systems.

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Table 1. List of the variables with the abbreviation codes.

Variable	Code
Natural capital (light grey in the figures 2 and 3)	
Climate Quality Index, CQI	+CQI
Soil capital, ES	+Soil-ES
Soil capital for the forested areas, ES	+Soil-ES-F
Vegetation Quality Index, VQI	+VQI
Vegetation Quality Index for the forested areas, VQI	+VQI-F
Water content in the soil - Soil moisture ratio, rθ	+Water-CS
Water content in forest soil - Soil moisture ratio for the forested areas, rθ	+Water-CS-F
Social capital (grey in the figures 2 and 3)	
Population density, n/km2	#Pop-Dens
Population growth rate, %	#Pop-Gr-Rate
Dependency ratio	#Dep-Ratio
Elderly index	#Eld-Index
Density of foreign citizenships, n/km^2	#Dens-F-Cit
Percentage of high school graduated, %	#Perc-H-Sch
Percentage of persons with Elementary degree, %	#Perc-Elem
Percentage of out-of-education persons, %	#Perc-Out-E
Percentage of University graduated, %	#Perc-Grad
Density of buildings on the total municipal surface area, n/km^2 †	#Dens-Build
Percentage of dwellings with toilet, % †	#Perc-Dwell
Economic Capital (dark grey in the figures 2 and 3)	
Density of enterprise local unit of production, n/km^2	@Dens-Ent-LU
Density of workers in local unit of production, n/km^2	@Dens-Wo-LU
Density of workers in tourism sector, n_tour/tot_workers	@Dens-Wo-Tour
Density of workers in silviculture sector, n_selv/tot_workers	@Dens-Wo-Silv
Percentage of workers in agriculture, %	@Perc-Wo-Agr
Percentage of workers in the industrial sector, %	@Perc-Wo-Ind
Percentage of workers in services, %	@Perc-Wo-Serv
Activity rate	@Activity-Rate
Occupancy rate	@Occup-Rate
Unemployment rate	@Unemp-Rate
Agricultural Surface Area per farm, km^2	@ASA-Farm
Farms on the total municipality area, n/km^2	@Farms-Mun
Percentage of farms with ASA < 1 ha, %	@Perc-Farm<1
Percentage of farms with ASA 5-10 ha, %	@Perc-Farm-5-10
Percentage of farms with ASA >50 ha, %	@Perc-Farm>50
Density of agricultural machinery per farm, n/n_farms	@Dens-Mac-Farm
Mean distances from neighbor cities, corrected to the quality of maintenance, km	@Road-conn
Density of bovins on the total ASA municipal surface area, n/km2	@Dens-Bov-ASA
Density of LSU on the total ASA municipal surface area, n/km2	@Dens-LSU-ASA
Surface of rural woodlands on the total ASA municipal surface area, km2	@Rural-Wo-ASA
Forest capital index	@Forest-Cap
Critical functions (black in the figures 2 and 3)	
Mean annual forest biomass increment, dry matter, t ha^{-1} year^{-1}	Prim-Prod-F
Regulation of hydrological process on forest areas, runoff on precipitation from Pesera model, %	Reg-Hydr
Naturality index on forest areas, index	Bio-Nat-ind
Pielou Evenness index	Bio-Pielou
Percent of surface of protected areas on the municipality forest surface, %	Bio-Prot-Areas

† As related to the quality of life

Table 2. Factor loadings and vector length for the considered period.

