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Research

An expert-based reference list of variables for characterizing and monitoring social-ecological systems

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ABSTRACT. The social-ecological system (SES) approach is fundamental for addressing global change challenges and to developing sustainability science. Over the last two decades, much progress has been made in translating this approach from theory to practice, although the knowledge generated is still sparse and difficult to compare. To better understand how SESs function across time, space, and scales, coordinated, long-term SES research and monitoring strategies under a common analytical framework are needed. For this purpose, the collection of standard datasets is a cornerstone, but we are still far from identifying and agreeing on the common core set of variables that should be used. In this study, based on literature reviews, expert workshops, and researcher perceptions collected through online surveys, we developed a reference list of 60 variables for the characterization and monitoring of SESs. The variables were embedded in a conceptual framework structured in 13 dimensions that were distributed throughout the three main components of the SES: the social system, the ecological system, and the interactions between them. In addition, the variables were prioritized according to relevance and consensus criteria identified in the survey responses. Variable relevance was positively correlated with consensus across respondents. This study brings new perspectives to address existing barriers in operationalizing lists of variables in the study of SESs, such as the applicability for place-based research, the capacity to deal with SES complexity, and the feasibility for long-term monitoring of social-ecological dynamics. This study may constitute a preliminary step to identifying essential variables for SESs. It will contribute toward promoting the systematic collection of data around most meaningful aspects of the SESs and to enhancing comparability across place-based research and long-term monitoring of complex SESs, and therefore, the production of generalizable knowledge.

Key Words: *coupled human and natural systems; essential social-ecological variables; essential variables; long-term social-ecological research; LTSER; place-based social-ecological research; social-ecological dimensions; social-ecological interactions; social-ecological monitoring; social-ecological system framework; social-ecological system functioning*

INTRODUCTION

The social-ecological system (SES) approach arose to formally recognize that human and natural systems are intertwined and interact across nested spatial and temporal scales (Berkes et al. 2000, Chapin et al. 2009). Currently, the SES approach is widely acknowledged as crucial for addressing global change challenges (Liu et al. 2007, Resilience Alliance 2007, Carpenter et al. 2009) and as a basis for the development of sustainability science (Ostrom 2009, Leslie et al. 2015). It provides new opportunities to understand and manage critical feedbacks between nature and society, which could lead to better ecosystem health, human well-being and social equity in the distribution of benefits provided by nature (Collins et al. 2011). However, the complex nature of SESs (Levin et al. 2013) and their heterogeneity across the world challenge place-based social-ecological research (Maass et al. 2016, Norström et al. 2017) and the production of generalizable knowledge from these studies.

Over the past two decades, there has been evident progress in moving the SES approach from theory to practice. First, theoretical studies have defined the general characteristics of SESs, explaining their complexity, dynamics, and emergent properties (e.g., Holling 2001, Berkes et al. 2003, Liu et al. 2007, Chapin et al. 2009). Second, conceptual frameworks were developed to operationalize the SES concept for place-based research (e.g., Scholz and Binder 2004, Redman et al. 2004, Chapin et al. 2006, Ostrom 2009). Such frameworks have provided lists of variables and components/dimensions of the SES, including the assumed structural relations between these building blocks, usually supported by a graphical representation (Meyfroidt et al. 2018). Third, the most recent empirical studies have dealt with place-based research through the development of mapping approaches that characterize the diversity of SESs at different spatial scales (e.g., Václavík et al. 2013, Hamann et al. 2015, Martín-López et al. 2017) or that analyze specific types of SESs at the local scale, e.g., such as fisheries, estuaries, and forest systems (Delgado-Serrano and Ramos 2015, Leslie et al. 2015). Although these empirical studies have provided valuable knowledge on SESs in diverse contexts, it is still difficult to compare and extract general insights from them on how SESs perform over time and across spatial scales (Václavík et al. 2016, Magliocca et al. 2018).

Long-term monitoring provides a fundamental basis for understanding the spatiotemporal dynamics of SESs. This has been made explicit in some global research networks, such as the International Long-Term Ecological Research Network (ILTER) and the Program on Ecosystem Change and Society (PECS;

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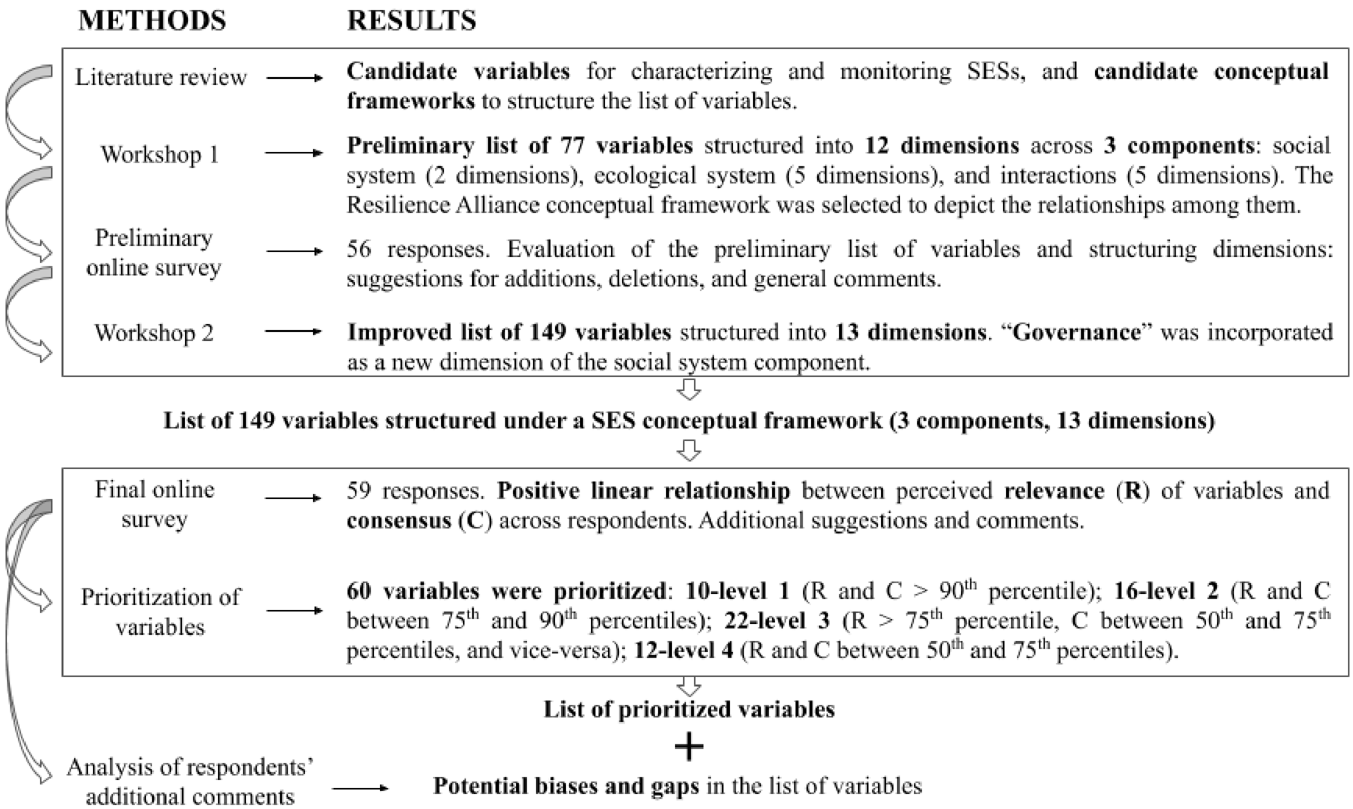
Holzer et al. 2018). ILTER includes long-term social-ecological research (LTSER) platforms based on the conceptual model of the SES (Collins et al. 2011). These networks constitute infrastructures for inter- and transdisciplinary research and data collection that aim to produce knowledge for addressing the complex environmental challenges that emerge from nature-society interactions and to guide sustainability policies (Dick et al. 2018, Mirtl et al. 2018). The main goal of PECS research is the integration of place-based and long-term social-ecological knowledge generated from case studies across the world to better understand social-ecological dynamics (Carpenter et al. 2012, Balvanera et al. 2017, Norström et al. 2017). In addition, the World Network of UNESCO Biosphere Reserves introduced the social-ecological approach into protected area management, as well as the need to monitor changes in the biosphere resulting from human-nature interactions (Holzer et al. 2018). Despite the promising advances in long-term social-ecological monitoring by these networks, one persistent challenge is the harmonization of monitoring protocols to promote cross-site comparability. This would foster more effective interoperability (Vargas et al. 2017) and knowledge generalization from locally driven research initiatives to broader contexts (Dick et al. 2018, Magliocca et al. 2018).

The systematic collection of standard datasets is the cornerstone for enhancing our ability to study the spatial patterns of SESs and their trajectories over time (Holzer et al. 2018). These datasets should be based on a common core set of variables that contribute to fostering a more comprehensive and comparable characterization and monitoring of SESs (Ostrom 2009, Frey 2017). Only a few theoretical studies have dealt with the identification of such common lists of key variables. In this sense, Ostrom (2009) set the most important approach by proposing a list of variables, which were organized in a multilevel nested framework, to understand the sustainability of SESs. Subsequent studies have further developed this list to make it more operational for the empirical study of SESs (e.g., McGinnis and Ostrom 2014, Delgado-Serrano and Ramos 2015, Frey 2017). However, the use of Ostrom's variables in place-based social-ecological research is challenged because of some limitations. For instance, some studies on specific SESs at local scales have reported difficulties in understanding and standardizing the variables and collecting the data (e.g., Basurto et al. 2013, Cox 2014, Delgado-Serrano and Ramos 2015, Leslie et al. 2015). Likely because of these constraints, only a few studies have used this approach for the spatially explicit mapping of SESs (Dressel et al. 2018, Rocha et al. 2020). To overcome these barriers to operationalization, a standard list of variables should be useful in dealing with the diversity of social-ecological contexts (McGinnis and Ostrom 2014, Frey 2017), the complex nature of SESs, and the availability of data (Rocha et al. 2020). Finding a set of variables that meets these requirements will enable the collection of datasets worldwide to enhance place-based research on complex SESs as well as the observation and tracking of long-term trends, encouraging cross-system comparisons.

A promising initiative contributing to the development of core lists of variables to make monitoring of the Earth system comparable across sites is the identification of essential variables (EVs). EVs constitute the minimum set of critical measurements for the study, report, and management of a system and its changes (Reyers et al. 2017, Guerra et al. 2019). Major steps have been taken in the fields of biodiversity (Pereira et al. 2013), climate (Bojinski et al. 2014), and oceans (Constable et al. 2016). However, in transdisciplinary fields, only guidelines have been suggested thus far to identify EVs. Reyers et al. (2017) proposed criteria for the selection of EVs that link socioeconomic and environmental concerns for monitoring sustainable development goals. Guerra et al. (2019) defined a framework for identifying EVs that characterize human-nature dynamics in the context of conservation, and Balvanera et al. (2016) developed a pathway for identifying essential ecosystem service variables. Hence, a widespread consensus on a comprehensive list of EVs for SES monitoring is still lacking, although recent studies have provided valuable insights for identifying relevant variables. For instance, Frey (2017) suggested that in addition to SES sustainability, variables could also inform on other outcomes, such as resilience, social equity, or economic efficiency. Holzer et al. (2018) proposed that indicators collected across LTSER platforms might include qualitative social, political, and economic variables, e.g., sense of place, property ownership, or governance structures, to understand trends in quantitative variables, e.g., population density, ecosystem services, or biodiversity. Additionally, within the LTSER context, Dick et al. (2018) highlighted the importance of collecting social and biophysical data for addressing complex challenges that emerge from nature-society interactions, e.g., climate change, biodiversity loss, or environmental hazards. Additional studies that have developed spatially explicit maps of SESs provide multiple examples of relevant variables from which it is feasible to collect data to characterize SES dynamics (e.g., Alessa et al. 2008, Ellis and Ramankutty 2008, Václavík et al. 2013, Castellarini et al. 2014, Hamann et al. 2015, Martín-López et al. 2017, Vallejos et al. 2020).

In summary, it is crucial to advance toward an established list of relevant and feasible variables for characterizing and monitoring SESs that can be used in science, policy, and management. Developing such a list could foster a long-term coordinated social-ecological monitoring network, allowing the intercomparability of place-based social-ecological research (Redman et al. 2004, Collins et al. 2011, Carpenter et al. 2012, Balvanera et al. 2017) and strengthening the production of generalizable knowledge on SESs across different regions of the world (Frey 2017). To our knowledge, the few integrative lists of SES variables have been built only from Ostrom's (2009) approach, and difficulties have been sometimes reported for their operationalization in empirical research (Delgado-Serrano and Ramos 2015). To progress in the development of a core set of integrative variables, it is important to provide new insights into the fundamental traits to characterize the functioning of SESs, i.e., how the system performs (Jax 2010). For this purpose, it is necessary to compile the variables used in previous studies and to incorporate the assessments of experts working in inter- and transdisciplinary fields (Redman et al. 2004). In this study, we aimed to develop a reference list of prioritized variables for characterizing and monitoring SESs. We provide evidence about the potential most relevant variables based on a comprehensive literature review, an iterative process driven by expert workshops, and researcher perceptions collected through online surveys.

Fig. 1. Workflow. The main methodological steps are identified on the left, and their respective results are on the right. The boxes group together the methodological steps to indicate the two main stages of this study: (1) the development of a list of variables structured under a social-ecological system (SES) conceptual framework and (2) the prioritization of the list of variables.



METHODS

Developing a comprehensive list of social-ecological system variables

The list of variables for characterizing and monitoring SESs was developed in four steps (Fig. 1). First, we performed a literature review to search for candidate variables. We also identified candidate conceptual frameworks to structure the list of variables and to depict the relationships among them. We searched Scopus for journal articles and book chapters with the following terms in their titles, keywords, or abstracts: "soci*-ecological system*" and ("map*" or "framework"). Then, we followed a "snowballing" approach (see van Oudenhoven et al. 2018) to identify additional papers that explicitly developed SES maps, SES conceptual frameworks, or were pivotal for understanding SES functioning (Appendix 1). From this search, we registered all variables and conceptual frameworks that were empirically used or theoretically introduced to characterize SESs. Second, we organized an initial workshop (November 2015) with experts on Earth system dynamics (carbon, water, energy, nutrient cycling) and sustainability science (ecosystem services, transdisciplinarity, translational ecology; see participants in Appendix 2) to develop a preliminary list of variables structured under an integrative conceptual framework. Experts analyzed the candidate variables and selected the most suitable framework. The variables were classified into a nested scheme of three SES components, and there were multiple dimensions within these components. Third, to complete the list of variables and to validate the structure of the dimensions and components, we conducted a preliminary online survey targeted at researchers with experience in SES science (August-December 2016; see acknowledgments). The survey (Appendix 3) introduced the list of variables classified into the dimensions and components and asked respondents to score each variable from 0 to 5 according to its relevance for characterizing and monitoring SESs. Scientists were also encouraged to suggest the addition or deletion of variables and to provide any other comments. These scores, suggestions, and comments were analyzed during a second scientific workshop (January 2017; see participants in Appendix 2) to improve the set of variables and dimensions. We then launched a final online survey (January-May 2017; Appendix 4) that was distributed to a new group of researchers with similar expertise in SES science (see acknowledgments). As in the preliminary survey, they were asked to score each variable from 0 to 5 and to provide comments and suggestions.

Prioritization of social-ecological variables

To prioritize the variables from the improved list, we conducted a "relevance vs. consensus" analysis using the scores from the final survey (Fig. 1) on the importance perceived by experts for each variable for characterizing and monitoring SESs. The relevance was evaluated as the mean of the scores assigned by the experts to each variable. The consensus was estimated as the difference between the maximum standard deviation of the scores found throughout the 149 variables and the standard deviation of the score for each variable (low differences indicated low consensus and high differences, high consensus). Then, the variables were separately ranked according to their percentile for relevance and consensus and grouped into five categories (four levels of priority and one nonpriority). Priority level 1 (top priority) included variables with relevance and consensus above the 90th percentile; level 2 included variables between the 75th and 90th percentiles; level 3 included variables with relevance above the 75th percentile but consensus between the 50th and 75th percentiles and vice versa; and finally, level 4 included variables with relevance and consensus between the 50th and 75th percentiles. The nonpriority category included variables with relevance and consensus below the 50th percentile. Finally, to assess potential biases and gaps in the list of variables, we analyzed the additional suggestions and comments provided by researchers in both surveys (Fig. 1). This analysis was performed by annotating key words and organizing them through generalization in a conceptual map. We identified recurrent key words (addressed five or more times by respondents) as "featured topics."

RESULTS

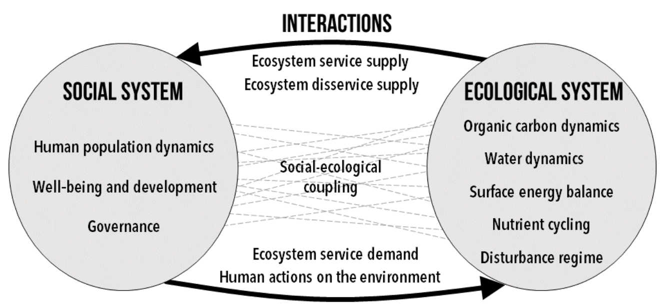
Variables and dimensions to guide the characterization and monitoring of SESs

We developed a list of 149 variables structured in 13 dimensions within the three components of the SESs: the social system, the ecological system, and their interactions (Table A5.1, Appendix 5). We selected the Resilience Alliance conceptual framework (Resilience Alliance 2007) in the first workshop as the most pragmatic and illustrative framework to depict the structural relations among the dimensions and to guide more coordinated SES characterization and monitoring (Fig. 2). In the social system, three dimensions (human population dynamics, well-being and development, and governance) containing 36 variables were identified. In the ecological system, five dimensions (organic carbon dynamics, water dynamics, nutrient cycling, surface energy balance, and disturbance regime) containing 51 variables were identified. In the interactions between nature and people, five dimensions (ecosystem service supply, ecosystem disservice supply, ecosystem service demand, human actions on the environment, and social-ecological coupling) containing 62 variables were identified. The featured topics derived from the researchers' comments in the preliminary online survey that guided the development of the list of variables and dimensions are shown in Fig. A6.1, Appendix 6, as well as in the conceptual map in Appendix 7.

Prioritization of social-ecological variables based on scientist scoring

The analysis of the final survey revealed a significant positive linear relationship (n = 149; r = 0.82; p-value < 0.001) between the average relevance for characterizing and monitoring SESs obtained for each variable and the consensus observed across respondents (Fig. 3). A positive slope lower than one (m = 0.33; p-value < 0.001; root-mean-square error = 0.12) indicated that relevance increased faster than consensus. By applying the prioritization thresholds, 60 variables were considered relevant because they were included at one of the four priority levels (Table 1). Ten variables were included under priority level 1 (highest priority), representing the dimensions of nutrient cycling, disturbance regime (ecological system component), ecosystem service supply, human actions on the environment, and social-ecological coupling (interaction component). Sixteen variables were considered at priority level 2, adding new dimensions such as well-being and development, governance (social system), water dynamics (ecological system), and ecosystem service demand (interaction component). Twenty-two variables constituted priority level 3, incorporating the dimensions human population dynamics (social system), organic carbon dynamics, and surface energy balance (ecological system). Finally, level 4 (lowest priority) added 12 variables, two of them belonging to the dimension of ecosystem disservice supply (interaction component). Thus, the prioritized variables represented all 13 dimensions proposed to characterize SES functioning, though we found it remarkable that no variables in the social system component reached priority level 1, reaching level 2 at the highest. Overall, 25% of the variables assessed for the social system were prioritized, 24% in the ecological system, and 48% for the interaction component. To explore in detail the relevance and consensus obtained for each variable, see Figs. A6.2 to A6.14 in Appendix 6 and Appendix 8.