Variables	1960		1990		2010		Vector length	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	1960-1990	1990-2010
+CQI	5.14	-0.43	5.46	-0.76	4.97	-2.08	0.46	1.41
+Soil-ES	4.95	0.62	4.95	0.62	4.95	0.62	0.00	0.00
+Soil-ES-F	4.69	0.19	5.05	-0.20	5.06	-0.25	0.53	0.06
+VQI	2.61	-0.66	2.97	0.00	3.16	-0.05	0.75	0.20
+VQI-F	2.51	-0.68	2.96	0.06	3.14	-0.04	0.87	0.21
+Water-CS	-0.71	-0.35	-2.04	-0.88	-1.52	-1.44	1.44	0.77
+Water-CS-F	-1.21	0.02	-1.67	-0.22	-1.06	-0.04	0.52	0.64
							mean 0.65	*mean 0.47*
#Pop-Dens	0.61	2.53	1.78	2.93	1.93	2.91	1.24	0.15
#Pop-Gr-Rate	1.61	1.68	2.98	1.53	3.60	1.77	1.38	0.66
#Dep-Ratio	-2.49	0.61	-2.90	-1.15	-4.38	-1.08	1.80	1.49
#Eld-Index	-2.94	-2.02	-4.16	-1.02	-4.70	-1.02	1.57	0.54
#Dens-F-Cit	0.24	-0.49	0.49	1.88	1.69	3.40	2.40	1.93
#Perc-H-Sch	1.42	1.00	1.51	1.36	2.70	0.21	0.37	1.65
#Perc-Elem	2.30	-0.17	0.85	-1.00	-2.41	-0.84	1.68	3.27
#Perc-Out-E	-4.59	-1.05	-4.90	-0.73	-4.51	-0.77	0.44	0.39
#Perc-Grad	0.58	0.67	1.01	1.84	0.84	1.15	1.25	0.71
#Dens-Build	0.45	3.33	1.49	3.22	1.59	3.28	1.04	0.11
#Perc-Dwell	0.01	0.64	1.46	0.32	1.64	0.58	1.49	0.31
							mean 1.33	*mean 1.02*
@Dens-Ent-LU	0.20	2.48	1.04	3.08	1.66	2.83	1.04	0.67
@Dens-Wo-LU	1.40	2.55	1.47	2.31	1.66	2.29	0.25	0.19
@Dens-Wo-Tour	-1.73	-1.23	-2.79	1.09	-1.54	2.22	2.54	1.69
@Dens-Wo-Silv	-1.02	0.07	-1.58	-1.02	0.28	1.30	1.22	2.97
@Perc-Wo-Agr	-2.08	0.14	-3.06	0.31	-3.04	1.15	1.00	0.85
@Perc-Wo-Ind	1.37	-2.93	2.21	-3.79	2.50	-3.93	1.20	0.32
@Perc-Wo-Serv	0.91	1.18	1.06	1.66	0.55	0.98	0.50	0.85
@Activity-Rate	0.59	0.08	0.38	1.54	1.80	1.69	1.47	1.43
@Occup-Rate	0.27	0.15	0.89	1.01	0.59	2.47	1.06	1.49
@Unemp-Rate	0.69	-1.06	1.22	-1.31	1.80	-2.20	0.58	1.07
@ASA-Farm	0.29	-3.69	-0.52	-4.14	-0.65	-3.35	0.93	0.80
@Farms-Mun	-0.77	2.34	0.71	3.17	1.21	3.42	1.70	0.56
@Perc-Farm<1	-1.43	0.55	0.71	-0.26	-0.07	-1.29	2.29	1.30
@Perc-Farm-5-10	2.26	0.51	0.75	1.57	0.80	1.66	1.85	0.11
@Perc-Farm>50	0.89	-4.12	0.20	-4.92	0.33	-4.21	1.06	0.73
@Dens-Mac-Farm	1.96	1.60	1.85	1.71	1.22	-2.77	0.16	4.52
@Road-conn	-1.55	0.56	-1.58	0.71	-1.69	0.59	0.14	0.16
@Dens-Bov-ASA	-2.90	2.46	-3.29	2.96	-2.56	3.06	0.63	0.73
@Dens-LSU-ASA	-4.08	1.96	-4.82	2.22	-4.03	2.00	0.78	0.82
@Rural-Wo-ASA	-3.05	0.68	-3.26	-1.32	-3.54	-0.33	2.01	1.03
@Forest-Cap	-1.30	3.18	-0.63	3.41	-1.10	3.19	0.70	0.52
							mean 1.10	*mean 1.09*
Prim-Prod-F	-0.49	-0.76	-0.44	-0.63	-0.14	-0.67	0.14	0.30
Reg-Hydr	-2.67	-3.22	-2.63	-2.94	-2.76	-2.68	0.28	0.29
Bio-Nat-ind	0.35	-0.36	0.38	-1.19	-0.07	-1.37	0.83	0.48
Bio-Pielou	2.01	0.98	1.83	0.12	1.60	-0.19	0.88	0.38
Bio-Prot-Areas	-0.16	-0.10	0.87	0.69	-2.54	0.97	1.30	3.42
							mean 0.69	*mean 0.97*

Table 3. Factor loadings for the considered period.

Municipality	Factor 1	Factor 2
Accettura	-0.58	0.06
Aliano	-0.44	-0.40
Bernalda	0.66	0.36
Calciano	-0.51	0.16
Cirigliano	-0.69	0.00
Colobraro	-0.34	-0.37
Craco	0.20	-0.53
Ferrandina	0.36	-0.56
Garaguso	-0.27	0.00
Gorgoglione	-0.67	0.06
Grassano	0.35	0.17
Grottole	0.52	-0.58
Irsina	0.41	-0.27
Matera	0.50	0.20
Miglionico	0.57	-0.27
Montalbano Jonico	0.52	-0.01
Montescaglioso	0.59	0.12
Nova Siri	0.07	0.51
Oliveto Lucano	-0.70	0.10
Pisticci	0.71	0.09
Policoro	0.36	0.66
Pomarico	0.31	-0.55
Rotondella	-0.23	0.28
Salandra	0.00	-0.57
San Giorgio Lucano	-0.58	0.02
San Mauro Forte	-0.23	-0.50
Scanzano Jonico	0.30	0.58
Stigliano	-0.27	-0.26
Tricarico	-0.29	0.14
Tursi	-0.01	-0.18
Valsinni	-0.49	0.14

Fig. 1. Location of the study site (Matera prefecture, southern Italy)