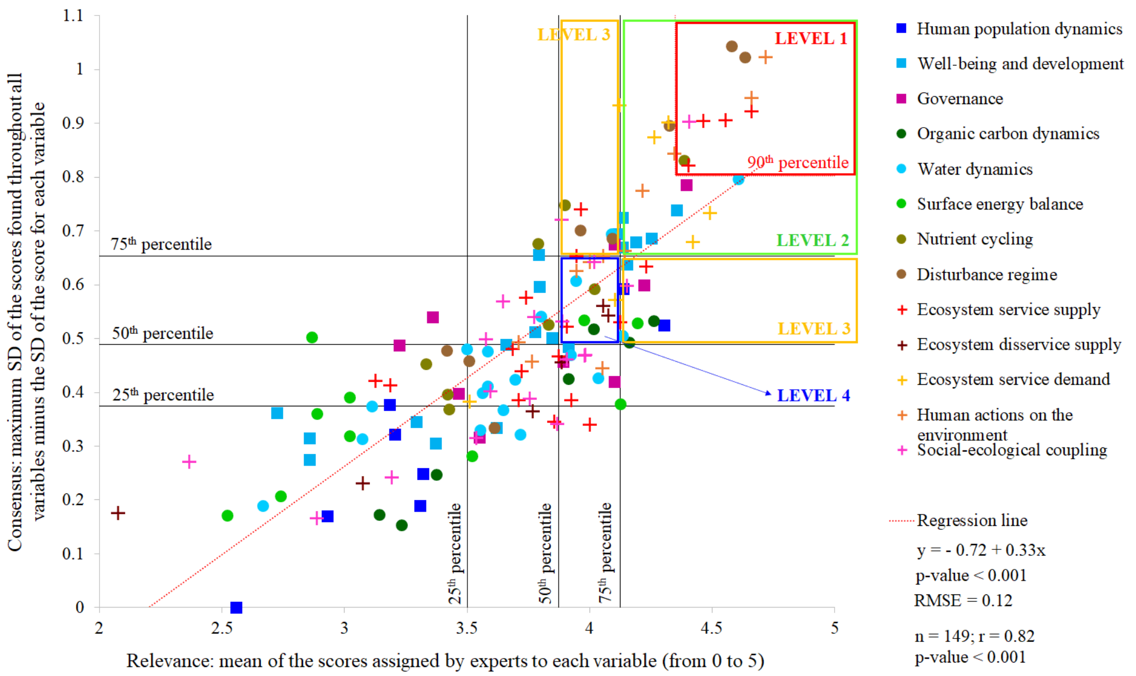
Fig. 2. Conceptual framework to guide the characterization and monitoring of social-ecological systems (SESs). The framework is structured in three components (social system, ecological system, and interactions between them) and 13 dimensions of SES functioning (modified from Resilience Alliance 2007).



Additional comments from the respondents

The analysis of respondents' comments and suggestions in the final survey allowed us to identify 14 featured topics indicating potential biases and gaps in the list of variables (Fig. 4 and Appendix 7). In the social system, several researchers emphasized the importance of "social equity" and "living conditions" to characterize the well-being and development dimension. In the ecological system, "biodiversity" was the most featured topic, which was considered the foundation for explaining the supply of provisioning, regulating, and cultural ecosystem services. Respondents also argued that the water dynamics dimension should be mainly based on the characterization of the "water balance," with some additional variables concerning water and soil salinity and seasonality. Within the interactions, the importance of measuring the "strength of links between people and nature" was the most addressed topic. Within this scope, other related featured topics were "resource consumption patterns," the

Fig. 3. Relevance and consensus obtained by variables for characterizing and monitoring social-ecological systems (SESs) in the final survey. Relevance was evaluated as the mean of the scores assigned by experts to each variable. The consensus was estimated as the difference between the maximum standard deviation of the scores found throughout the 149 variables and the standard deviation of the score for each variable (low differences indicated low consensus and high differences, high consensus). Squares, circles, and plus signs identify the variables belonging to the social system, ecological system, and interaction components, respectively. Horizontal and vertical lines represent the 25th, 50th, 75th, and 90th percentiles of relevance and consensus. Boxes over the grid illustrate the clustering of the variables by priority levels. The red box (priority level 1) includes those variables with relevance and consensus above the 90th percentile; the green box (level 2) includes those variables with both values between the 75th and 90th percentiles; the yellow box (level 3) includes those with relevance above the 75th percentile but consensus between the 50th and 75th percentiles and vice versa; and the blue box (level 4) includes variables with relevance and consensus between the 50th and 75th percentiles. At the bottom right of the figure, the equation of the regression line, the significance of the line slope (p-value) and the root-mean-square error (RMSE) are indicated, as are the number of variables (n), the Pearson's correlation coefficient (r), and its significance (p-value).



"cultural value of nature," "cultural ecosystem service demand," "local ecological knowledge," and the "beneficial human actions on the environment." Other highlighted issues were transversal to the three SES components. Some researchers argued that all "variables should reflect the underlying processes and functions" occurring in SESs, instead of outcomes or symptoms of their functioning. In addition, the need to consider more variables related to "energy fluxes" as indicators of system complexity was also suggested. Finally, researchers also stated that variable relevance might be "context-dependent" and that SES complexity makes it "difficult to assess some variables." An extended version of Fig. 4 with the whole list of topics is available in Fig. A6.15, Appendix 6.

DISCUSSION

With this study, we contributed to the identification of a common core set of relevant variables for the study and monitoring of SESs by providing a reference list of 60 variables, which were structured in 13 dimensions of SES functioning embedded in the social, ecological, and interaction components of the SES (Fig. 2). The use of such a nested framework contributes to understanding the relationships among variables, aims to maintain the holistic approach in the study of SESs, and promotes transdisciplinary communication by acting as a boundary object (Ostrom 2009, Meyfroidt et al. 2018, van Oudenhoven et al. 2018). The variables were classified into four levels of priority according to researcher consensus on their relevance (Fig. 3 and Table 1) to facilitate their adaptation to the data availability, context, and sociopolitical needs. The prioritization revealed the crucial role that social-ecological interactions have in characterizing SES complexity (Liu et al. 2007, Carpenter et al. 2009) but also showed that all the dimensions of social-ecological functioning are necessary to disentangle SES dynamics (Table 1). In general, the development of reference lists of variables is an emerging need in sustainability research to foster the collection of structured, long-term, coordinated core datasets across SESs (Frey 2017, Holzer et al.

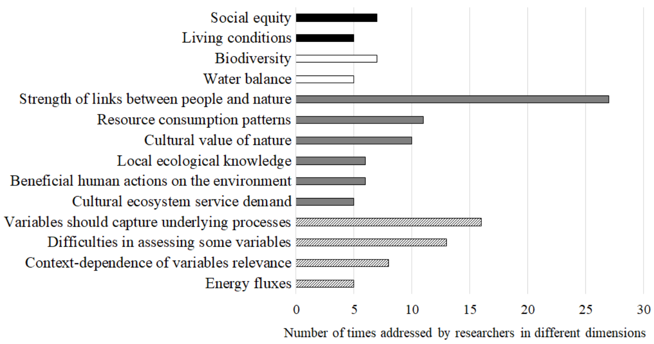
Table 1. List of prioritized variables for characterizing and monitoring social-ecological systems (SESs). The list is structured into 13 dimensions across the three components of a SES (see Fig. 2). Priority level 1 includes variables with relevance and consensus above the 90th percentile; level 2 includes variables with both values between the 75th and 90th percentile; level 3 contains those variables whose relevance was above the 75th percentile and consensus between the 50th and 75th percentiles and vice versa; and finally, level 4 includes those variables with relevance and consensus between the 50th and 75th percentiles. An extended version of this table including the nonpriority variable category, as well as examples and explanations for the variables, is available in Table A5.2, Appendix 5.

Component	Dimension	Priority variables (decreasing priority from 1 to 4)			
		Level 1	Level 2	Level 3	Level 4
Social system	Human population dynamics			• Population density • Population distribution	
	Well-being and development		• Access to drinking water • Educational level • Environmental quality • Poverty • Social equity	• Water sanitation • Water scarcity	
	Governance		• Current conflicts	• Corruption level • Political stability	
Ecological system	Organic carbon dynamics			• Net primary productivity • Organic carbon storage	• Ecosystem composition by plant functional type
	Water dynamics		• Precipitation	• Actual evapotranspiration • Actual water deficit (or excess)	• Soil water infiltration capacity
	Surface energy balance			• Net solar radiation	• Land surface temperature
	Nutrient cycling	• Nitrogen fixation		• Soil phosphorus availability	• Nitrogen deposition
	Disturbance regime	• Drought occurrence • Flood occurrence	• Fire occurrence	• Hurricanes/storms occurrence • Pest outbreaks occurrence	
Interactions	Ecosystem service supply[†1]	• Cropland production (P) • Livestock production (P) • Surface and groundwater sources for drinking (P) • Hydrological cycle and water flow maintenance (R)		• Surface and groundwater sources for nondrinking purposes (P) • Local climate regulation (R) • Pest and disease control (R) • Pollination and seed dispersal (R)	• Chemical conditions maintenance of freshwaters and salt waters (R)
	Ecosystem disservice supply[2]				• Abiotic-economic (e.g., droughts, fires) • Bioeconomic (e.g., biological invasions)
	Ecosystem service demand		• Appropriation of land for agriculture • Energy use level • Water use level • Water use for irrigated crops	• Material use level	• Human appropriation of net primary production (HANPP)
	Human actions on the environment	• Land cover/land use change • Land use intensity	• Eutrophication of water bodies • Land protection • Pollution • Soil erosion	• Anthropogenic water management	• Net CO_2 flux • Territorial connectivity
	Social-ecological coupling	• Local natural capital dependence		• Access to natural and seminatural areas • Biocapacity	• Import/export rates of agricultural products • Renewable energy use

[†]P = provisioning services; R = regulating services
[1]Haines-Young and Potschin (2013), [2] Shackleton et al. (2016) (see Table A5.2, Appendix 5)

2018). This will help to enhance our ability to study SESs over time and across space, enabling cross-system comparisons and the standardization of monitoring protocols.

Fig. 4. Featured topics (addressed by five or more respondents in different dimensions) related to potential biases and gaps in the list of variables identified from comments and suggestions in the final survey. Black, white, and gray bars represent the social system, ecological system, and interaction components, respectively, while striped bars reflect issues that are transversal to the whole conceptual framework. (See also these topics in the conceptual map of Appendix 7).



Insights to address existing barriers in SES research

The list of variables presented in this study offered new perspectives for addressing the main barriers, i.e., applicability to place-based research, representativeness of SES complexity, and feasibility for monitoring, detected in operationalizing existing lists to assess SESs (e.g., Ostrom 2009, McGinnis and Ostrom 2014, Delgado-Serrano and Ramos 2015, Frey 2017). First, regarding their applicability for place-based research, according to van Oudenhoven et al. (2018), variables not only need to be credible, i.e., scientifically sound based on expert judgment, scientific literature, and a conceptual framework, but also practically feasible for collection. For instance, Ostrom's list of variables, which was conceived to diagnose the sustainability of SESs (Ostrom 2009), has sometimes been considered too abstract and general to characterize concrete systems (Cox 2014, Delgado-Serrano and Ramos 2015, Hinkel et al. 2015, Leslie et al. 2015). To overcome such limitations, we emphasized the selection of variables easily derivable from primary data that have been used in previous research for the spatially explicit mapping of SESs (Appendix 1; Table A5.3, Appendix 5). In addition, the list of variables and the conceptual framework must offer certain flexibility to be adapted to the diversity of contexts and scales of analysis and to data availability (McGinnis and Ostrom 2014). The Ostrom SES framework presents a hierarchical structure at different levels (tiers), with variables and subvariables that could be adapted depending on the type of SES (Delgado-Serrano and Ramos 2015) but that lack any guidance on their relevance. In our study, we not only hierarchically structured the variables under the dimensions and components of SESs but also distributed them into priority levels according to their agreed relevance for characterizing SESs. By doing so, we provide guidance for adapting variable selection according to the research context while retaining consistency regarding the relevance and representativeness of variables across SES dimensions.

Second, regarding their representativeness of SES complexity, variables not only need to provide information on the different "pieces" of the system but also must help to understand the linkages among such "pieces" (Ostrom 2009). To achieve this goal, embedding variables within a nested conceptual framework helps to organize them across components and hierarchical levels while depicting the structural relationships between them (Frey 2017, Ostrom 2009, McGinnis and Ostrom 2014). For instance, Ostrom's SES framework uses an anthropocentric perspective of SESs, where variables that are supposed to focus on the ecological subsystem also have a social origin or reflect the interaction between humans and nature (Binder et al. 2013). However, if most variables make sense only if humans exist, it implies that there exists an unbalanced representation among the social, ecological, and interaction variables, which is acknowledged as a key principle for addressing SES complexity (Liu et al. 2007, Resilience Alliance 2007, Reyers et al. 2017). Our proposal provides a scheme that categorizes all variables into 13 expert-validated dimensions embedded into the three key components of a SES, i.e., social system, ecological system, and interactions. The variables for characterizing the ecological system followed an "ecocentric" perspective (sensu Binder et al. 2013) and were structured into five dimensions, where the system and its processes were analyzed independently of their links to humans. For the social system, our variables focused on understanding human population dynamics, well-being and development, and governance dimensions without considering ecological processes. Finally, for the interactions between humans and nature, similar to Ostrom (2009), our variables addressed the reciprocity between the social and ecological systems (Binder et al. 2013). However, we suggested a more detailed structure for the variables, which we divided into five dimensions, depending on the type and direction of the interactions: (a) from the ecological to the social system (ecosystem service and disservice supply), (b) from the social to the ecological system (ecosystem service demand and human actions on the environment), and (c) bidirectionally between the social and the ecological system (social-ecological coupling). We recognize that relying on a single framework might be unrealistic, but understanding and generalizing the complexity of SESs requires common hierarchical analytical structures that comprehensively integrate the multiple dimensions and components of SESs (Reyers et al. 2017, Magliocca et al. 2018, Meyfroidt et al. 2018).

Third, regarding the feasibility of the variables for long-term monitoring (van Oudenhoven et al. 2018), our list facilitates SES characterization at the system level, i.e., it focuses on the macrolevels according to Binder et al. (2013) to integrate properties of the SES components as a whole. Aggregated variables at the system level have been clearly more used to characterize, map, and track SESs than variables collected at the individual level, i.e., variables focused on the microlevels according to Binder et al. (2013) to measure properties of the SES individual building blocks, e.g., plant, animal, individual producer, user, or consumer (see examples in Table A5.3). In fact, even those SES mapping strategies based on Ostrom's framework, which combines both system- and individual-level perspectives, i.e., macro- and microlevels according to Binder et al. (2013), have only used system level metrics (e.g., Dressel et al. 2018, Rocha et al. 2020). Several studies show that system-level characterizations can better inform on social-ecological processes from local to global scales (e.g., Václavík et al. 2013, Martín-López et al. 2017, Levers et al. 2018, Vallejos et al. 2020) and could help to overcome current limitations to upscale place-based research for the coproduction of generalizable knowledge on SES (Balvanera et al. 2017).

Potential biases and gaps in the list of variables

The analysis of the researchers' comments revealed potential conceptual biases introduced by the proposed framework during the construction of the list of variables (Fig. 4). In the interaction component, a majority of comments highlighted that sociocultural values and identities might be underrepresented and that the variables addressing the "strength of the links between people and nature" and the "cultural value of nature" could be enhanced, for instance, by incorporating the variable "local ecological knowledge." However, interestingly, cultural ecosystem service variables (following the categories of the Common International Classification of Ecosystem Services, CICES; Haines-Young and Potschin 2013) were not prioritized by researchers during the survey (Table A5.2, Appendix 5; Appendix 8). Although these findings may seem contradictory, they align with new insights into the nature's contributions to people (NCP) paradigm (Díaz et al. 2018) and the plurality of values associated with these contributions (UNEP 2015, Pascual et al. 2017). Under the new NCP paradigm, culture plays a central role in defining all links between people and nature (Díaz et al. 2018). Thus, further lists of SES variables should expand the ecosystem service supply dimension by giving culture and traditional/indigenous knowledge a more transversal role across ecosystem services categories, beyond the independent cultural category of CICES and the Millennium Assessment (MA 2005). Furthermore, enhancing the characterization of the cultural contexts and identities goes further for the instrumental values of ecosystem services and NCP by incorporating those values that emerge from individual and collective relationships of humans with nature (Chan et al. 2018). To address these "relational values," new variables, such as sense of belonging, responsibility toward nature, or maintenance of traditions (Chan et al. 2016), may be added to the list.

In the ecological system component, the explicit role of biodiversity might also be underrepresented because many comments suggested the addition of more biodiversity variables or of a whole biodiversity dimension within this component. Given the role of biodiversity in SESs as the natural capital that supports social metabolism (Costanza et al. 1997) and the biocentric conservationist tradition (Mace 2014), we agree that biodiversity could be explicitly named in the framework. However, we initially excluded the structural and compositional biodiversity facets because of their slower response to disturbances compared to functional variables (McNaughton et al. 1989, Milchunas and Lauenroth 1995). Instead, we focused on the functional aspects of biodiversity at the ecosystem level, such as the candidates to become essential biodiversity variables for the ecosystem function class (e.g., Pereira et al. 2013, Pettorelli et al. 2018).

We are also aware of additional sources of potential methodological biases. On the one hand, the way that the variables were sorted in our framework during the survey could have influenced respondents in assigning priority levels. By displaying the variables sorted into dimensions, we aimed to facilitate the completion of the survey. We are aware that a random display or other sorting could have led to different variable scores. However, this impact may have been low because there was no significant correlation between the priority scores and variable order in the online survey. On the other hand, because the field of expertise of most respondents was sustainability science and ecology (Appendix 9), the social variables might have received lower scores than expected. Indeed, the social variables never reached the highest priority level (level 1; Table A5.2, Appendix 5) despite their importance for human well-being and for explaining the form and intensity of human-nature interactions, e.g., education and population density, respectively (Ellis and Ramankutty 2008, Hamann et al. 2016). Most inter- and transdisciplinary efforts in social-ecology and sustainability science come from ecology (Lowe et al. 2009, Holzer et al. 2019), but a wide range of perspectives still exist among ecologists for integrating concepts and methods from social science. This disparity of perspectives might be because some researchers consider ecology as a basic science that studies wild nature (where people are only the "ecological audience"), others see it as an instrument for guiding ecosystem and species management (treating people as "ecological agents"), and still others view it as a discipline that considers human societies to be integrated in ecosystems (people as "ecological subjects/objects"; Lowe et al. 2009, Mace 2014). Indeed, these perceptions of ecology have been evidenced throughout the development and implementation of the long-term social-ecological monitoring network, which mainly originated from ecological monitoring and research. Despite the adoption of a new social-ecological paradigm, the network continues to monitor primarily ecological processes, although it is progressing toward incorporating economic and social data and conducting more germane transdisciplinary research (Dick et al. 2018, Angelstam et al. 2019). In our study, the potential coexistence of these three perceptions among the surveyed researchers could be the basis of the lack of consensus around the most relevant social variables. This highlights the need to strengthen cooperation between natural and social scientists and experts to lead to a truly integrated approach for long-term social-ecological research (Dick et al. 2018). Finally, many scientists have reported difficulties in scoring the variables without considering a specific SES, arguing that variable relevance is context dependent. Although biodiversity, climate, oceans, or sustainable development goal variables may have more evident global perspectives, this is not easily applicable to SES variables given the place-based nature of SES research (Carpenter et al. 2012). All these potential biases should be considered when using our list of variables and formally analyzing them in future assessments.

Toward the definition of essential variables for social-ecological systems

The development of essential variables (EVs) that harmonize global observation networks is a priority for tracking changes and coordinating monitoring efforts (e.g., Pereira et al. 2013, Bojinski et al. 2014, Constable et al. 2016). Despite the call from sustainability science to extend this systemic thinking to areas of interaction between the social and the biophysical domains, building a list of essential social-ecological system variables is still needed (Reyers et al. 2017). The set of dimensions and variables developed here can contribute to creating a common structure to study SESs and to starting to work toward such essential variables. Because the variables and dimensions were based on consensual expert knowledge, their credibility, salience, and feasibility were reaffirmed (van Oudenhoven et al. 2018). In addition, fundamental steps in EV development were followed in the codesign process (Reyers et al. 2017): (1) adoption, through an expert-driven process, of a conceptual model of SESs functioning, representing the social and ecological systems as well as the interactions between them; (2) identification of the broad categories and disaggregated inputs of candidate variables; (3) refining and prioritization of variables based on the consensus on their relevance; and all this by means of (4) an iterative procedure fed by scientific expert knowledge obtained from workshops and online surveys. However, given the preliminary nature of our exercise, further work is needed to build a global consensus around a set of EVs for the study of SESs. For instance, new surveys should address the potential biases and limitations outlined above, for instance (1) by explicitly considering the role of biodiversity and of relational values about NCP; (2) by having a greater and more balanced number of respondents (particularly the inclusion of social scientists); and (3) by reporting on the most frequently relevant variables in relation to specific place-based social-ecological contexts.

To further develop EVs for SESs, finding common aspects and variables among the existing lists could also help to establish a baseline. Some variables suggested in Ostrom's (2009) and Frey's (2017) lists were also relevant in our study. The most common aspects were found for the interaction component. For instance, the harvesting variable on Ostrom's list was related to human appropriation of net primary production, material use, water use, or energy use on our list. Similarly, pollution patterns on Ostrom's list were related to eutrophication of water or net CO_2 flux on our list; constructed facilities on Ostrom's list and accessibility on Frey's list were related to territorial connectivity, access to natural areas, or anthropogenic water management on our list; and importance of resources on Ostrom's list and dependency on resources on Frey's list with dependence on local natural capital on our list. In the social system, economic development and socioeconomic attributes (Ostrom 2009) were associated with poverty, educational level, or social equity variables on our list, and number of actors (Ostrom 2009) with population density. Similarly, governance-related variables, such as conflicts and political stability, were included on both Ostrom's list and our list, while Frey (2017) considered conflict management as a crucial aspect for the stability of rule systems and resource use. In the ecological system, Ostrom's (2009), Frey's (2017), and our list converged on including climate characteristics and primary productivity or the regeneration rate of resources.