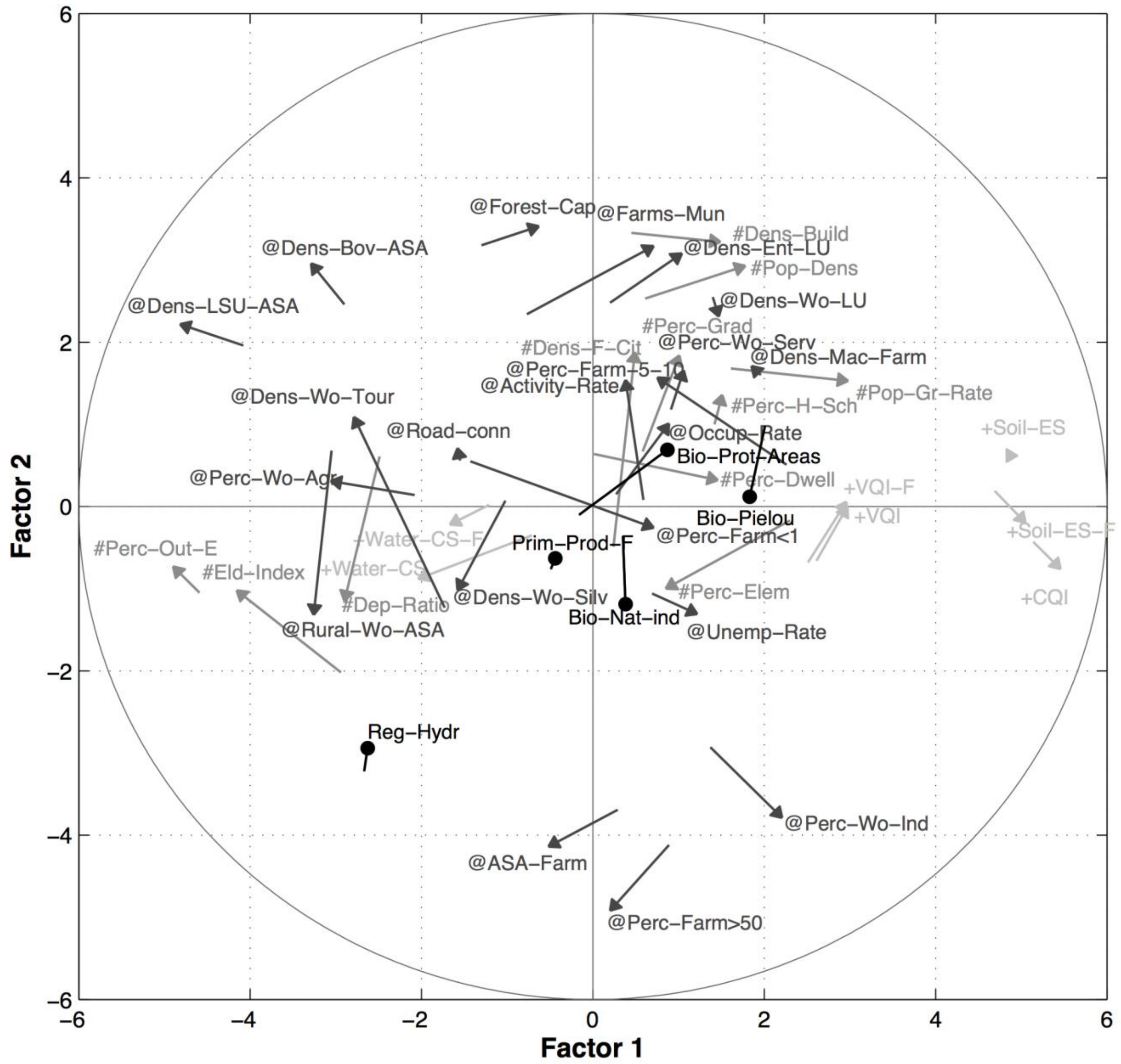

Fig. 2. Factor score plot for the first period (1960-1990). Refer to Table 1 for the codes.

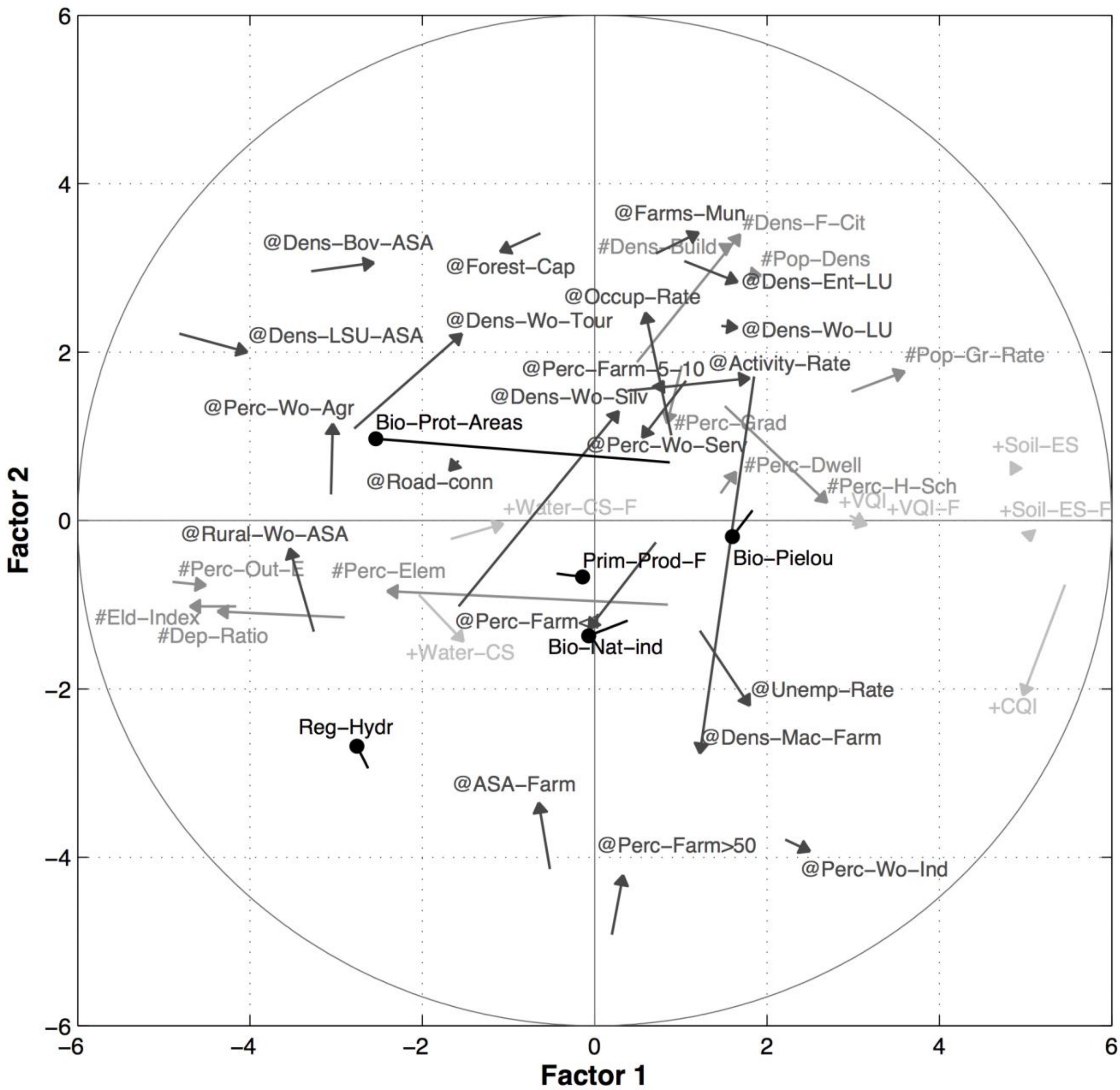

Fig. 3. Factor score plot for the second period (1990-2010). Refer to Table 1 for the codes.

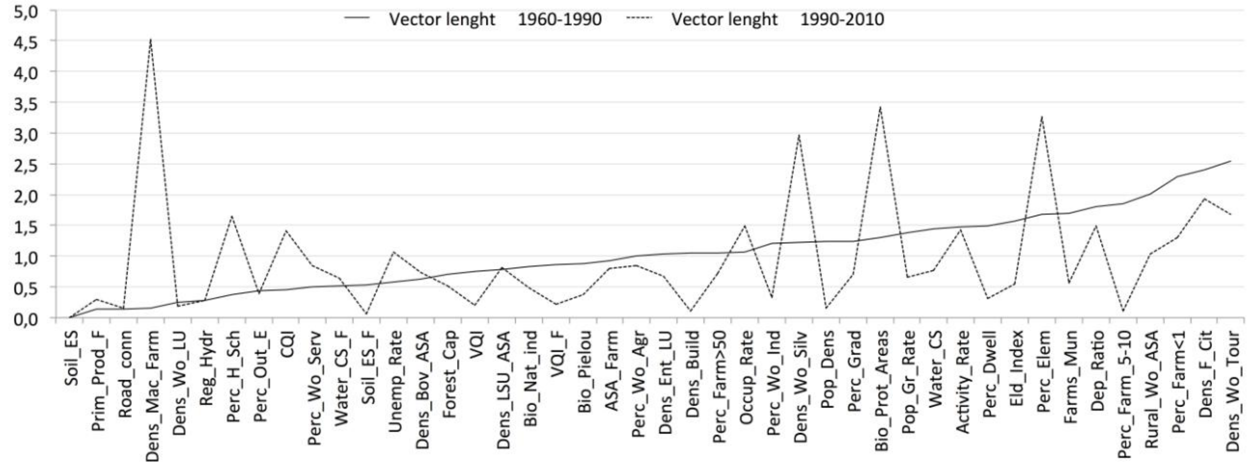

Fig.4. Vector length between two points in the factorial spaces over time of each variable (changes increase with the vector length).