In addition, some of our prioritized variables from the ecological and interaction components of SESs are related to six of the nine major environmental challenges listed in the planetary boundaries framework (Rockström et al. 2009, Steffen et al. 2015). For instance, the monitoring of net solar radiation and net CO_2 flux could provide information to assess "climate change" and "atmospheric aerosol loading"; information on biological invasions, pest outbreak occurrence, and ecosystem composition by plant functional types to assess "changes in biosphere integrity"; measuring nitrogen deposition and eutrophication of water to evaluate interferences with "biogeochemical flows"; the appropriation of land for agriculture and land use intensity for "land-system change"; and finally, water use level and water use for irrigated crops to assess "freshwater use."

From a general perspective, additional steps should be given to foster the institutionalization of the development and implementation of essential SES variables (see Pereira et al. 2013, Bojinski et al. 2014, Constable et al. 2016, Reyers et al. 2017). As a first step, the compliance of the variables with the criteria to be considered essential should be thoroughly checked, for instance, to be (i) state variables, sensitive for long-term monitoring of changes; (ii) representative for the system level, between primary observations and indicators; (iii) flexible to adapt to multiple monitoring programs; and (iv) feasible to observe and derive and to be scaled to meet local, regional or subglobal needs. Second, consensus should be built and coordinated to align the development of the variable list with research and policy needs by setting an open platform for scientist, policy maker, and stakeholder cooperation. Third, the learning loop should be optimized to refine and stabilize the list of EVs by establishing a transparent process with specific targets and time lines to plan the development of the list and track the updates. Finally, to increase the global efficiency of Earth monitoring systems, the interconnection of the EVs that may emerge from our list with other sets of EVs (for biodiversity, climate, oceans, etc.) should be coordinated.

CONCLUSION

The development of reference lists of variables is an emerging need in sustainability research to foster the systematic collection of comprehensive and coordinated datasets of SESs and to enhance our ability to study SESs across time and space. These lists of variables structured under a conceptual framework provide a common language that facilitates comparisons and the generalization of knowledge from empirical studies. Although the development of such lists in specific fields of Earth systems (climate, biodiversity, oceans) has progressed significantly in recent years, integrative approaches for SESs are still scarce. With this study, we contributed to the identification of a common core set of variables for the characterization and monitoring of SESs. Our 60-variable list gathered relevant traits and processes of the SES from scientific literature reviews and expert knowledge. This list was embedded in a framework of 13 dimensions across the three key components of the SES (social system, ecological system, and the interactions between them) to help maintain an integrative approach when working with SESs. In addition, variables were classified into priority levels to provide more flexibility in their application to place-based research. Throughout this process, new insights have arisen that could contribute to overcoming existing barriers in the operationalization of lists of variables in the study of SESs, such as the applicability to place-based research, the capacity to deal with SES complexity, or the feasibility for long-term monitoring of social-ecological dynamics. Our list of variables may constitute a preliminary step in the direction of identifying essential variables for SESs, whose further development will provide an opportunity to boost the long-term social-ecological research network. This could strengthen our capacity to respond to global change challenges, extend systemic thinking to the field of human-nature interactions, and foster sustainability sciences through more efficient operationalization of the social-ecological approach.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/11676

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Data Availability Statement:

The aggregate data that support the findings of this study are available in the appendices of this paper. The individual responses to the survey conducted in this study are not publicly available because they contain information that could compromise the privacy of research participants.

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Appendix 2. Workshop participants.

List of participants in workshop 1 - *"Capturing the functioning of social-ecological systems"*

Venue: University of Granada (Spain)

Dates: 18th – 20th November 2015

Surname / name	Institution	Area of expertise
Alcaraz-Segura, Domingo	Universidad de Granada (Spain)	Remote sensing, ecosystem ecology, conservation biology
Blanco-Sacristán, Javier	Università degli Studi di Milano-Bicocca (Italy)	Remote sensing, ecosystem functioning
Berbery, Hugo	University of Maryland (USA)	Land surface-atmosphere interactions, climate system, water and energy budgets
Cabello, Javier	Universidad de Almería (Spain)	Sustainability, ecology and conservation, ecosystem functions and services
Castro, Antonio	Universidad de Almería (Spain)	Human-environment relationships, sustainability, social-ecological systems
Epstein, Howard	University of Virginia (USA)	Ecosystem functioning, vegetation dynamics, climate change, carbon cycling, carbon-water interactions, disturbances regime
Fernández, Néstor	German Centre for Integrative Biodiversity Research – iDiv (Germany)	Ecosystem functioning, biodiversity and conservation, ecological modelling, remote sensing
Jobbágy, Esteban	Universidad Nacional de San Luis (Argentina)	Ecosystem ecology, human control of ecosystem processes, ecohydrology

Lourenço, Patricia	Universidade de Évora (Portugal)	Ecosystem functioning, remote sensing, conservation biology
Oyonarte, Cecilio	Universidad de Almería (Spain)	Soil science, geochemistry, carbon dynamics, climate change
Pacheco-Romero, Manuel	Universidad de Almería (Spain)	Social-ecological systems, sustainability
Paruelo, José	Universidad de Buenos Aires (Argentina)	Ecosystem structure and functioning, ecological modelling, remote sensing, ecosystem services
Peñas, Julio	Universidad de Granada (Spain)	Conservation biology, biodiversity, plant ecology, biogeography
Pérez-Cazorla, Beatriz	Universidad de Almería (Spain)	Ecosystem functioning, remote sensing, conservation biology
Requena-Mullor, Juan Miguel	Boise State University (USA)	Ecological modelling, conservation biology, remote sensing
Reyes, Andrés	Universidad de Almería (Spain)	Ecosystem functioning, remote sensing, conservation biology

List of participants in Workshop 2 - *"Towards the identification of Social-Ecological Functional Types"*

Venue: University of Buenos Aires (Argentina)

Dates: 6th - 11th February 2017

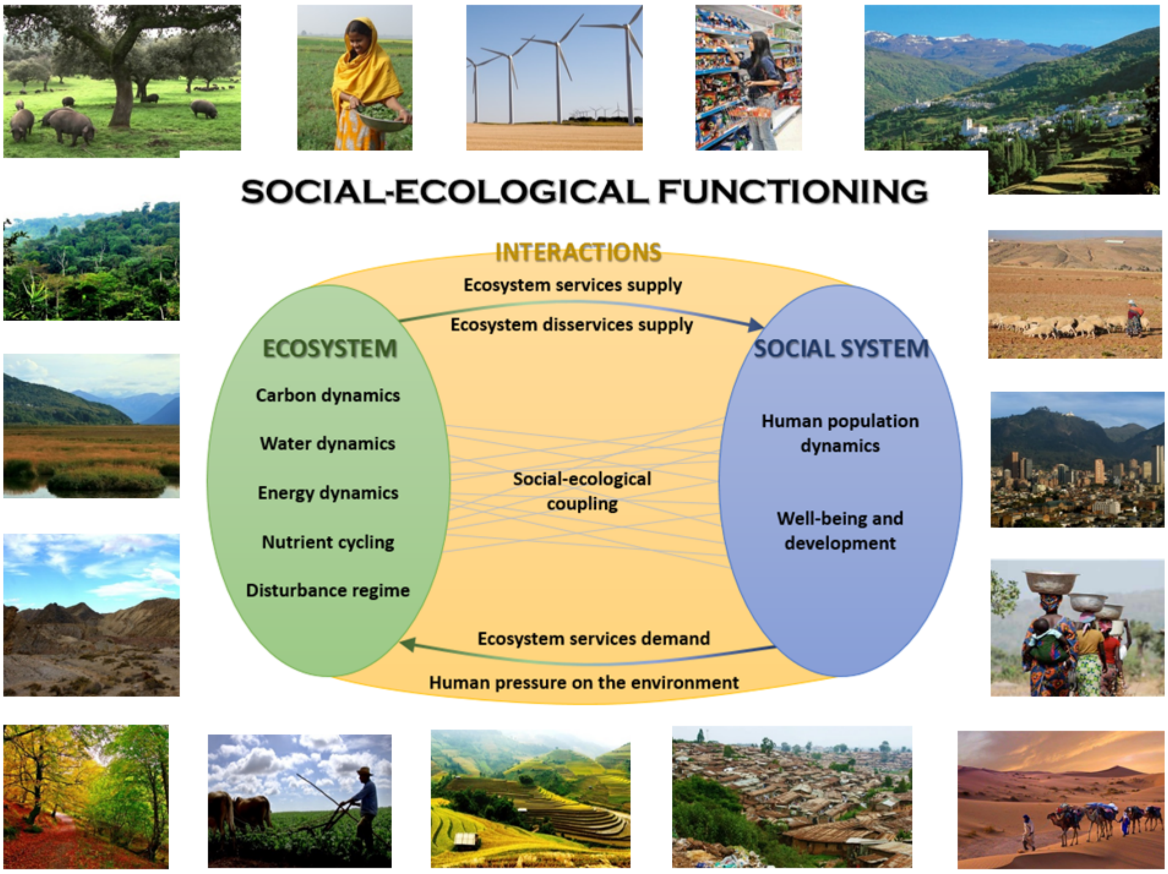
Surname / name	Institution	Area of expertise
Aguiar, Sebastián	Universidad de Buenos Aires (Argentina)	Natural resource management, territorial planning, political ecology, sustainability
Alcaraz-Segura, Domingo	Universidad de Granada (Spain)	Remote sensing, ecosystem ecology, conservation biology

Bagnato, Camilo	Universidad de Buenos Aires (Argentina)	Ecosystem functioning, remote sensing, territorial planning
Blanco-Sacristán, Javier	Università degli Studi di Milano-Bicocca (Italy)	Remote sensing, ecosystem functioning
Berbery, Hugo	University of Maryland (USA)	Land surface-atmosphere interactions, climate system, water and energy budgets
Cabello, Javier	Universidad de Almería (Spain)	Sustainability, ecology and conservation, ecosystem functions and services
Epstein, Howard	University of Virginia (USA)	Ecosystem functioning, vegetation dynamics, climate change, carbon cycling, carbon-water interactions, disturbances regime
Fernández, Néstor	German Centre for Integrative Biodiversity Research – iDiv (Germany)	Ecosystem functioning, biodiversity and conservation, ecological modelling, remote sensing
Gallego, Federico	Universidad de la República de Uruguay (Uruguay)	Sustainability, natural resource management, social-ecological systems, ecosystem services, territorial planning
Jobbágy, Esteban	Universidad Nacional de San Luis (Argentina)	Ecosystem ecology, human control of ecosystem processes, ecohydrology
Pacheco-Romero, Manuel	Universidad de Almería (Spain)	Social-ecological systems, sustainability
Paruelo, José	Universidad de Buenos Aires (Argentina)	Ecosystem structure and functioning, ecological modelling, remote sensing, ecosystem services
Peñas, Julio	Universidad de Granada (Spain)	Conservation biology, biodiversity, plant ecology, biogeography

Pérez-Cazorla, Beatriz	Universidad de Almería (Spain)	Ecosystem functioning, remote sensing, conservation biology
Piñeiro, Gervasio	Universidad de Buenos Aires (Argentina)	Biodiversity, ecosystem ecology, sustainability, natural resource management
Vallejos, María	Universidad de Buenos Aires (Argentina)	Sustainability, natural resource management, social-ecological systems, ecosystem services, territorial planning

Appendix 3. Preliminary online survey

Essential variables to describe the functioning of Social-Ecological Systems



Participating Institutions

UBA Universidad de Buenos Aires *Argentina virtus robur et studium*

UNIVERSIDAD DE ALMERÍA

Universidad Nacional de San Luis

iDiv German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig

Universidad de Granada

UNIVERSITY OF MARYLAND

CSIC Spanish Council of Research

UNIVERSITY OF VIRGINIA 1819

Idaho State UNIVERSITY

Introduction

We aim to integrate biophysical and social processes to produce a functional characterization and mapping of social-ecological systems at the regional scale and landscape level. This survey aims to agree on a set of 'Essential Social-Ecological Functional Variables' (ESEFVs) to be used in such process.

A list of candidate variables is structured in three 'Components' of the social-ecological system (Social System, Ecosystem and Interactions) and each Component into several 'Functional Dimensions' (dimensions of the social system functioning, dimensions of ecosystem functioning, and dimensions of the interactions between the social system and the ecosystems). Possible indicators are shown in some cases only to exemplify, but the answers should focus on the variables (whatever the indicator is).

****
We ask you to select and punctuate only those variables that you consider essential to describe the functioning of social-ecological systems
****

We consider as essential those variables that encompass and integrate critical processes to characterize the functioning of social-ecological systems. Following GEOBON approach for Essential Biodiversity Variables, ESEFVs should be state variables, but useful for change monitoring. Also, they should be coherent and appropriate for comparing across social-ecological systems diversity. Spatially, these variables aim to target the ecosystem level and the human community level. Ideally, they should be already available or technically feasible and economically viable for regional or global implementation in monitoring programs, regional land-use planning, and sustainability and resilience assessment. Please, feel free to visit 'E&SEFT Project' webpage (http://functionaltypes.caescg.org/) to know about project goals, scientists involved, and other partners.

Personal data (optional)

In any case, your answers will be treated as confidential

1. **First name:**

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2. **Last name:**

   ____

3. **Institution/Department:**

   ____

4. **e-mail:**

   ____

5. **Area of expertise:**

   Selecciona todos los que correspondan.

   - [ ] Biophysical sciences
   - [ ] Social sciences
   - [ ] Sustainability Science
   - [ ] Environmental management / Territorial planning
   - [ ] Remote sensing
   - [ ] Biodiversity Science
   - [ ] Otro: ________________________

6. **Tick if you want to be acknowledged in derived publications:**

Selecciona todos los que correspondan.

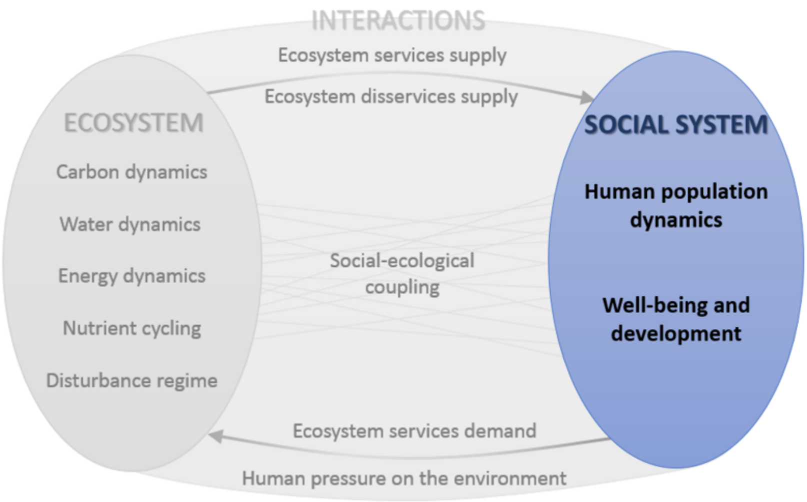
- [ ] Yes, include my name in the acknowledgments

7. **Tick if you want to receive the results of this study:**

Selecciona todos los que correspondan.

- [ ] Yes, send to me the results of this study

COMPONENT 1. SOCIAL SYSTEM



Dimension 1a. Human population dynamics

(You are in: Component 1. Social System)

8. **In your opinion, which variables that describe human population dynamics are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Population size						
Population density						
Population distribution (e.g.: % rural population vs. % urban population)						
Age structure (e.g.: median age, population ageing index)						
Sex Ratio						
Human migrations (e.g.: % of inmigrants/emigrants in a population)						

9. **Would you add/modify any variable of human population dynamics to better describe social-ecological systems functioning? Please specify:**

Dimension 1b. Well-being and development

(You are in: Component 1. Social System)

10. **In your opinion, which variables that describe human well-being and development are essential to characterize social-ecological systems functioning?**
Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")
Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Life expectancy (e.g.: life expectancy at birth)						
Mortality (e.g.: infant mortality rate)						
Access to drinking water (e.g.: distance to drinking water)						
Electricity access						
Water sanitation (e.g.: % of houses using improved sanitation facilities)						
Overcrowding (e.g.: people/ home)						
Employment (e.g.: economically active population)						
Economic level of the population (e.g.: income per house/ per capita)						
Educational level of the population (e.g.: illiteracy rate, % of population with higher education, school enrolment rate, out of school rate for adolescents)						
Social equality (e.g.: wealth distribution, women participation in goverment, women literacy rate)						
Institutional diversity						
Access to internet						
Environmental quality (e.g.: air, water and soil pollution levels)						
Land protection (% of protected area)						

11. **Would you add/modify any variable of social well-being and development to better describe social-ecological systems functioning? Please specify:**

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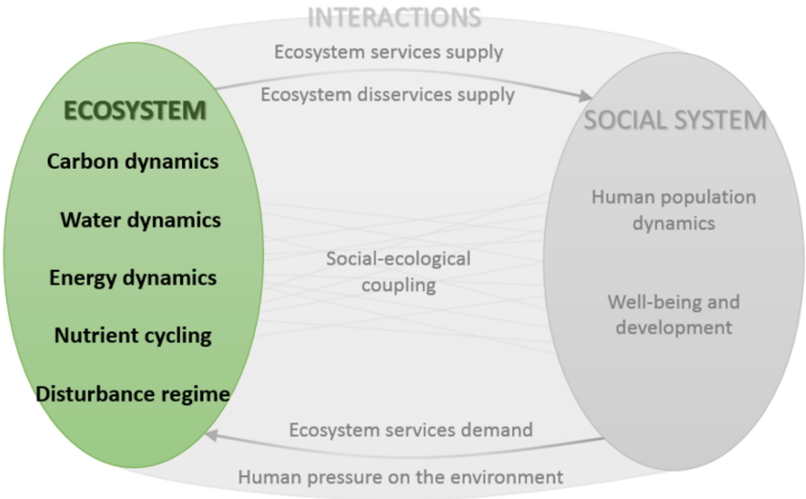
COMPONENT 2. ECOSYSTEM



Dimension 2a. Carbon dynamics

(You are in: Component 2. Ecosystem)

12. **Do you consider Net Primary Productivity as essential to characterize social-ecological systems functioning?**
Please, punctuate this variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")
Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Net Primary Productivity	◯	◯	◯	◯	◯	◯

13. **Would you add/modify any variable of carbon dynamics to better describe social-ecological systems functioning? Please specify:**

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Dimension 2b. Water dynamics

(You are in: Component 2. Ecosystem)

14. **Do you consider evapotranspiration as essential to characterize social-ecological systems functioning?**

Please, punctuate this variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Evapotranspiration						

15. **Would you add/modify any variable of water dynamics to better describe social-ecological systems functioning? Please specify:**

Dimension 2c. Energy dynamics

(You are in: Component 2. Ecosystem)

16. **In your opinion, which variables that describe energy dynamics are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Land surface energy balance						
Land surface temperature						
Albedo						

17. **Would you add/modify any variable of energy dynamics to better describe social-ecological systems functioning? Please specify:**

Dimension 2d. Nutrient cycling

(You are in: Component 2. Ecosystem)

18. **In your opinion, which variables that describe nutrient cycling are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Nitrogen cycling	◯	◯	◯	◯	◯	◯
Phosphorus cycling	◯	◯	◯	◯	◯	◯

19. **Would you add/modify any variable of nutrient cycling to better describe social-ecological systems functioning? Please specify:**

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Dimension 2e. Disturbance regime

(You are in: Component 2. Ecosystem)

20. **In your opinion, which variables that describe disturance regime are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Fire occurrence	◯	◯	◯	◯	◯	◯
Drought occurrence	◯	◯	◯	◯	◯	◯

21. **Would you add/modify any variable of disturbance regime to better describe social-ecological systems functioning? Please specify:**

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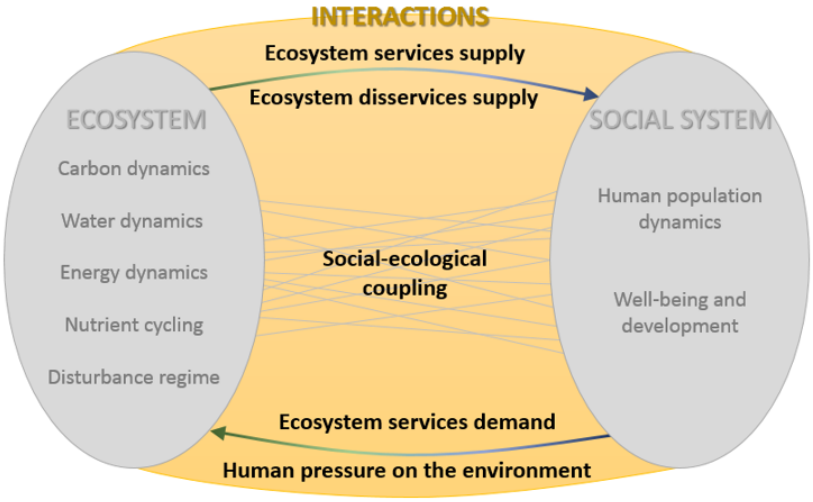
COMPONENT 3. INTERACTIONS



Dimension 3a. Ecosystem services supply

(You are in: Component 3. Interactions)

22. **In your opinion, which variables that describe provisioning services supply are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Agricultural production						
Livestock production						
Wild plants, algae and their outputs for food						
Wild animals and their outputs for food						
Surface and ground water sources for drinking						
Surface and ground water sources for non-drinking purposes						
Fibres and other materials from plants, algae and animals for direct use or processing						
Biomass-based energy sources						

23. **In your opinion, which variables that describe regulation & maintenance services supply are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Bio-remediation/ filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals (of waste, toxics and other nuisances)						
Mass stabilisation and control of erosion rates						
Hydrological cycle and water flow maintenance						
Ventilation and transpiration						
Pollination and seed dispersal						
Pest and disease control						
Weathering, decomposition and fixing rates (for soil formation)						
Chemical conditions maintenance of freshwaters and salt waters						
Global climate regulation (by reduction of greenhouse gas concentrations)						

24. **In your opinion, which variables that describe cultural services supply are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Physical and experiential interactions (with plants, animals, landscapes, seascapes)						
Intellectual and representative interacions (scientific, educational, heritage and cultural, entertainment, aesthetic contemplation)						
Spiritual and/or emblematic (symbolic, sacred and/or religious) interactions						

25. **Would you add/modify any variable of ecosystem services supply to better describe social-ecological systems functioning? Please specify:**

Dimension 3b. Ecosystem disservices supply

(You are in: Component 3. Interactions)

26. **In your opinion, which variables that describe ecosystem disservices supply are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Bio-economic (e.g.: biological invasions, agricultural and fisheries pests and diseases incidence, red tydes)	⬭	⬭	⬭	⬭	⬭	⬭
Abiotic-economic (e.g.: droughts and fires occurrence, siltation, leaching of nutrients)	⬭	⬭	⬭	⬭	⬭	⬭
Bio-health (e.g.: human diseases incidence from pathogens, allergens)	⬭	⬭	⬭	⬭	⬭	⬭
Abiotic-health (e.g.: flood and storm events occurrence)	⬭	⬭	⬭	⬭	⬭	⬭
Bio-cultural (e.g.: bird droppings on outdoor sculptures, tree roots cracking pavements)	⬭	⬭	⬭	⬭	⬭	⬭
Abiotic-cultural (e.g.: soil erosion rates, mud/landslide scar events, unpleasant odours from rotting organic matter)	⬭	⬭	⬭	⬭	⬭	⬭

It is noted that this candidate variables express the incidence of different kinds of harmful events. For simplicity, they have been classified according to their origin and primary dimension of human well-being affected, following Shackleton et al. (2016) approach.