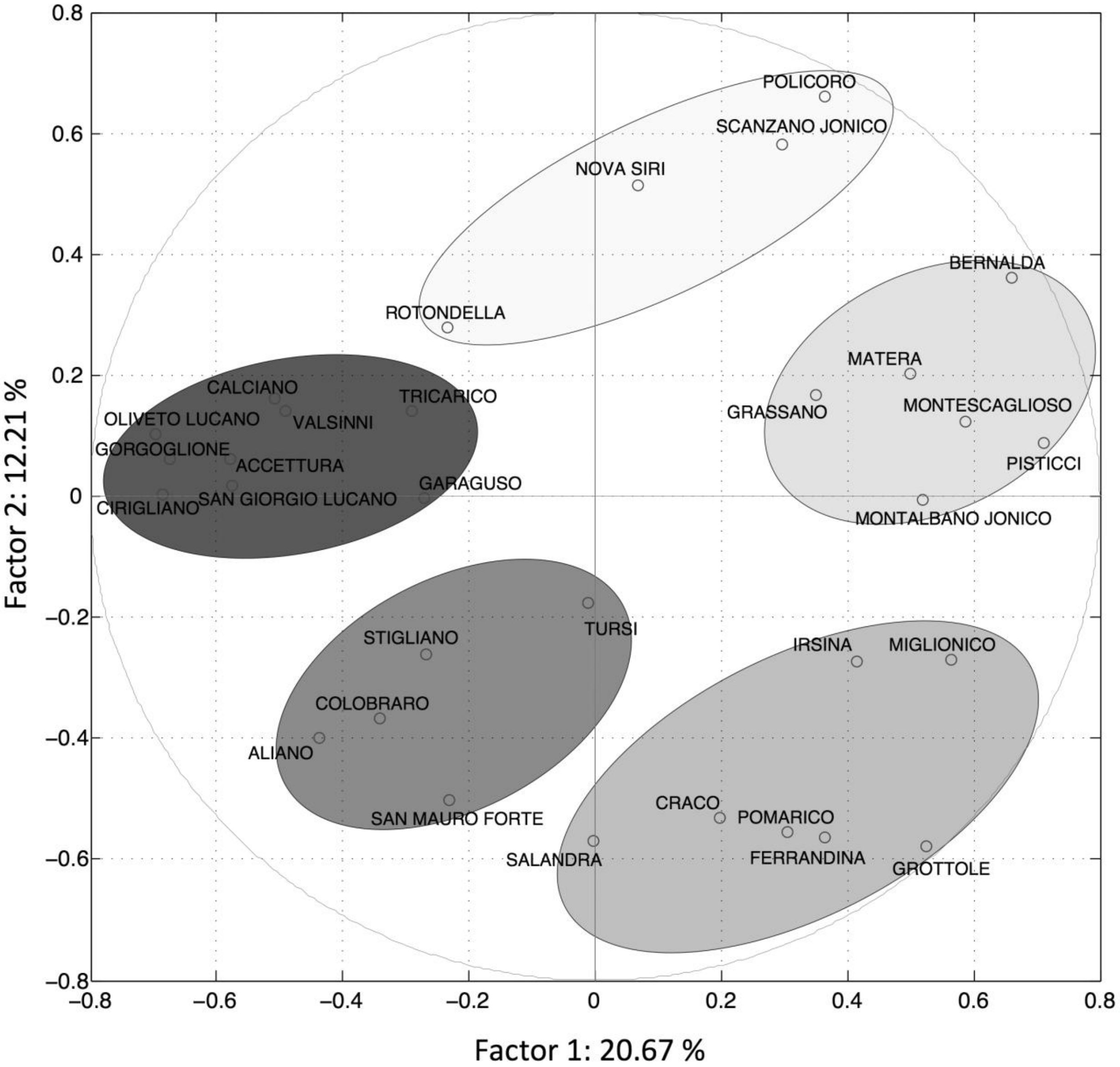

Fig. 5. Factor loading plot (expressing the position of the municipalities in the factorial plain)

Fig. 6. Spatial distribution of the municipality clusters.