27. **Would you add/modify any variable of ecosystem disservices supply to better describe social-ecological systems functioning? Please specify:**

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Dimension 3c. Ecosystem services demand

(You are in: Component 3. Interactions)

28. **In your opinion, which variables that describe the human capture of ecosystem goods and services are essential to characterize social-ecological systems functioning?**
Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")
Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Human Appropriation of Net Primary Production (e.g.: Tn C extracted/ha/year)						
Material use level (e.g.: raw materials consumed per capita/ per year)						
Energy use level (e.g.: energy consumed per capita/ per year)						
Water use level (e.g.: water consumed per capita/ per year)						

29. **Would you add/modify any variable of ecosystem services demand to better describe social-ecological systems functioning? Please specify:**

Dimension 3d. Human pressure on the environment

(You are in: Component 3. Interactions)

30. **In your opinion, which variables that describe the human pressure on environment are essential to characterize social-ecological systems functioning?**
Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")
Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Isolation (e.g.: distance to main roads, travel time to major cities)						
Land use intensity						
Carbon dioxide emissions						
Pollution (toxic emissions and spills)						

31. **Would you add/modify any variable of human pressure on environment to better describe social-ecological systems functioning? Please specify:**

Dimension 3e. Social-ecological coupling

(You are in: Component 3. Interactions)

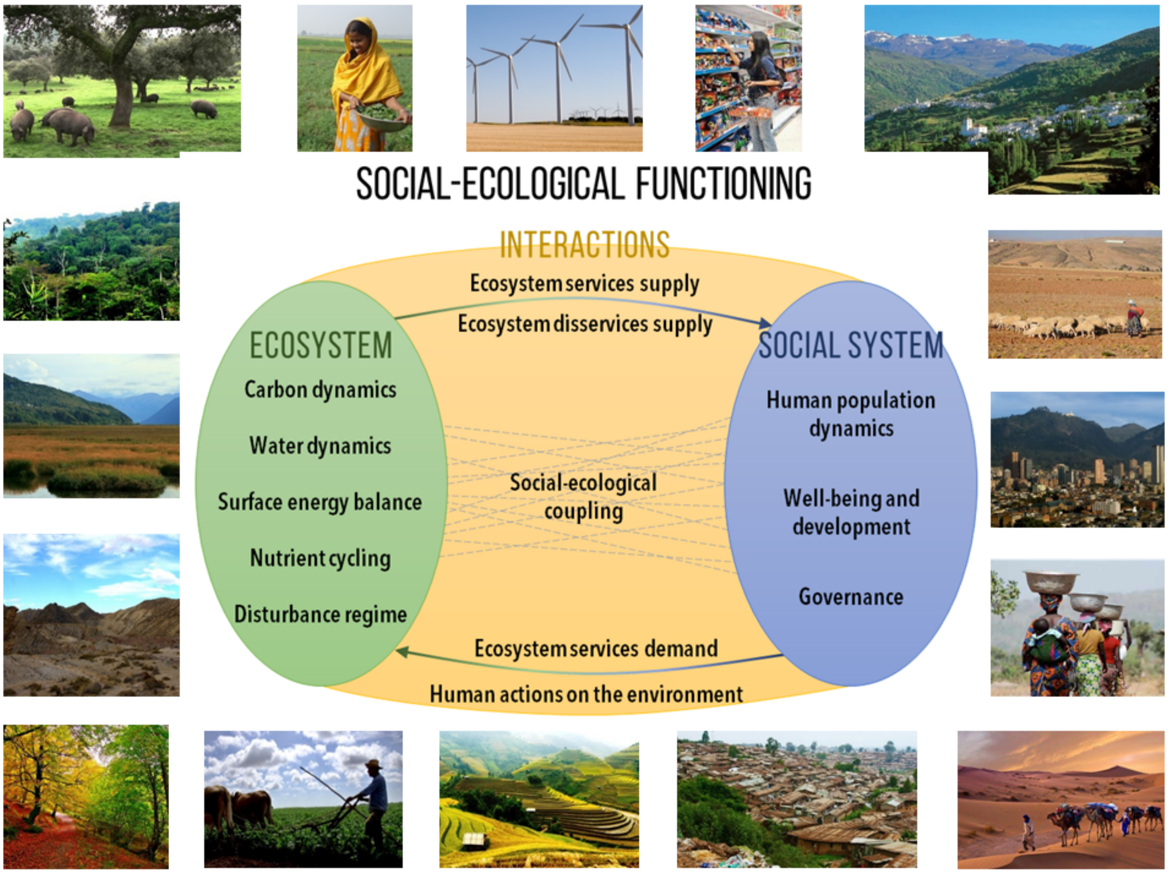
32. **In your opinion, which variables that describe the degree of connection of a community to its local environment are essential to characterize social-ecological systems functioning?**
Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")
Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Weight of farming [industry, services] sector in the economy						
Population employed in farming [industry, services] sectors						
Land tenure structure (e.g.: % communal lands)						
Local natural capital dependence (e.g.: % of final ecosystem services consumed by the population that are provided directly by local environment)						
Dependence on fossil energies (e.g.: % of energy consumed coming from fossil resources)						
Renewable energy use (e.g.: % of energy consumed coming from renewable sources)						
Non-ecosystem services demand (e.g.: socioeconomic services like hospitals, schools, culture, internet)						
Weight in the economy of the non-ecosystem services market						
Human perception of ecosystem services						
Access to natural or seminatural areas (e.g.: distance to a natural or seminatural area)						
Human population ethnicity (e.g.: % of indigenous population)						
Local green initiatives (e.g.: in agriculture, cities, touristic activities, local companies)						
Import [export] rates						
Airports [ports] activity						

33. **Would you add/modify any variable of social-ecological coupling to better describe social-ecological systems functioning? Please specify:**

Appendix 4. Final online survey

Essential variables to characterize the functioning of Social-Ecological Systems



Participating Institutions

UBA Universidad de Buenos Aires *Argentina virtus robur et studium*

Universidad de Almería

Universidad Nacional de San Luis

iDiv German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig

Universidad de Granada

University of Maryland

CSIC Spanish Council of Research

University of Virginia

Idaho State University

Introduction

This survey aims to collect expert opinions and knowledge about key variables to characterize social-ecological systems functioning.

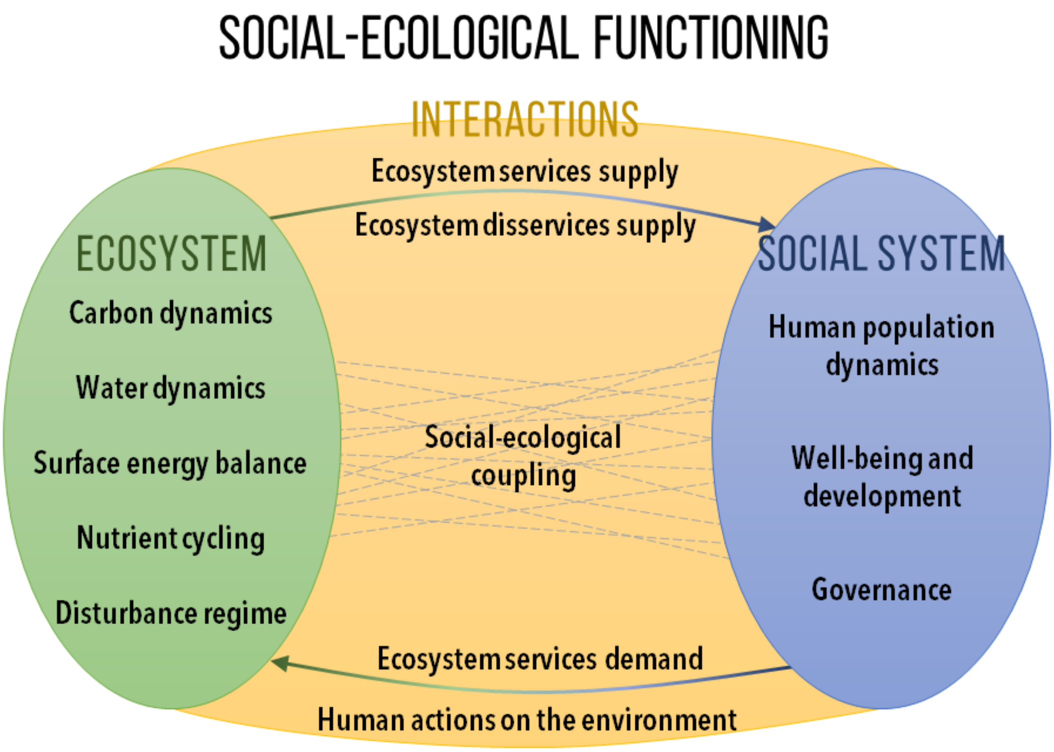
The list of candidate variables is structured in three 'Components' of the social-ecological system (Social System, Ecosystem and Interactions) and each Component into several 'Functional Dimensions' (dimensions of the social system functioning, dimensions of ecosystem functioning, and dimensions of the interactions between the social system and the ecosystem). Possible indicators are shown in some cases only to exemplify, but the answers should focus on the variables.

We ask you to punctuate each variable according to its relevance to characterize the functioning of social-ecological systems. A key aspect to deal with is the issue of context-dependence. We are aware of the difficulties to assess the relevance of proposed variables without bearing in mind any specific social-ecological system. However, we call for a common effort to identify those variables that better explain the differences among social-ecological systems across the world.

We consider as essential those variables that encompass and integrate critical processes to characterize the functioning of social-ecological systems. They should be coherent and appropriate for comparing across social-ecological systems diversity. Spatially, these variables aim to target the ecosystem level and the human community level. Ideally, they should be viable for regional or global implementation in monitoring programs, regional land-use planning, and sustainability and resilience assessment. Our final goal is to integrate both biophysical and social processes to produce a functional characterization and mapping of social-ecological systems at the regional scale and landscape level.

Please, feel free to visit the webpage of the E&SEFT Project: "Ecosystem & Socio-Ecosystem Functional Types: integrating biophysical and social functions to characterize and map the ecosystems of the Anthropocene" (http://functionaltypes.caescg.org/) to know more about project goals, scientists involved, and other partners. In this webpage you can also learn more about the variables included in this survey (selection process, definitions, etc.).

*Important: if you are viewing this survey through your mobile phone, we recommend that you use it in horizontal position for better visualization.



Personal data (optional)

In any case, your answers will be treated as confidential

1. **First name:**

2. **Last name:**

3. **Institution/Department:**

4. **e-mail:**

5. **Area of expertise:**
Selecciona todos los que correspondan.

- [ ] Biophysical sciences
- [ ] Social sciences
- [ ] Sustainability Science
- [ ] Environmental management / Territorial planning
- [ ] Remote sensing
- [ ] Biodiversity Science
- [ ] Otro: ______________________

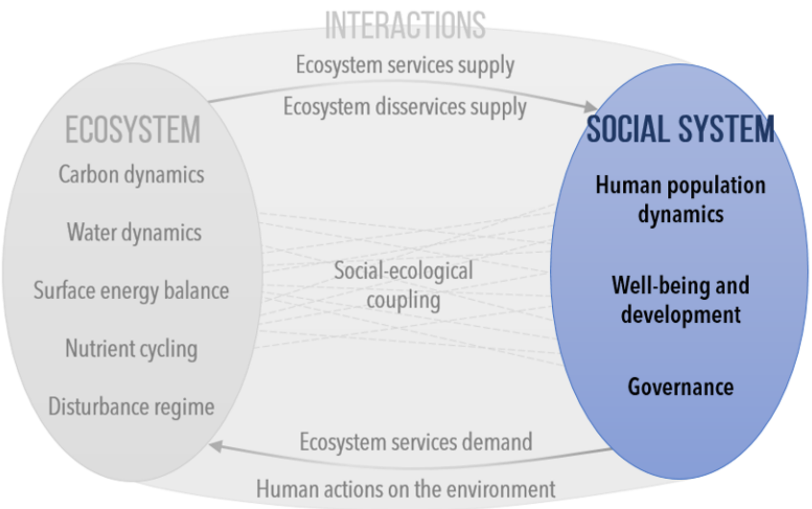
6. **Tick if you want to be acknowledged in derived publications:**
Selecciona todos los que correspondan.

- [ ] Yes, include my name in the acknowledgments

7. **Tick if you want to receive the results of this study:**
Selecciona todos los que correspondan.

- [ ] Yes, send to me the results of this study

COMPONENT 1. SOCIAL SYSTEM



Dimension 1a. Human population dynamics

(You are in: Component 1. Social System)

8. **In your opinion, which variables that describe human population dynamics are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Population density						
Population distribution (e.g.: % rural population vs. % urban population)						
Population size						
Human migrations (e.g.: ratio of inmigrantion/emigration)						
Population growth rate by natural increase						
Population growth rate by inmigration						
Age structure (e.g.: median age, population ageing index, dependency ratio)						
Sex Ratio						

9. **Would you add/modify any variable of human population dynamics to better describe social-ecological systems functioning? Please specify:**

Dimension 1b. Well-being and development

(You are in: Component 1. Social System)

10. **In your opinion, which variables that describe human well-being and development are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Access to drinking water (e.g.: distance to drinking water)						
Water sanitation (e.g.: % of houses using improved sanitation facilities)						
Water scarcity						
Electricity access						
Access to internet						
Educational level of the population (e.g.: illiteracy rate, % of population with higher education, school enrolment rate, out of school rate for adolescents)						
Employment (e.g.: employment rate, unemployment rate)						
Economic level of the population (e.g.: household income, income per capita)						
Poverty (e.g. % of population with unsatisfied basic needs)						
Social equality (e.g.: wealth distribution, women participation in government, women literacy rate, Gini Index)						
Environmental quality (e.g.: air, water and soil pollution levels)						
Access to healthcare and other basic social services (e.g.: % of population receiving public assistance)						
Infant mortality rate						
Life expectancy (e.g.: life expectancy at birth)						
Total fertility rate						
Average household size (e.g.: people per home)						
Subjective well-being (e.g.: life satisfaction)						
Security (e.g.: crime rate)						
Social trust (in government, institutions)						

11. **Would you add/modify any variable of social well-being and development to better describe social-ecological systems functioning? Please specify:**

Dimension 1c. Governance

12. **In your opinion, which variables that describe regional governance are essential to characterize social-ecological systems functioning?**
Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")
Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Institutional diversity (degree of polycentrism and nesting level in government, with efficient horizontal and vertical coordination)	◯	◯	◯	◯	◯	◯
Agenda effectiveness (degree in which the agenda is adequately formulated and assessed to achieve specific goals and have a popular understanding)	◯	◯	◯	◯	◯	◯
Stakeholders participation in decision making (degree of stakeholders inclusiveness, with an adequate leadership arrangement and commitment to group and purpose)	◯	◯	◯	◯	◯	◯
Internal capacity (degree of sufficiency of resources -money, information and expertise, authority and legitimacy- to achieve success on a specific goal)	◯	◯	◯	◯	◯	◯
External capacity (skills and reach of the government to connect to - at both the national and international levels- and secure external resources to support regional goals)	◯	◯	◯	◯	◯	◯
Implementation experience (level of experience addressing regional goals and degree of institutionalization of these experience in policies and processes)	◯	◯	◯	◯	◯	◯
Political stability	◯	◯	◯	◯	◯	◯
Corruption level	◯	◯	◯	◯	◯	◯
Current conflicts (e.g.: armed conflicts, political violence)	◯	◯	◯	◯	◯	◯

Candidate variables from 2 to 6 have been included following Foster & Barnes (2012) proposal of indicators for regional governance.

13. **Would you add/modify any variable of governance to better describe social-ecological systems functioning? Please specify:**

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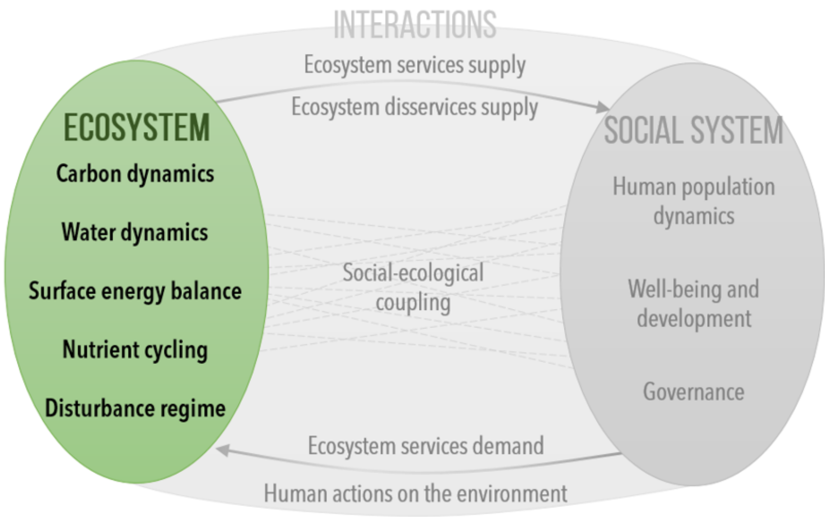
COMPONENT 2. ECOSYSTEM



Dimension 2a. Carbon dynamics

(You are in: Component 2. Ecosystem)

14. **In your opinion, which variables that describe carbon dynamics are essential to characterize social-ecological systems functioning?**

Please, punctuate this variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Gross Primary Productivity (total amount of carbon fixed in the photosynthesis by plants in an ecosystem)	◯	◯	◯	◯	◯	◯
Net Primary Productivity (net productivity of organic carbon by plants in an ecosystem, e.g.: Net Ecosystem Exchange, Net Carbon Flux, carbon acumulation rate)	◯	◯	◯	◯	◯	◯
Respiration (natural carbon dioxide emissions by ecosystems)	◯	◯	◯	◯	◯	◯
Secondary productivity (represents the formation of living mass of a heterotrophic population or group of populations)	◯	◯	◯	◯	◯	◯
Organic Carbon Storage (biomass + litter + soil organic carbon)	◯	◯	◯	◯	◯	◯
Radiation Use Efficiency (organic carbon produced by unit of absorbed solar radiation)	◯	◯	◯	◯	◯	◯
Ecosystem composition by Plant Functional Types (plant classification according to their physical, phylogenetic and phenological characteristics)	◯	◯	◯	◯	◯	◯

15. **Would you add/modify any variable of carbon dynamics to better describe social-ecological systems functioning? Please specify:**

Dimension 2b. Water dynamics

(You are in: Component 2. Ecosystem)

16. **In your opinion, which variables that describe water dynamics are essential to characterize social-ecological systems functioning?**

Please, punctuate this variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Precipitation (water + snow)						
Snow precipitations						
Snow storage						
Horizontal precipitation (e.g.: fog, dew, frost)						
Extra-precipitation water contributions (e.g.: surface or groundwater inputs by rivers or acuifers, respectively)						
Potential evapotranspiration						
Actual evapotranspiration						
Potencial water deficit -or excess- (due to climate conditions)						
Actual water deficit -or excess- (due to climatic and ecohydrological conditions)						
Evaporation - Transpiration ratio						
Soil water infiltration capacity						
Deep drainage (to aquifers)						
Groundwater depth						
Actual Soil Water Storage						
Total water yield or "blue water" (runoff + deep drainage)						
Flows of green water (water in and on soils and on vegetation canopy)						
Precipitation Use Efficiency (organic carbon produced by unit of precipitation or by unit of evapotranspiration)						
Vegetation water stress (e.g. precipitation minus [potential or actual] evapotranspiration)						

17. **Would you add/modify any variable of water dynamics to better describe social-ecological systems functioning? Please specify:**

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Dimension 2c. Surface energy balance

(You are in: Component 2. Ecosystem)

18. **In your opinion, which variables that describe surface energy balance are essential to characterize social-ecological systems functioning?**
Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")
Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Net solar radiation (insolation)						
Downward shortwave (visible [0.4-0.8 μm] + near ultraviolet [0.4-0.3 μm] + near infrared [0.8-2.5 μm]) radiation						
Upward shortwave (visible [0.4-0.8 μm] + near ultraviolet [0.4-0.3 μm] + near infrared [0.8-2.5 μm]) radiation (i.e. albedo)						
Upward longwave radiation (electromagnetic radiation)						
Sensible heat, land surface temperature						
Downward longwave radiation (thermal infrared [2.5-50 μm])						
Latent heat flux (heat spent in water evapotranspiration)						
Snow heat flux						
Deep ground heat flux						
Air temperature						

19. **Would you add/modify any variable of surface energy balance to better describe social-ecological systems functioning? Please specify:**

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Dimension 2d. Nutrient cycling

(You are in: Component 2. Ecosystem)

20. **In your opinion, which variables that describe nutrient cycling are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Nitrogen fixation (atmospheric nitrogen fixed by N-fixer organisms, e.g.: Rhizobium)						
Nitrogen deposition (wet and dry deposition of ammonium, nitrate, and particulate nitrogen)						
Phosphorus deposition (e.g.: aerosols and atmospheric dust, etc.)						
Gross nitrogen mineralization (e.g.: rate of production of ammonium in soils)						
Net nitrogen mineralization (e.g.: net rate of production of plant-available nitrogen)						
Soil phosphorus availability (e.g.: concentrations of non-occluded soil phosphorus)						
Nitrogen status of plants (e.g.: plant tissue nitrogen concentrations)						
Phosphorus status of plants (e.g.: plant tissue phosphorus concentrations)						

21. **Would you add/modify any variable of nutrient cycling to better describe social-ecological systems functioning? Please specify:**

Dimension 2e. Disturbance regime

(You are in: Component 2. Ecosystem)

22. **In your opinion, which variables that describe disturance regime are essential to characterize social-ecological systems functioning?**

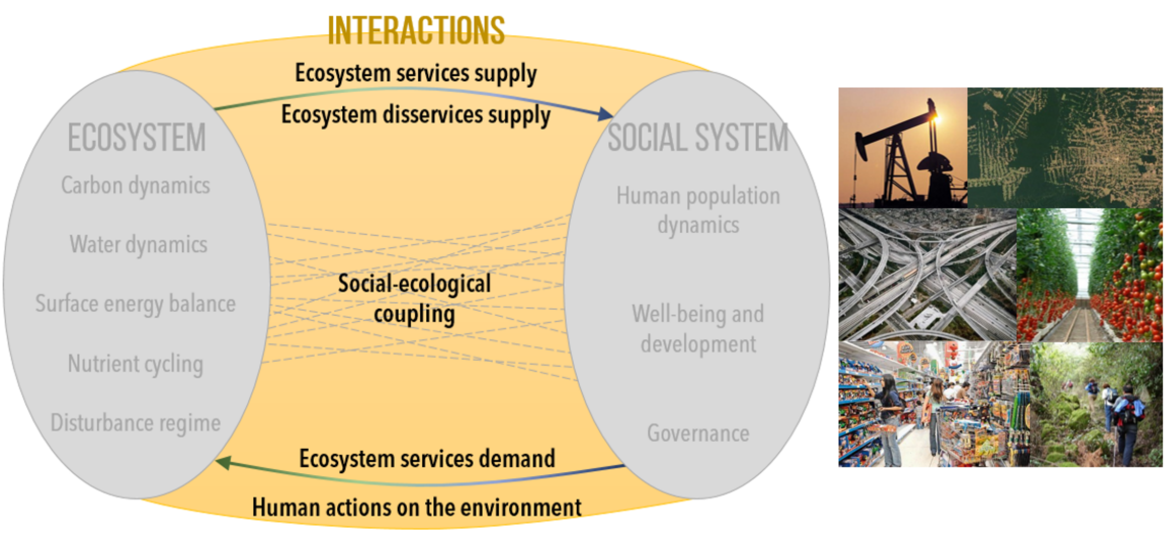
Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Drought occurrence [frequency, severity, extension]						
Fire occurrence [frequency, severity, extension]						
Flood occurrence [frequency, severity, extension]						
Herbivory (natural, not cattle grazing) [frequency, severity, extension]						
Pest outbreaks occurrence [frequency, severity, extension]						
Hurricanes/ storms occurence [frequency, severity, extension]						
Landslides occurrence [frequency, severity, extension]						
Volcanic eruptions occurrence [frequency, severity, extension]						

23. **Would you add/modify any variable of disturbance regime to better describe social-ecological systems functioning? Please specify:**

COMPONENT 3. INTERACTIONS



Dimension 3a. Ecosystem services supply

(You are in: Component 3. Interactions)

24. **In your opinion, which variables that describe provisioning services supply are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Agricultural production						
Livestock production						
Surface and ground water sources for drinking						
Surface and ground water sources for non-drinking purposes						
Biomass-based energy sources						
Fibres and other materials from plants, algae and animals for direct use or processing						
Wild plants, algae and their outputs for food						
Wild animals and their outputs for food						

25. **In your opinion, which variables that describe regulation & maintenance services supply are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Hydrological cycle and water flow maintenance						
Local climate regulation						
Pollination and seed dispersal						
Pest and disease control						
Bioremediation						
Chemical conditions maintenance of freshwaters and salt waters						
Mass stabilisation and control of erosion rates						
Ventilation (air renewal)						

26. **In your opinion, which variables that describe cultural services supply are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Physical and experiential interactions (with plants, animals, landscapes, seascapes)						
Intellectual and representative interacions (scientific, educational, heritage and cultural, entertainment, aesthetic contemplation)						
Spiritual and/or emblematic (symbolic, sacred and/or religious) interactions						

This candidate variables have been adapted from the Common International Classification of Ecosystem Services (CICES) 4.3 version (‘class’ level of this classification for provisioning and regulating services, and 'group' level for cultural services) (European Environment Agency, 2013).

27. **Would you add/modify any variable of ecosystem services supply to better describe social-ecological systems functioning? Please specify:**

Dimension 3b. Ecosystem disservices supply

(You are in: Component 3. Interactions)

28. **In your opinion, which variables that describe ecosystem disservices supply are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Bio-economic (e.g.: biological invasions, agricultural and fisheries pests and diseases incidence, red tydes)						
Abiotic-economic (e.g.: droughts and fires occurrence, siltation, leaching of nutrients)						
Bio-health (e.g.: human diseases incidence from pathogens, allergens)						
Abiotic-health (e.g.: flood and storm events occurrence)						
Bio-cultural (e.g.: bird droppings on outdoor sculptures, tree roots cracking pavements)						
Abiotic-cultural (e.g.: soil erosion rates, mud/landslide scar events, unpleasant odours from rotting organic matter)						

It is noted that this candidate variables express the incidence of different kinds of harmful events. For simplicity, they have been classified according to their origin and primary dimension of human well-being affected, following Shackleton et al. (2016) approach.

29. **Would you add/modify any variable of ecosystem disservices supply to better describe social-ecological systems functioning? Please specify:**

Dimension 3c. Ecosystem services demand

(You are in: Component 3. Interactions)

30. **In your opinion, which variables that describe the human capture of ecosystem goods and services are essential to characterize social-ecological systems functioning?**
Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")
Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Water use level (e.g.: water consumed per capita/ per year)						
Water use for irrigated agriculture (e.g.: water use per hectare/ per year)						
Energy use level (e.g.: energy consumed per capita/ per year)						
Material use level (e.g.: raw materials consumed per capita/ per year)						
Human Appropriation of Net Primary Production (e.g.: Tn C extracted/ per hectare/ per year)						
Appropriation of land for agriculture						
Nature tourism (e.g.: number of visitors to natural areas)						

31. **Would you add/modify any variable of ecosystem services demand to better describe social-ecological systems functioning? Please specify:**

Dimension 3d. Human actions on the environment

(You are in: Component 3. Interactions)

32. **In your opinion, which variables that describe the human actions on the environment are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Land cover/Land use change (e.g.: agriculturization, urbanisation, land abandonment)						
Land use intensity						
Territorial connectivity (e.g.: distance to main roads, travel time to major cities)						
Anthropogenic water management (e.g.: water delivery, drainage and storage systems)						
Anthropogenic carbon dioxide emissions (e.g.: per capita CO2 emissions, CO2 emissions by sector of economic activity)						
Net carbon dioxide flux (e.g.: CO2 emissions - CO2 sequestration)						
Pollution (toxic emissions and spills)						
Eutrofization of water bodies						
Soil erosion (by anthropogenic practices)						
Conservation tillage (sustainable agricultural practices for soil preservation)						
Ecological restoration						
Land protection (e.g.: % of the territory declared as natural protected area with a management plan)						

33. **Would you add/modify any variable of human actions on the environment to better describe social-ecological systems functioning? Please specify:**

Dimension 3e. Social-ecological coupling

(You are in: Component 3. Interactions)

34. **In your opinion, which variables that describe the degree of connection of a community to its local environment are essential to characterize social-ecological systems functioning?**

Please, punctuate each variable according to its relevance for being considered as 'Essential Social-Ecological Functional Variable' (from 1 "less essential" to 5 "more essential")

Marca solo un óvalo por fila.

	No essential	1	2	3	4	5
Local natural capital dependence (e.g.: % of final ecosystem services consumed by the population that are provided directly by local environment)						
Import [export] rates of agricultural and livestock products						
Weight in the economy of the non-ecosystem services market (goods and services that do not come directly from ecosystems, e.g.: socioeconomic services like hospitals, schools or culture, internet, manufactured products, technology)						
Airports [ports] activity						
Dependence on fossil energies (e.g.: % of energy consumed coming from fossil resources)						
Renewable energy use (e.g.: % of energy consumed coming from renewable sources)						
Weight of sectors in the economy (agriculture vs. industry vs. services)						
Weight of traditional (vs. intensive) agricultural and livestock sector in the economy						
Population employed by sectors (agriculture vs. industry vs. services)						
Population employed in traditional (vs. intensive) agriculture and stockbreeding						
Biocapacity (capacity of ecosystems to meet people's local demand and assimilate waste products)						
Land tenure (e.g.: % communal lands vs. private lands vs. government lands)						
Access to natural or seminatural areas (e.g.: distance to a natural or seminatural area)						
Human perception of ecosystem services (awareness level of the population about services provided by local ecosystems)						
Human population ethnicity (e.g.: % of indigenous population)						
Cultural attachment to nature						
Local green initiatives (e.g.: in agriculture, cities, touristic activities, local companies)						

	No essential	1	2	3	4	5
Non-ecosystem services demand (goods and services that do not come directly from ecosystems, e.g.: socioeconomic services like hospitals, schools or culture, internet, manufactured products, technology)						

35. **Would you add/modify any variable of social-ecological coupling to better describe social-ecological systems functioning? Please specify:**

Appendix 5. Tables

Table A5.1. Preliminary and enhanced lists of variables for characterizing and monitoring SESs, structured into dimensions across the three components of a SES. The preliminary list contains 77 variables structured into 12 dimensions and was generated through literature review and an initial expert workshop. The improved list contains 149 variables structured into 13 dimensions and was the result of analyzing the preliminary survey results (56 responses) in a second scientific workshop. This improved list was then introduced in the final survey with the aim of using scientist scorings to prioritize the variables.

Component	Dimension	Preliminary list (77 variables in 12 dimensions)	Improved list (149 variables in 13 dimensions)
Social system	Human population dynamics	Population density	Population density
		Population distribution	Population distribution
		Population size	Population size
		Human migrations	Human migrations
		Age structure	Age structure
		Sex Ratio	Sex Ratio
			Population growth rate by natural increase
			Population growth rate by immigration
	Wellbeing and development	Access to drinking water	Access to drinking water
		Water sanitation	Water sanitation
		Electricity access	Electricity access
		Access to internet	Access to internet
		Educational level of the population	Educational level of the population
		Employment	Employment
		Economic level of the population	Economic level of the population
		Social equity	Social equity
		Environmental quality	Environmental quality
		Mortality	Infant mortality rate
		Overcrowding	Average household size
		Life expectancy	Life expectancy
		Institutional diversity	-

		Land protection	-
			Water scarcity
			Poverty
			Access to healthcare and other basic social services
			Total fertility rate
			Subjective wellbeing
			Security
			Social trust
	Governance (not included in 1st survey)		Institutional diversity
			Agenda effectiveness[1]
			Stakeholders participation in decision making[1]
			Internal capacity[1]
			External capacity[1]
			Implementation experience[1]
			Political stability
			Corruption level
			Current conflicts
Ecological system	Organic carbon dynamics (Carbon dynamics in 1st survey)	Net Primary Productivity	Net Primary Productivity
			Gross Primary Productivity
			Respiration
			Secondary productivity
			Organic carbon storage
			Radiation Use Efficiency
			Ecosystem composition by Plant Functional Types
	Water dynamics	Evapotranspiration	Actual evapotranspiration
			Potential evapotranspiration
			Precipitation
			Snow precipitations
			Snow storage
			Horizontal precipitation
			Extra-precipitation water contributions
			Potential water deficit -or excess-

		Actual water deficit -or excess-
		Evaporation - Transpiration ratio
		Soil water infiltration capacity
		Deep drainage
		Groundwater depth
		Actual Soil Water Storage
		Total water yield or "blue water"
		Flows of green water
		Precipitation Use Efficiency
		Vegetation water stress
Surface energy balance (Energy dynamics in 1st survey)	Land surface energy balance	-
	Albedo	Upward shortwave radiation
	Land surface temperature	Sensible heat, land surface temperature
		Net solar radiation
		Downward shortwave radiation
		Upward longwave radiation
		Downward longwave radiation
		Latent heat flux
		Snow heat flux
		Deep ground heat flux
		Air temperature
Nutrient cycling	Nitrogen cycling	-
	Phosphorus cycling	-
		Nitrogen fixation
		Nitrogen deposition
		Phosphorus deposition
		Gross nitrogen mineralization
		Net nitrogen mineralization
		Soil phosphorus availability
		Nitrogen status of plants
		Phosphorus status of plants
Disturbance regime	Drought occurrence	Drought occurrence

		Fire occurrence	Fire occurrence Flood occurrence Herbivory Pest outbreaks occurrence Hurricanes/storms occurrence Landslides occurrence Volcanic eruptions occurrence
Interactions	Ecosystem service supply[2]†	Cropland production (P) Livestock production (P) Surface and groundwater sources for drinking (P) Surface and ground water sources for nondrinking purposes (P) Biomass-based energy sources (P) Fibres and other materials from plants, algae and animals for direct use or processing (P) Wild plants, algae and their outputs for food (P) Wild animals and their outputs for food (P) Hydrological cycle and water flow maintenance (R) Global climate regulation (R) Pollination and seed dispersal (R) Pest and disease control (R) Bioremediation (R) Chemical conditions maintenance of freshwaters and salt waters (R) Mass stabilisation and control of erosion rates (R) Ventilation and transpiration (R)	Cropland production (P) Livestock production (P) Surface and groundwater sources for drinking (P) Surface and ground water sources for nondrinking purposes (P) Biomass-based energy sources (P) Fibres and other materials from plants, algae and animals for direct use or processing (P) Wild plants, algae and their outputs for food (P) Wild animals and their outputs for food (P) Hydrological cycle and water flow maintenance (R) Local climate regulation (R) Pollination and seed dispersal (R) Pest and disease control (R) Bioremediation (R) Chemical conditions maintenance of freshwaters and salt waters (R) Mass stabilisation and control of erosion rates (R) Ventilation (R)

	Weathering, decomposition and fixing rates (for soil formation) (R)	-
	Physical and experiential interactions (C)	Physical and experiential interactions (C)
	Intellectual and representative interacions (C)	Intellectual and representative interacions (C)
	Spiritual and/or emblematic interactions (C)	Spiritual and/or emblematic interactions (C)
Ecosystem disservice supply[3]	Bio-economic	Bio-economic
	Abiotic-economic	Abiotic-economic
	Bio-health	Bio-health
	Abiotic-health	Abiotic-health
	Bio-cultural	Bio-cultural
	Abiotic-cultural	Abiotic-cultural
Ecosystem service demand	Water use level	Water use level
	Energy use level	Energy use level
	Material use level	Material use level
	Human Appropriation of Net Primary Production	Human Appropriation of Net Primary Production
		Water use for irrigated crops
		Appropriation of land for agriculture
		Nature tourism
Human actions on the environment	Land use intensity	Land use intensity
	Isolation	Territorial connectivity
	Carbon dioxide emissions	Anthropogenic carbon dioxide emissions
	Pollution	Pollution
		Land cover/Land use change
		Anthropogenic water management
		Net carbon dioxide flux
		Eutrophication of water bodies
		Soil erosion
		Conservation tillage
		Ecological restoration
		Land protection

	Social-ecological coupling	Local natural capital dependence	Local natural capital dependence
		Import [export] rates	Import [export] rates of crop and livestock products
		Weight in the economy of the non-ecosystem services market	Weight in the economy of the non-ecosystem services market
		Airports [ports] activity	Airports [ports] activity
		Dependence on fossil energies	Dependence on fossil energies
		Renewable energy use	Renewable energy use
		Weight of farming [industry, services] sector in the economy	Weight of sectors in the economy
		Population employed in farming [industry, services] sectors	Population employed by sectors
		Land tenure structure	Land tenure
		Access to natural or semi natural areas	Access to natural or seminatural areas
		Human perception of ecosystem services	Human perception of ecosystem services
		Human population ethnicity	Human population ethnicity
		Local green initiatives	Local green initiatives
		Non-ecosystem services demand	Non-ecosystem services demand
			Weight of traditional (vs. intensive) agricultural sector in the economy
			Population employed in traditional (vs. intensive) agriculture
			Biocapacity
			Cultural attachment to nature

† P = provisioning services; R = regulating services; C = cultural services

[1] Foster, K. A., and W. R. Barnes. 2012. Reframing Regional Governance for Research and Practice. *Urban Affairs Review* 48(2):272–283.

[2] Haines-Young, R., and M. Potschin. 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. [online] URL: https://www.cices.eu

[3] Shackleton, C. M., S. Ruwanza, G. K. Sinasson Sanni, S. Bennett, P. De Lacy, R. Modipa, N. Mtati, M. Sachikonye, and G. Thondhlana. 2016. Unpacking Pandora's Box: Understanding and Categorising Ecosystem Disservices for Environmental Management and Human Wellbeing. *Ecosystems* 19(4):587–600. [online] URL: https://doi.org/10.1007/s10021-015-9952-z

Table A5.2. List of prioritized variables for characterizing and monitoring SES (extended version with examples and explanations). The list is structured into 13 dimensions across the three components of a SES (Fig. 2 in the paper). Priority level 1 (top priority) includes variables with relevance and consensus above the 90th percentile; level 2 includes variables between the 75th and 90th percentiles; level 3 includes variables with relevance above the 75th percentile but consensus between the 50th and 75th percentiles and vice versa; and finally, level 4 includes variables with relevance and consensus between the 50th and 75th percentiles. The nonpriority category includes variables with relevance and consensus below the 50th percentile.

Component	Dimension	Priority variables (decreasing priority from 1 to 4)				Nonpriority variables
		Level 1	Level 2	Level 3	Level 4	
Social system	Human population dynamics			Population density Population distribution (e.g., % rural population vs. % urban population)		Age structure (e.g., median age, population ageing index, dependency ratio) Human migrations (e.g., ratio of immigration/emigration) Population growth rate by immigration Population growth rate by natural increase Population size Sex Ratio
	Wellbeing and development		Access to drinking water (e.g., distance to drinking water) Educational level (e.g., illiteracy rate, % of population with higher education, school enrolment rate, out	Water sanitation (e.g., % of houses using improved sanitation facilities) Water scarcity		Access to healthcare and other basic social services (e.g., % of population receiving public assistance) Access to internet Average household size (e.g., people per home) Economic level (e.g., household income, income per capita) Electricity access

	of school rate for adolescents) Environmental quality (e.g., air, water and soil pollution levels) Poverty (e.g., % of population with unsatisfied basic needs) Social equity (e.g., wealth distribution, women participation in government, women literacy rate, Gini Index)			Employment (e.g., employment rate, unemployment rate) Infant mortality rate Life expectancy (e.g., life expectancy at birth) Security (e.g., crime rate) Social trust (in government, institutions) Subjective wellbeing (e.g., life satisfaction) Total fertility rate
Governance	Current conflicts (e.g., armed conflicts, political violence)	Corruption level Political stability		Agenda effectiveness (degree in which the agenda is adequately formulated and assessed to achieve specific goals and have a popular understanding)[1] External capacity (skills and reach of the government to connect to - at both the national and international levels- and secure external resources to support regional goals)[1] Implementation experience (level of experience addressing regional goals and degree of institutionalization of these experience in policies and processes)[1] Institutional diversity (degree of polycentrism and nesting level in

						government, with efficient horizontal and vertical coordination) Internal capacity (degree of sufficiency of resources -money, information and expertise, authority and legitimacy- to achieve success on a specific goal) Stakeholders participation in decision making (degree of stakeholder's inclusiveness, with an adequate leadership arrangement and commitment to group and purpose)
Ecological system	Organic carbon dynamics			Net primary productivity (net productivity of organic carbon by plants in an ecosystem, e.g., Net Ecosystem Exchange, Net Carbon Flux, carbon accumulation rate) Organic carbon storage (biomass + litter + soil organic carbon)	Ecosystem composition by plant functional type (plant classification according to their physical, phylogenetic and phenological characteristics)	Gross Primary Productivity (total amount of carbon fixed in the photosynthesis by plants in an ecosystem) Radiation Use Efficiency (organic carbon produced by unit of absorbed solar radiation) Respiration (natural carbon dioxide emissions by ecosystems) Secondary productivity (represents the formation of living mass of a heterotrophic population or group of populations)
	Water dynamics		Precipitation (water + snow)	Actual evapotranspiration Actual water deficit -or excess- (due to climatic and ecohydrological conditions)	Soil water infiltration capacity	Actual Soil Water Storage Deep drainage (to aquifers) Extra-precipitation water contributions (e.g., surface or groundwater inputs by rivers or aquifers, respectively)

Evaporation - Transpiration ratio

Flows of green water (water in and on soils and on vegetation canopy)

Groundwater depth

Horizontal precipitation (e.g., fog, dew, frost)

Potential evapotranspiration

Potential water deficit -or excess- (due to climate conditions)

Precipitation Use Efficiency (organic carbon produced by unit of precipitation or by unit of evapotranspiration)

Snow precipitations

Snow storage

Total water yield or "blue water" (runoff + deep drainage)

Vegetation water stress (e.g., precipitation minus [potential or actual] evapotranspiration)

Surface energy balance		Net solar radiation (insolation)	Land surface temperature (sensitive heat)	Air temperature Deep ground heat flux Downward longwave radiation (thermal infrared [2.5-50 μm]) Downward shortwave radiation (visible [0.4-0.8 μm] + near ultraviolet [0.4-0.3 μm] + near infrared [0.8-2.5 μm]) Latent heat flux (heat spent in water evapotranspiration) Snow heat flux Upward longwave radiation (electromagnetic radiation) Upward shortwave radiation (visible [0.4-0.8 μm] + near ultraviolet [0.4-0.3 μm] + near infrared [0.8-2.5 μm]) (i.e. albedo)
Nutrient cycling	Nitrogen fixation (atmospheric nitrogen fixed by N-fixer organisms, e.g., Rhizobium)	Soil phosphorus availability (e.g., concentrations of non-occluded soil phosphorus)	Nitrogen deposition (wet and dry deposition of ammonium, nitrate and particulate nitrogen)	Gross nitrogen mineralization (e.g., rate of production of ammonium in soils) Net nitrogen mineralization (e.g., net rate of production of plant-available nitrogen) Nitrogen status of plants (e.g., plant tissue nitrogen concentrations) Phosphorus deposition (e.g., aerosols and atmospheric dust, etc.) Phosphorus status of plants (e.g., plant tissue phosphorus concentrations)

	Disturbance regime	Drought occurrence Flood occurrence	Fire occurrence	Hurricanes/storms occurrence Pest outbreaks occurrence		Herbivory (natural, not cattle grazing) Landslides occurrence Volcanic eruptions occurrence
Interactions	Ecosystem service supply[2]†	Cropland production (P) Livestock production (P) Surface and groundwater sources for drinking (P) Hydrological cycle and water flow maintenance (R)		Surface and groundwater sources for nondrinking purposes (P) Local climate regulation (R) Pest and disease control (R) Pollination and seed dispersal (R)	Chemical conditions maintenance of freshwater and saltwater (R)	Biomass-based energy sources (P) Bioremediation (R) Fibres and other materials from plants, algae and animals for direct use or processing (P) Intellectual and representative interactions (scientific, educational, heritage and cultural, entertainment, aesthetic contemplation) (C) Mass stabilisation and control of erosion rates (R) Physical and experiential interactions (with plants, animals, landscapes, seascapes) (C) Spiritual and/or emblematic interactions (symbolic, sacred and/or religious) (C) Ventilation (air renewal) (R) Wild plants, algae and their outputs for food (P) Wild animals and their outputs for food (P)
	Ecosystem disservice supply[3]				Abiotic-economic (e.g., droughts and fires	Abiotic-cultural (e.g., soil erosion rates, mud/landslide scar events,

				occurrence, siltation, leaching of nutrients) Bio-economic (e.g., biological invasions, agricultural and fisheries pests and diseases incidence, red tides)	unpleasant odours from rotting organic matter) Abiotic-health (e.g., flood and storm events occurrence) Bio-cultural (e.g., bird droppings on outdoor sculptures, tree roots cracking pavements) Bio-health (e.g., human diseases incidence from pathogens, allergens)
Ecosystem service demand		Appropriation of land for agriculture Energy use level (e.g., energy consumed per capita and year) Water use level (e.g., water consumed per capita and year) Water use for irrigated crops (e.g., water use per hectare and year)	Material use level (e.g., raw materials consumed per capita and year)	Human Appropriation of Net Primary Production (HANPP) (e.g., Tn C extracted per hectare and year)	Nature tourism (e.g., number of visitors to natural areas)
Human actions on the environment	Land cover/Land use change (e.g., agriculturization, urbanisation, land abandonment)	Eutrophication of water bodies Land protection (e.g., % of the territory declared as natural protected	Anthropogenic water management (e.g., water delivery, drainage and storage systems)	Net CO_2 flux (e.g., CO2 emissions - CO2 sequestration) Territorial connectivity (e.g., distance to main roads, travel time to major cities)	Anthropogenic carbon dioxide emissions (e.g., per capita CO2 emissions, CO2 emissions by sector of economic activity) Conservation tillage (sustainable agricultural practices for soil preservation)

	Land use intensity	area with a management plan) Pollution (toxic emissions and spills) Soil erosion (by anthropogenic practices)			Ecological restoration
Social-ecological coupling	Local natural capital dependence (e.g., % of final ecosystem services consumed by the population that are provided directly by local environment)		Access to natural and semi-natural areas (e.g., distance to a natural or seminatural area) Biocapacity (capacity of ecosystems to meet people's local demand and assimilate waste products)	Import [export] rates of agricultural products Renewable energy use (e.g., % of energy consumed coming from renewable sources)	Airports [ports] activity Cultural attachment to nature Dependence on fossil energies (e.g., % of energy consumed coming from fossil resources) Human perception of ecosystem services (awareness level of the population about services provided by local ecosystems) Human population ethnicity (e.g., % of indigenous population) Land tenure (e.g., % communal lands vs. private lands vs. government lands) Local green initiatives (e.g., in agriculture, cities, touristic activities, local companies) Non-ecosystem services demand (goods and services that do not come

	directly from ecosystems, e.g., socioeconomic services like hospitals, schools or culture, internet, manufactured products, technology)
	Population employed by sectors (agriculture vs. industry vs. services)
	Population employed in traditional (vs. intensive) agriculture
	Weight in the economy of the non-ecosystem services market (goods and services that do not come directly from ecosystems, e.g., socioeconomic services like hospitals, schools or culture, internet, manufactured products, technology)
	Weight of sectors in the economy (agriculture vs. industry vs. services)
	Weight of traditional (vs. intensive) agricultural sector in the economy

† P = provisioning services; R = regulating services; C = cultural services.

[1] Foster, K. A., and W. R. Barnes. 2012. Reframing Regional Governance for Research and Practice. *Urban Affairs Review* 48(2):272–283. [online] URL: https://doi.org/10.1177/1078087411428121

[2] Haines-Young, R., and M. Potschin. 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. [online] URL: https://www.cices.eu

[3] Shackleton, C. M., S. Ruwanza, G. K. Sinasson Sanni, S. Bennett, P. De Lacy, R. Modipa, N. Mtati, M. Sachikonye, and G. Thondhlana. 2016. Unpacking Pandora's Box: Understanding and Categorising Ecosystem Disservices for Environmental Management and Human Wellbeing. *Ecosystems* 19(4):587–600. [online] URL: https://doi.org/10.1007/s10021-015-9952-z

In this paper, ecosystem disservices are defined as *"the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing."*

We based on Shackleton et al. (2016) classification to distinguish among 6 categories of ecosystem disservices, according to their origin (biological or abiotic) and the nature of their impacts on human wellbeing (economic; physical and mental health and safety; aesthetics and culture): bio-economic, abiotic-economic, bio-health, abiotic-health, bio-cultural, abiotic-cultural. Examples of ecosystem disservices for each category are include in the Table above.

Table A5.3. Examples of studies that have used prioritized variables to map SES distribution and dynamics. The specific metrics used to map SESs associated with the priority variables identified in our study are listed. Nonpriority variables (those that obtained the lowest scores in the survey) and additional variables not included in our list are also matched to the metrics used to map SESs.

Component	Variable	Variable priority level	Reference	Metric
Social system	Educational level	2	Castellarini et al. (2014)	Human Development Index
			Hamann et al. (2016)	People with completed secondary schooling or higher
			Martín-López et al. (2017)	Illiterates
				People with university degree
			Rocha et al. (2020)	Literacy rate
			Vallejos et al. (2020)	School density
	Poverty	2	Václavík et al. (2013)	Gross Domestic Product
			Castellarini et al. (2014)	Human Development Index
			Hamann et al. (2016)	Household income
			Vallejos et al. (2020)	Unsatisfied basic needs
	Environmental quality	2	Queiroz et al. (2015)	Standing water quality
				Running water quality
			Dittrich et al. (2017)	Soil quality
	Conflicts	2	Dressel et al. (2018)	Potential for conflict index on moose managers evaluation of moose population
	Population density	3	Ellis and Ramankutty (2008) Asselen and Verburg (2012) Václavík et al. (2013) Hamann et al. (2015) Renard et al. (2015) Dittrich et al. (2017) Martín-López et al. (2017) Spake et al. (2017) Levers et al. (2018) Vallejos et al. (2020)	Population density
			Rocha et al. (2020)	Population density Change in population density

Population distribution	3	Ellis and Ramankutty (2008)	Urban and non-urban population
Political stability	3	Václavík et al. (2013)	Political stability index
Population size	nonpriority	Hanspach et al. (2016)	Total population size
Migrations	nonpriority	Hanspach et al. (2016)	Net migration
		Martín-López et al. (2017)	Foreign population
		Rocha et al. (2020)	Inter & intra regional migrations
Age structure	nonpriority	Hanspach et al. (2016)	Proportion of pupils
		Martín-López et al. (2017)	People younger than 20
			People older than 65
		Rocha et al. (2020)	Ratio of children
Sex ratio	nonpriority	Dittrich et al. (2017)	Ratio female/male
		Rocha et al. (2020)	Ratio of woman
Life expectancy	nonpriority	Hamann et al. (2016)	Average age of death
Employment	nonpriority	Hamann et al. (2016)	Unemployed people
			Discouraged work-seeker
		Hanspach et al. (2016)	Unemployment rate
		Dittrich et al. (2017)	Unemployment rate
		Martín-López et al. (2017)	Unemployed inhabitants
		Levers et al. (2018)	Total labour input
		Vallejos et al. (2020)	Permanent workers
Economic level	nonpriority	Václavík et al. (2013)	Gross Domestic Product
		Castellarini et al. (2014)	Human Development Index
		Hamann et al. (2015)	Household income
		Hamann et al. (2016)	Household income
		Martín-López et al. (2017)	Income per capita
		Levers et al. (2018)	Economic activity index
Access to internet	nonpriority	Martín-López et al. (2017)	Number of ADSL lines

	Security	nonpriority	Hamann et al. (2016)	Property ownership (Percentage of households where dwelling is owned and fully paid off)
	Internal capacity of the government	nonpriority	Dittrich et al. (2017)	District debts
	Stakeholders participation in decision making	nonpriority	Dressel et al. (2018)	Proportion of general public that are relevant actors
Ecological system	Precipitation	2	Asselen and Verburg (2012) Václavík et al. (2013) Dittrich et al. (2017) Martín-López et al. (2017) Spake et al. (2017) Rocha et al. (2020)	Precipitation Precipitation Precipitation seasonality Mean precipitation vegetation period Mean annual precipitation Minimum annual precipitation Maximum annual precipitation Annual precipitation Number of months with precipitation >60 mm
	Net Primary Productivity	3	Alessa et al. (2008) Ellis and Ramankutty (2008) Václavík et al. (2013) Hamann et al. (2015) Spake et al. (2017) Vallejos et al. (2020)	Net Primary Productivity Index Net Primary Productivity (g m^{-2}) NDVI – mean NDVI – seasonality Area with high grazing potential Potential Net Primary Productivity (tC m^{-2} yr) EVI – mean EVI – seasonality
	Organic carbon storage	3	Raudsepp-Hearne et al. (2010) Asselen and Verburg (2012) Václavík et al. (2013) Renard et al. (2015) Spake et al. (2017) Levers et al. (2018)	Carbon sequestration (kg C km^{-2}) Soil organic carbon (g C kg^{-1} of soil) Soil organic carbon (g C kg^{-1} of soil) Carbon sequestration (kg C km^{-2}) Carbon stocks from above-ground and below-ground biomass, dead organic matter and soils (tC km^{-2}) Soil organic carbon (tC ha^{-1})
	Actual evapotranspiration	3	Martín-López et al. (2017)	Mean annual evapotranspiration

			Minimum annual evapotranspiration
			Maximum annual evapotranspiration
Actual water deficit (or excess)	3	Levers et al. (2018)	Ratio of mean annual precipitation & mean annual potential evapotranspiration
		Rocha et al. (2020)	Mean aridity gradient
Net solar radiation	3	Václavík et al. (2013)	Solar radiation (W m^{-2})
		Dittrich et al. (2017)	Mean sunshine duration
Soil phosphorus availability	3	Raudsepp-Hearne et al. (2010)	Soil phosphorus retention
		Queiroz et al. (2015)	
Land surface temperature	4	Asselen and Verburg (2012)	Mean temperature
		Václavík et al. (2013)	Temperature
			Diurnal temperature range
			Extreme temperatures
		Dittrich et al. (2017)	Mean temperature vegetation period
		Levers et al. (2018)	Growing degree days (T>0º)
		Rocha et al. (2020)	Mean temperature
Groundwater depth	nonpriority	Dittrich et al. (2017)	Groundwater level
Biodiversity	not in our list	Václavík et al. (2013)	Species richness
		Castellarini et al. (2014)	Distribution of ecoregions
		Hanspach et al. (2016)	Species richness
		Spake et al. (2017)	Species richness
		Levers et al. (2018)	Distribution of ecoregions
Natural capital	not in our list	Vallejos et al. (2020)	Native forest area
Other abiotic conditions	not in our list	Asselen and Verburg (2012)	Soil characteristics
			Altitude
			Slope
		Castellarini et al. (2014)	Ecorregions map
		Renard et al. (2015)	Soil capability for agriculture
		Hanspach et al. (2016)	Altitude
			Terrain ruggedness

				Slope
				Terrain wetness index
				Heatload
			Sinare et al. (2016)	Topography
			Dittrich et al. (2017)	Ruggedness
			Martín-López et al. (2017)	Altitude
				Slope
				Lithology
				Geomorphology
			Spake et al. (2017)	Elevation
			Levers et al. (2018)	Topographic heterogeneity
			Rocha et al. (2020)	Slope
Interactions	Cropland production	1	Raudsepp-Hearne et al. (2010)	Cropland production
			Václavík et al. (2013)	
			Hamann et al. (2015)	
			Queiroz et al. (2015)	
			Renard et al. (2015)	
			Dittrich et al. (2017)	
			Spake et al. (2017)	
			Levers et al. (2018)	
			Rocha et al. (2020)	Variance of crop production
				Kilocalories for diverse crops
			Vallejos et al. (2020)	Annual crops area
	Livestock production	1	Raudsepp-Hearne et al. (2010)	Livestock production
			Asselen and Verburg (2012)	
			Hamann et al. (2015)	
			Queiroz et al. (2015)	
			Renard et al. (2015)	
			Dittrich et al. (2017)	
			Martín-López et al. (2017)	
			Levers et al. (2018)	
			Rocha et al. (2020)	Cattle per km^2
				Small ruminants per capita
			Vallejos et al. (2020)	Forage crops area
				Pregnant cows

Surface and groundwater sources for drinking	1	Raudsepp-Hearne et al. (2010)	Drinking water quality - IQBP indicator (1-5)
		Dittrich et al. (2017)	Clean water - nitrogen concentration in rivers (mg N l^{-1})
Hydrological cycle and water flow maintenance	1	Hamann et al. (2015)	Mean annual runoff
		Renard et al. (2015)	Flood control
		Dittrich et al. (2017)	Flood protection (biophysical dependent flood regulation by catchments)
		Spake et al. (2017)	Physical water quantity regulation
		Rocha et al. (2020)	Soil water holding capacity
Land cover/Land use change	1	Ellis and Ramankutty (2008)* Asselen and Verburg (2012)* Václavík et al. (2013) Castellarini et al. (2014)* Hamann et al. (2015)* Hanspach et al. (2016)* Sinare et al. (2016)* Martín-López et al. (2017) * Spake et al. (2017)* Levers et al. (2018) Vallejos et al. (2020)*	Multiple categories * (These studies include land cover and land use variables but not address changes directly)
		Dressel et al. (2018)	Diversity of land cover type
Land use intensity	1	Asselen and Verburg (2012)	Efficiency of agricultural production
		Václavík et al. (2013)	Multidimensional (N fertilizer, irrigation, soil erosion, yields, HANPP)
		Hanspach et al. (2016)	Landscape heterogeneity
		Martín-López et al. (2017)	Cropland irrigation Greenhouses crops
		Levers et al. (2018)	Wood production Fertilizer application rates Yields Stocking density Grassland yields
		Vallejos et al. (2020)	Irrigated area Tractor density Stocking density

Soil erosion	1	Václavík et al. (2013)	Soil erosion
Land protection	1	Martín-López et al. (2017) Spake et al. (2017) Levers et al. (2018)	Surface in the municipality in the protected area Protected area coverage (Natura 2000) Changes in protected areas (Natura 2000)
Local natural capital dependence	1	Hamann et al. (2015)	Demand of ecosystem services provided by the local environment (wood for heating, wood production, crop production, animal production, freshwater, building materials) Female headed households
Water use level	2	Hamann et al. (2015) Martín-López et al. (2017) Rocha et al. (2020)	Use of freshwater from a natural source (a river or spring) Water consumption Dams
Water use for irrigated crops	2	Václavík et al. (2013)	Irrigated surface
Appropriation of land for agriculture	2	Ellis and Ramankutty (2008) Raudsepp-Hearne et al. (2010) Asselen and Verburg (2012) Václavík et al. (2013) Hamann et al. (2015) Renard et al. (2015) Queiroz et al. (2015) Hanspach et al. (2016) Spake et al. (2017) Martín-López et al. (2017) Levers et al. (2018)	Surface dedicated to agriculture
Pollination and seed dispersal	3	Queiroz et al. (2015) Dittrich et al. (2017)	Amount of pollinator habitat within a buffer of 200m from crop production areas Pollination potential (habitat suitable for pollinators)
Bio-economic ecosystem disservices	4	Dressel et al. (2018)	Competition (presence of other ungulate species) Predation (presence of bears)

			Predation (presence of wolves) Fresh browsing damage on Scots pine (Pinus sylvestris)
Human Appropriation of Net Primary Production (HANPP)	4	Václavík et al. (2013) Levers et al. (2018)	HANPP HANPP harvest for arable croplands, permanent crops and grasslands
Territorial connectivity	4	Václavík et al. (2013) Hamann et al. (2015) Renard et al. (2015) Hanspach et al. (2016) Levers et al. (2018) Rocha et al. (2020) Vallejos et al. (2020)	Accessibility (travel time to major cities and market places) Distance to city Distance from main city Remoteness (travel time by car to the next town >20000) Accessibility (travel time to major city >50000) Market access index Transport network connectivity (road density)
Import and export rates of agricultural products	4	Asselen and Verburg (2012)	Market influence Market accessibility
Wild plants, algae and their outputs for food	nonpriority	Raudsepp-Hearne et al. (2010)	Maple syrup
Fibres and other materials from plants, algae and animals for direct use or processing	nonpriority	Dressel et al. (2018) Levers et al. (2018)	Index of moose forage availability Variation in moose forage availability over 10 years Grassland yields Wood production
Wild animals and their outputs for food (P)	nonpriority	Dressel et al. (2018)	Size of moose management area Number of shot moose per square kilometre Ratio of moose to other ungulate species Frequency of moose meat consumption
Biomass-based energy sources	nonpriority	Hamann et al. (2015) Dittrich et al. (2017)	Wood for cooking, wood for heating Energy crops (amount of methane provided by crops for biogas production)

		Spake et al. (2017)	Potential woody biomass supply for stemwood and logging residues
Bioremediation	nonpriority	Dittrich et al. (2017)	Ability of rivers to remove nitrogen
Bio-health ecosystem disservices	nonpriority	Dressel et al. (2018)	Number of moose-car-collisions
Human perceptions of ecosystem services	nonpriority	Sinare et al. (2016)	Use of ecosystem services reported by locals
Nitrogen fertilizer	not in our list	Václavík et al. (2013)	Fertilized surface
		Levers et al. (2018)	Fertilizer application rates [kg ha^{-1}]; <50 kg ha^{-1}, 50-150 kg ha^{-1}, >150 kg ha^{-1}
Urban solid waste	not in our list	Martín-López et al. (2017)	Urban solid waste production (Ton year^{-1} ha^{-1})
Weight of sectors in the economy	nonpriority	Václavík et al. (2013)	GDP in agriculture
			Capital stock in agriculture
		Martín-López et al. (2017)	Hotel bedroom places
		Levers et al. (2018)	Economic size of farms
			Total monetary inputs in farms
		Rocha et al. (2020)	Ratio of farmers
Land tenure	nonpriority	Hamann et al. (2015)	Area under traditional authority rule
		Dressel et al. (2018)	Level of self-organization (geographic coverage of moose management units)
			Number of sub-units (i.e. license areas) per moose management area
			Diversity index of forest ownership types
			Diversity index of agriculture ownership types
			Property size classes of private forest owners
		Levers et al. (2018)	Total utilised agricultural area (owner occupation or rented for >= 1 year)
		Vallejos et al. (2020)	Area with legal type of farmer ‘Physical Person’
			Area with land tenure regime ‘Owner’
Ethnicity	nonpriority	Hanspach et al. (2016)	Proportion of the main ethnic groups

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Appendix 6. Figures.

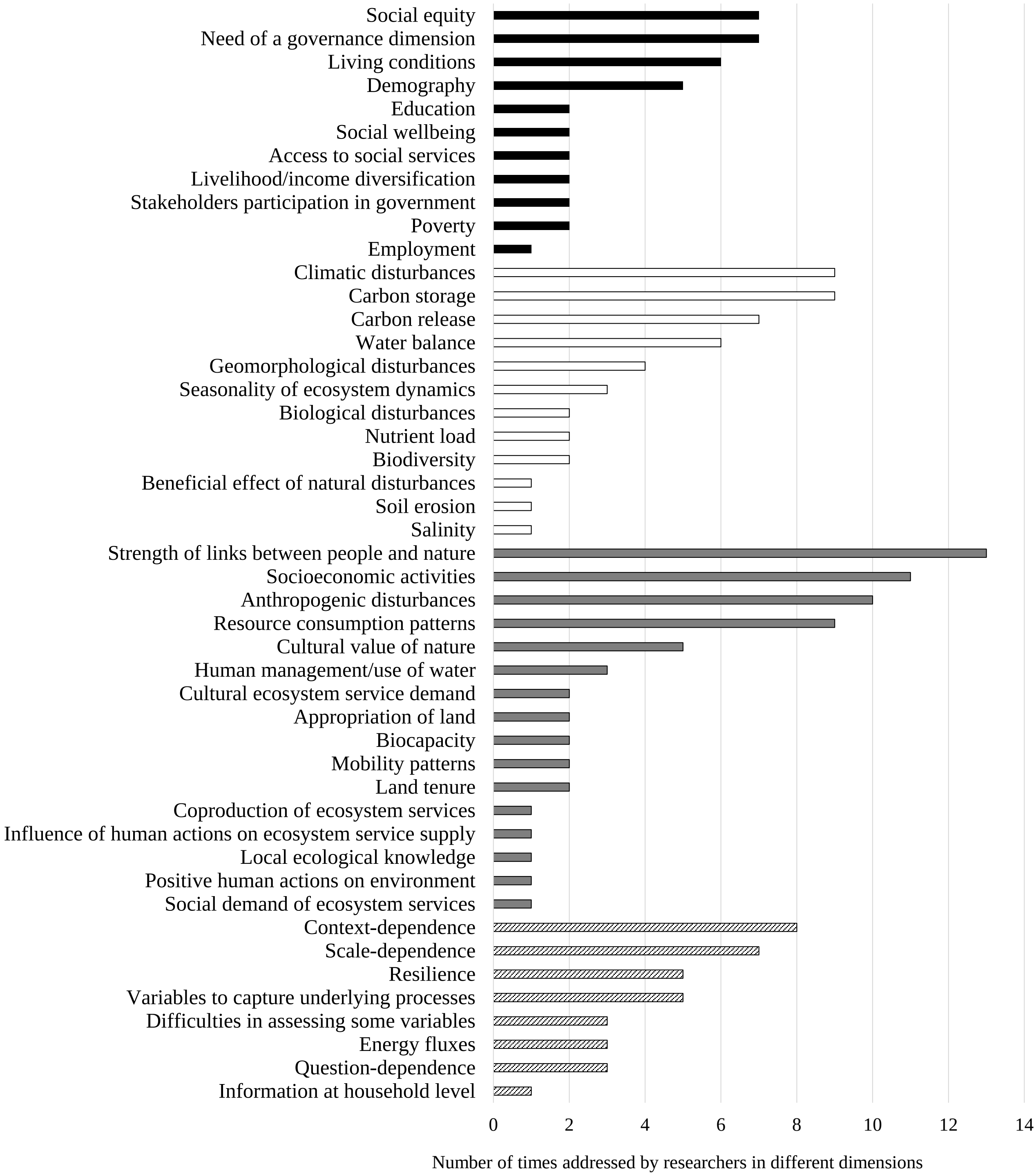
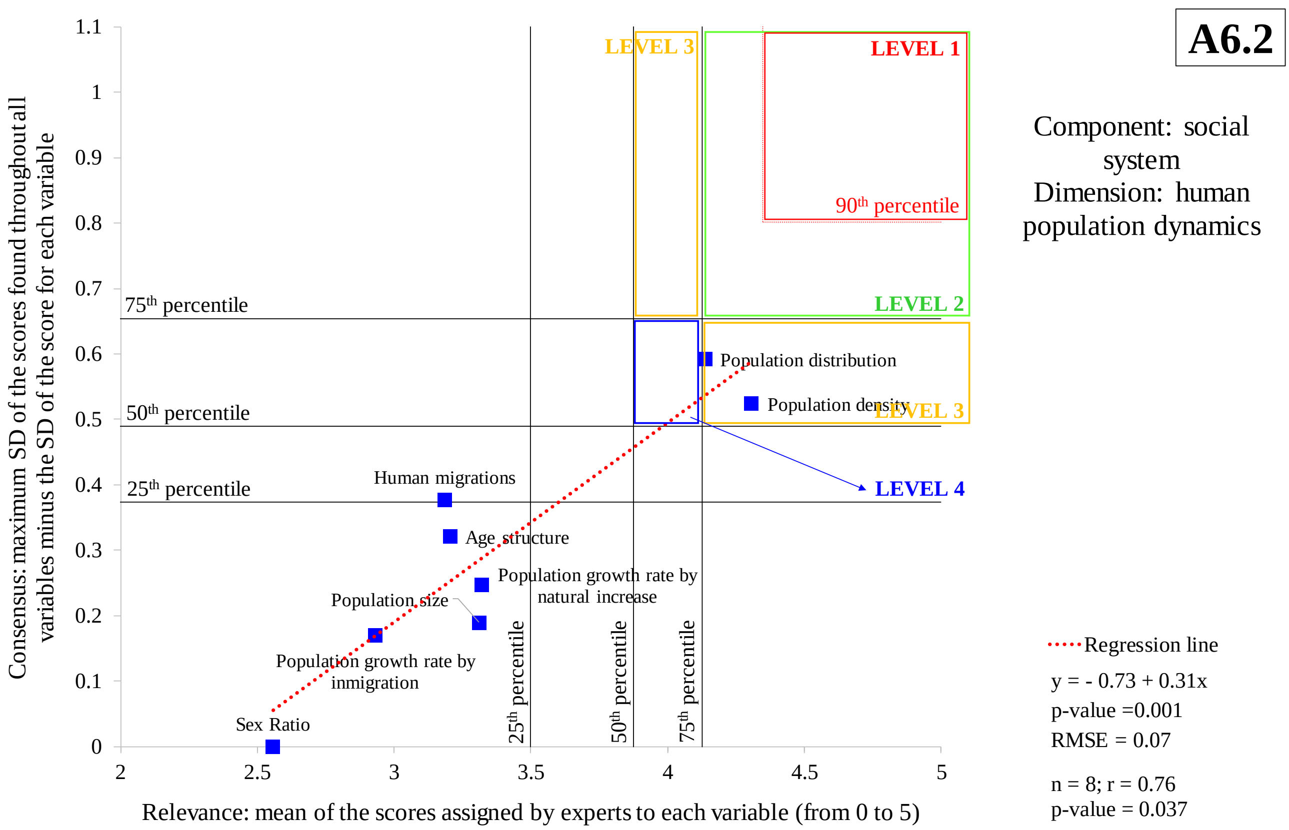


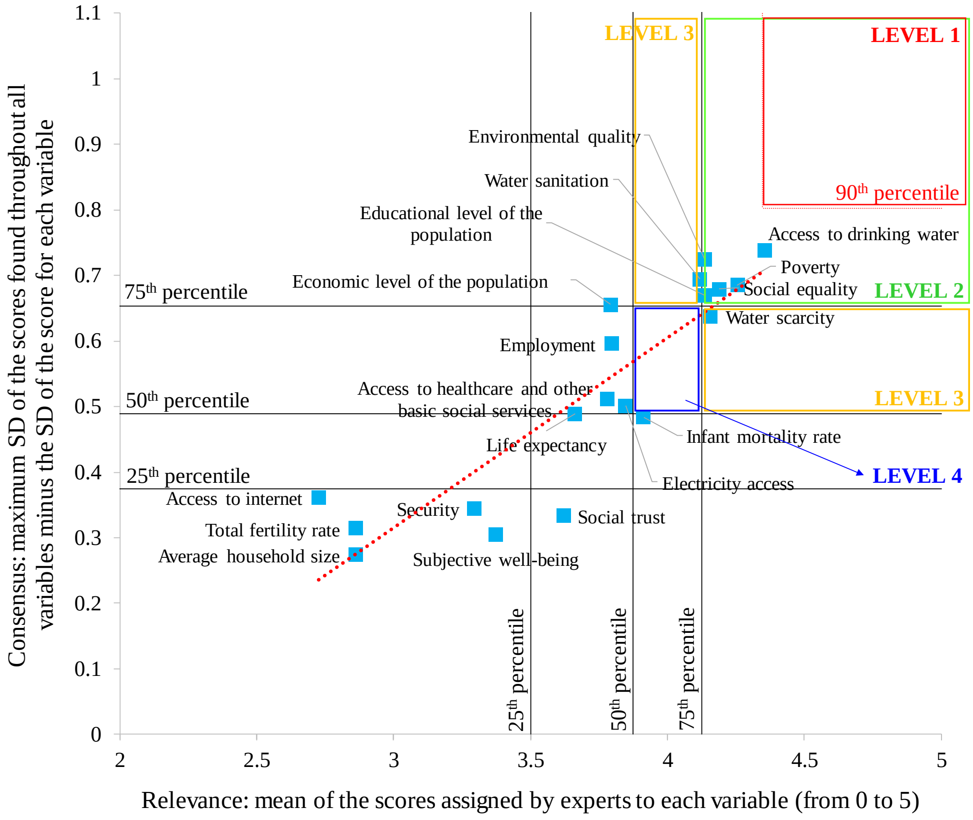
Figure A6.1. Featured topics identified from suggestions and comments in the preliminary survey, which were used to improve the preliminary list of variables and dimensions for characterizing and monitoring SES. Black, white and gray bars represent the social system, ecological system and interaction components, respectively, while stripped bars reflect issues that are transversal to the whole conceptual framework. (See also these topics in the conceptual map of Appendix 7).

Figures A6.2 to A6.14. Detail view of the relationship between average relevance and consensus obtained by the variables belonging to each dimension of social-ecological system functioning. Relevance was evaluated as the mean of the scores assigned by experts to each variable. The consensus was estimated as the difference between the maximum standard deviation of the scores found throughout the 149 variables and the standard deviation of the score for each variable (low differences indicated low consensus and high differences, high consensus). Horizontal and vertical lines represent the 25th, 50th, 75th and 90th percentiles of relevance and consensus for the whole set of variables belonging to the 13 dimensions of social-ecological functioning. Boxes over the grid illustrate the clustering of the variables by priority levels. The red box (priority level 1) includes those variables with relevance and consensus above the 90th percentile; the green box (level 2) includes those variables with both values between the 75th and 90th percentiles; the yellow box (level 3) includes those with relevance above the 75th percentile but consensus between the 50th and 75th percentiles and vice versa; and the blue box (level 4) includes variables with relevance and consensus between the 50th and 75th percentiles. At the bottom right of each figure, the equation of the regression line, the significance of the line slope (p-value) and the root-mean-square error (RMSE) are indicated, as are the number of variables (n), the Spearman's correlation coefficient (r) and its significance (p-value).



A6.3

Component: social system
Dimension: wellbeing and development

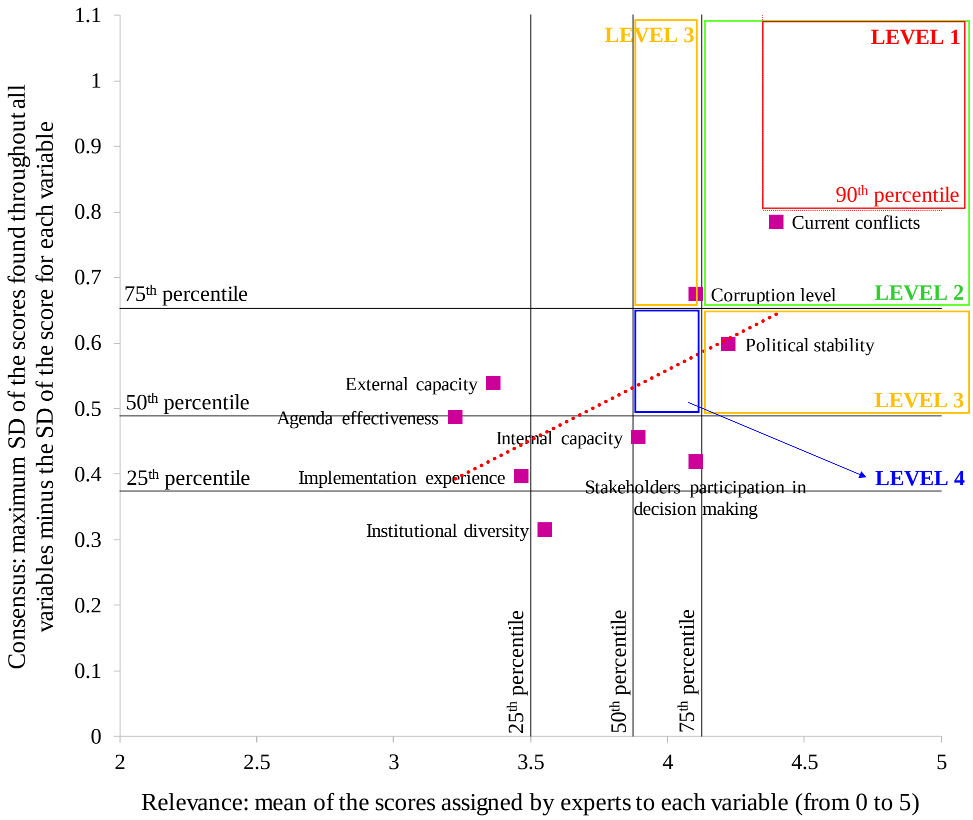


Regression line
y = - 0.55 + 0.29x
p-value < 0.001
RMSE = 0.07

n = 19; r = 0.87
p-value < 0.001

A6.4

Component: social system
Dimension: governance

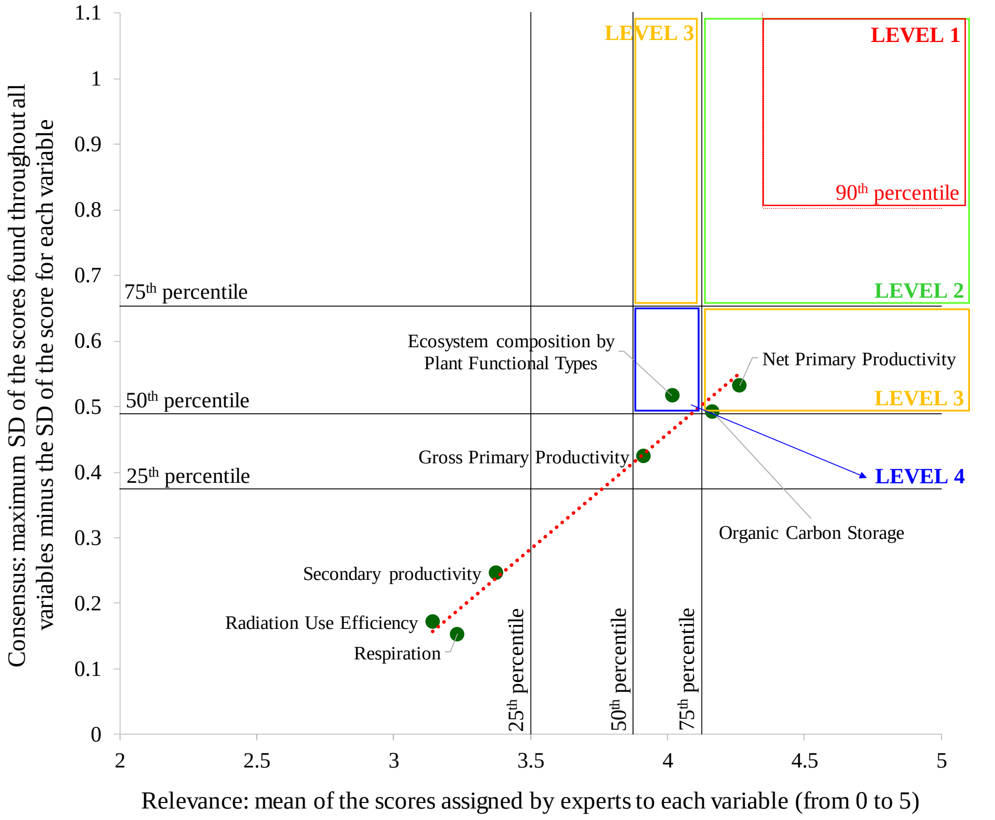


Regression line
y = - 0.30 + 0.21x
p-value = 0.079
RMSE = 0.11

n = 9; r = 0.51
p-value = 0.160

A6.5

Component: ecological system
Dimension: organic carbon dynamics

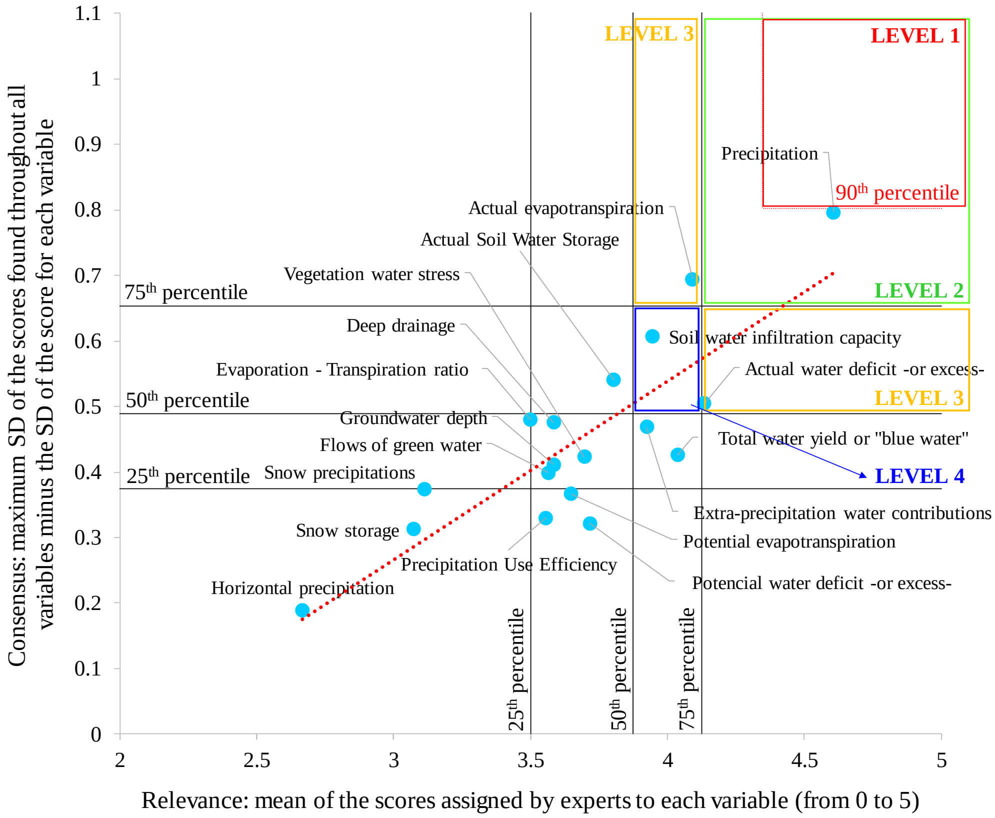


Regression line
y = - 0.95 + 0.35x
p-value < 0.001
RMSE = 0.03

n = 7; r = 0.93
p-value = 0.007

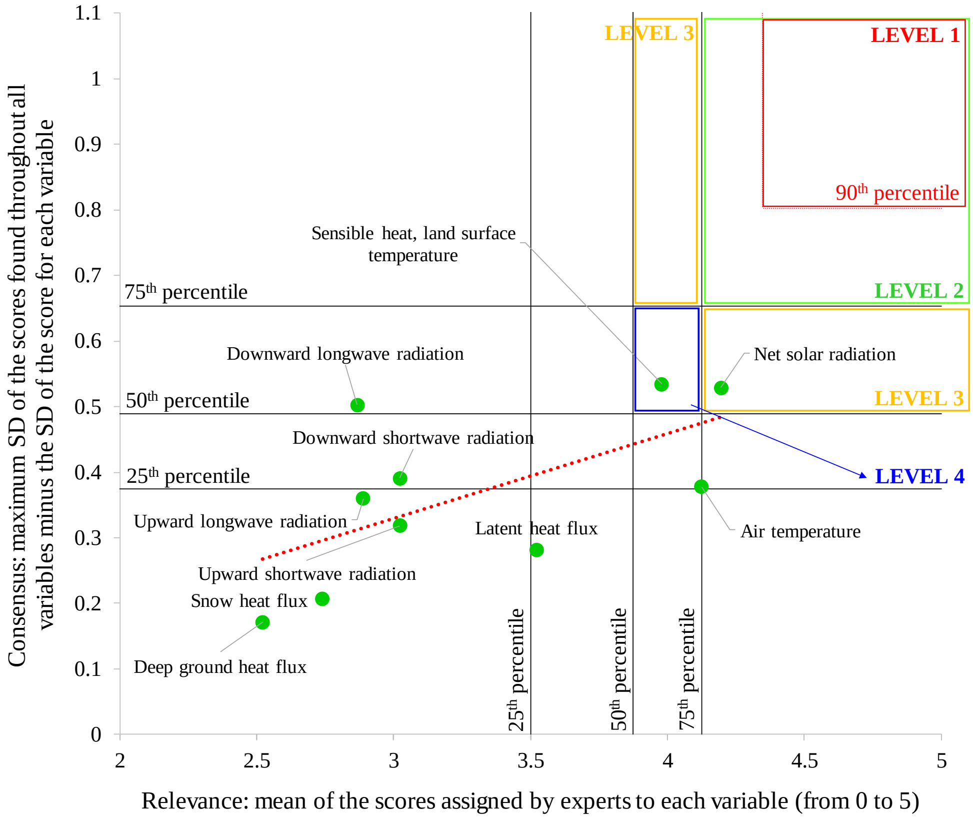
A6.6

Component: ecological system
Dimension: water dynamics



Regression line
y = - 0.55 + 0.27x
p-value < 0.001
RMSE = 0.08

n = 18; r = 0.75
p-value < 0.001

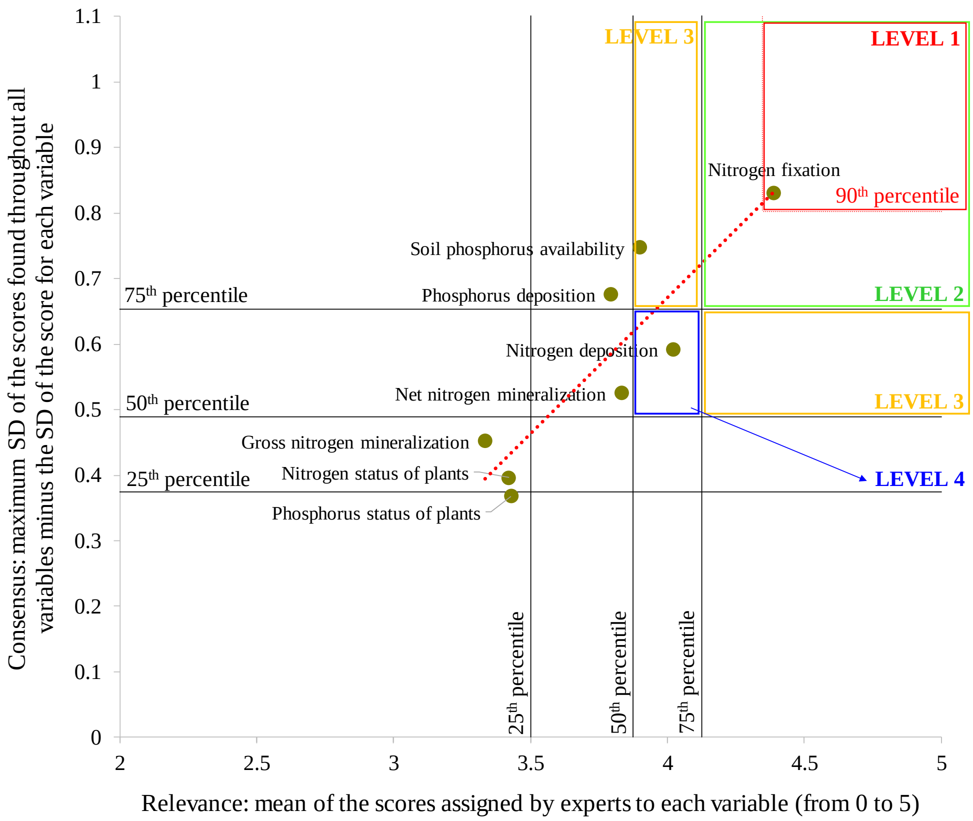


A6.7

Component: ecological system
Dimension: surface energy balance

Regression line
y = - 0.06 + 0.13x
p-value = 0.055
RMSE = 0.10

n = 10; r = 0.65
p-value = 0.050



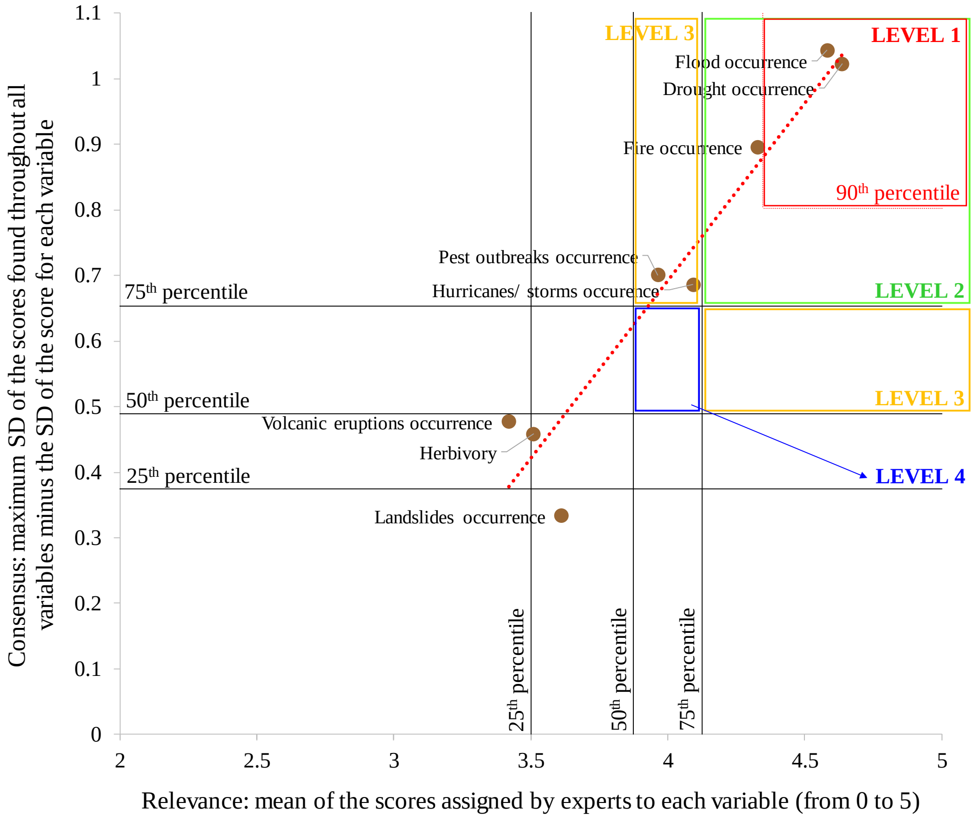
A6.8

Component: ecological system
Dimension: nutrient cycling

Regression line
y = - 0.99 + 0.41x
p-value = 0.004
RMSE = 0.07

n = 8; r = 0.79
p-value =0.028

A6.9

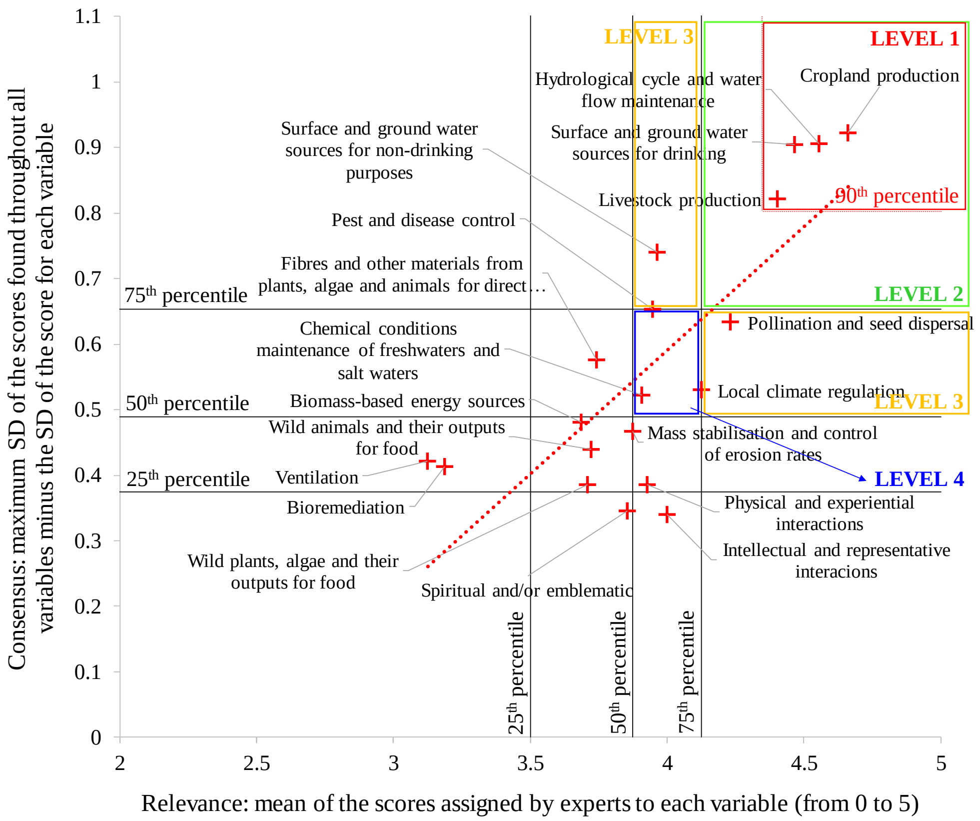


Component: ecological system
Dimension: disturbance regime

Regression line
y = - 1.47 + 0.54x
p-value < 0.001
RMSE = 0.07

n = 8; r = 0.86
p-value = 0.011

A6.10

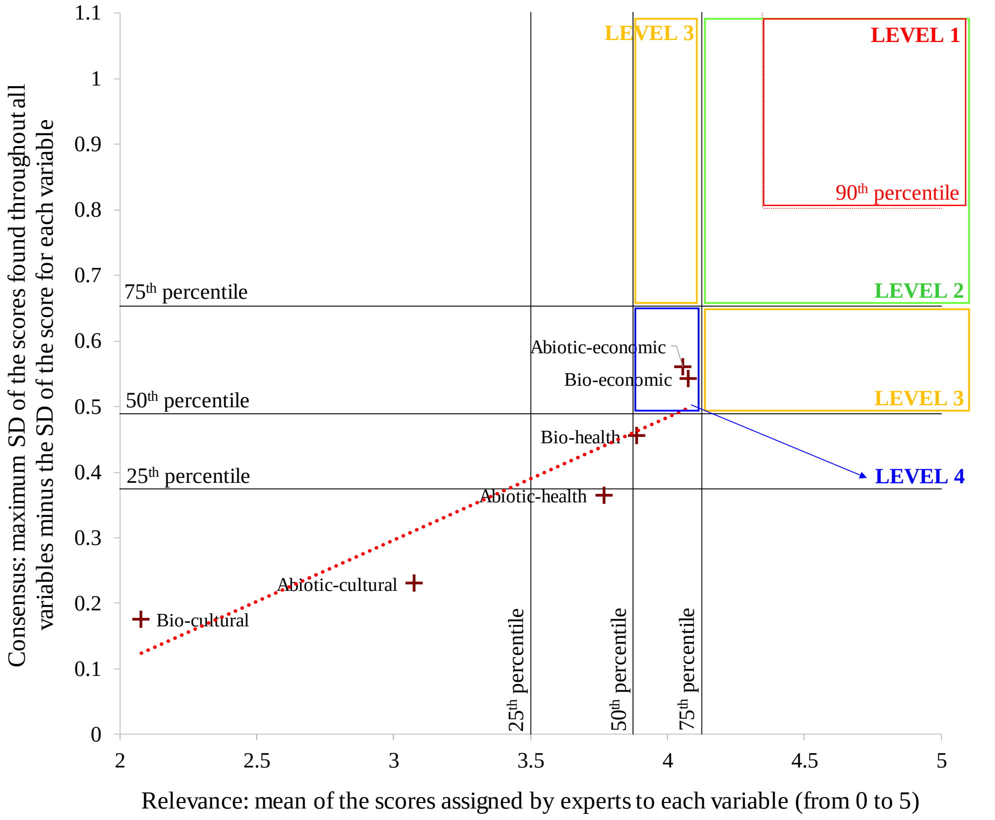


Component: interactions
Dimension: ecosystem service supply

Regression line
y = - 0.92 + 0.38x
p-value < 0.001
RMSE = 0.12

n = 19; r = 0.69
p-value = 0.001

A6.11

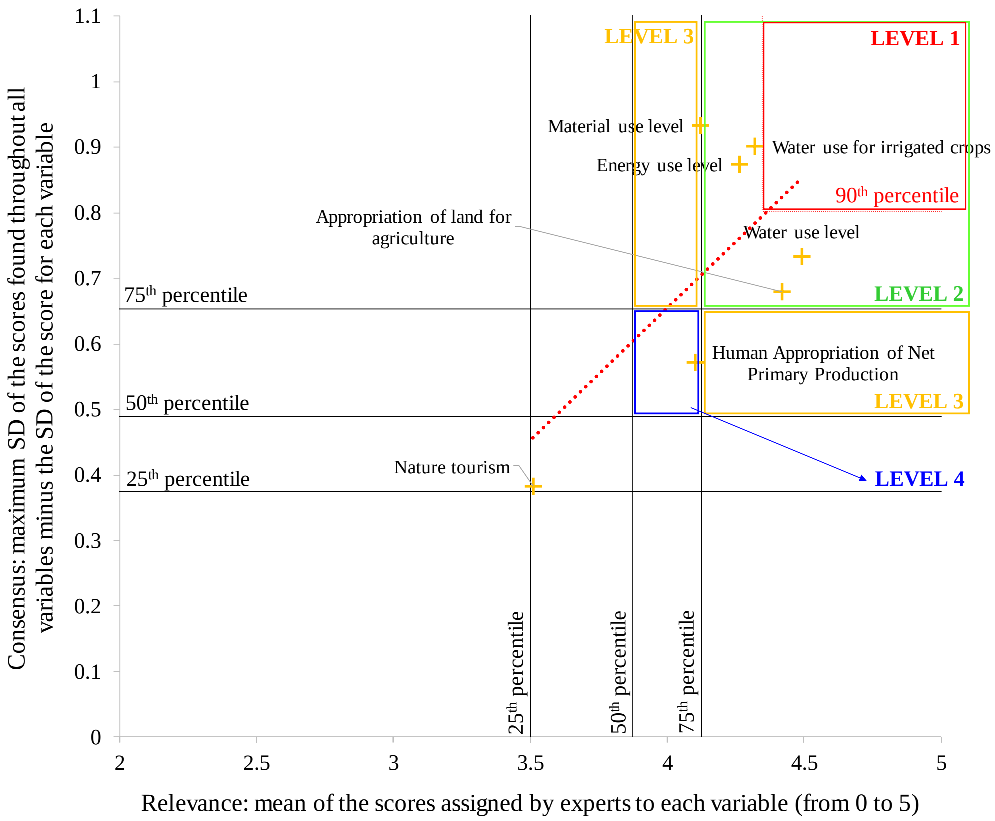


Component: interactions
Dimension: ecosystem disservice supply

Regression line
y = - 0.26 + 0.19x
p-value = 0.011
RMSE = 0.06

n = 6; r = 0.94
p-value = 0.017

A6.12



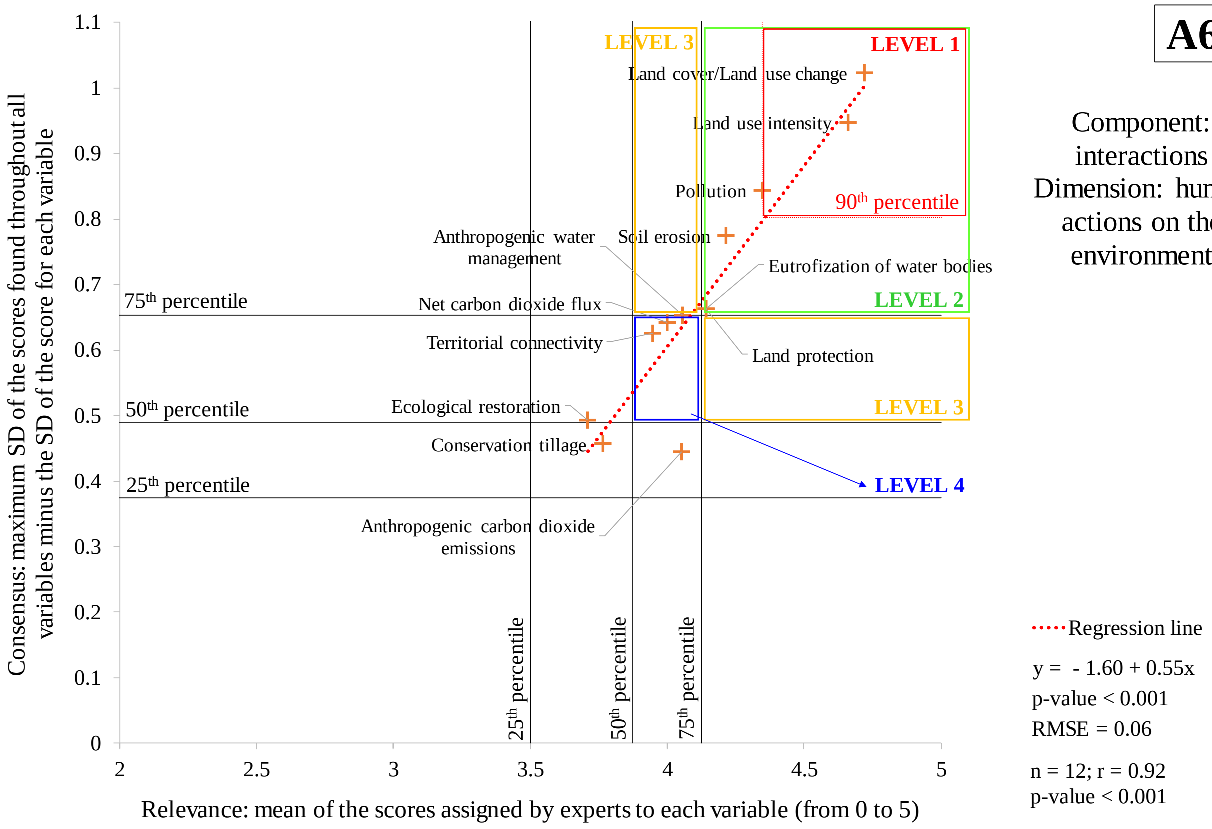
Component: interactions
Dimension: ecosystem service demand

Regression line
y = - 0.96 + 0.40x
p-value = 0.107
RMSE = 0.14

n = 7; r = 0.36
p-value =0.444

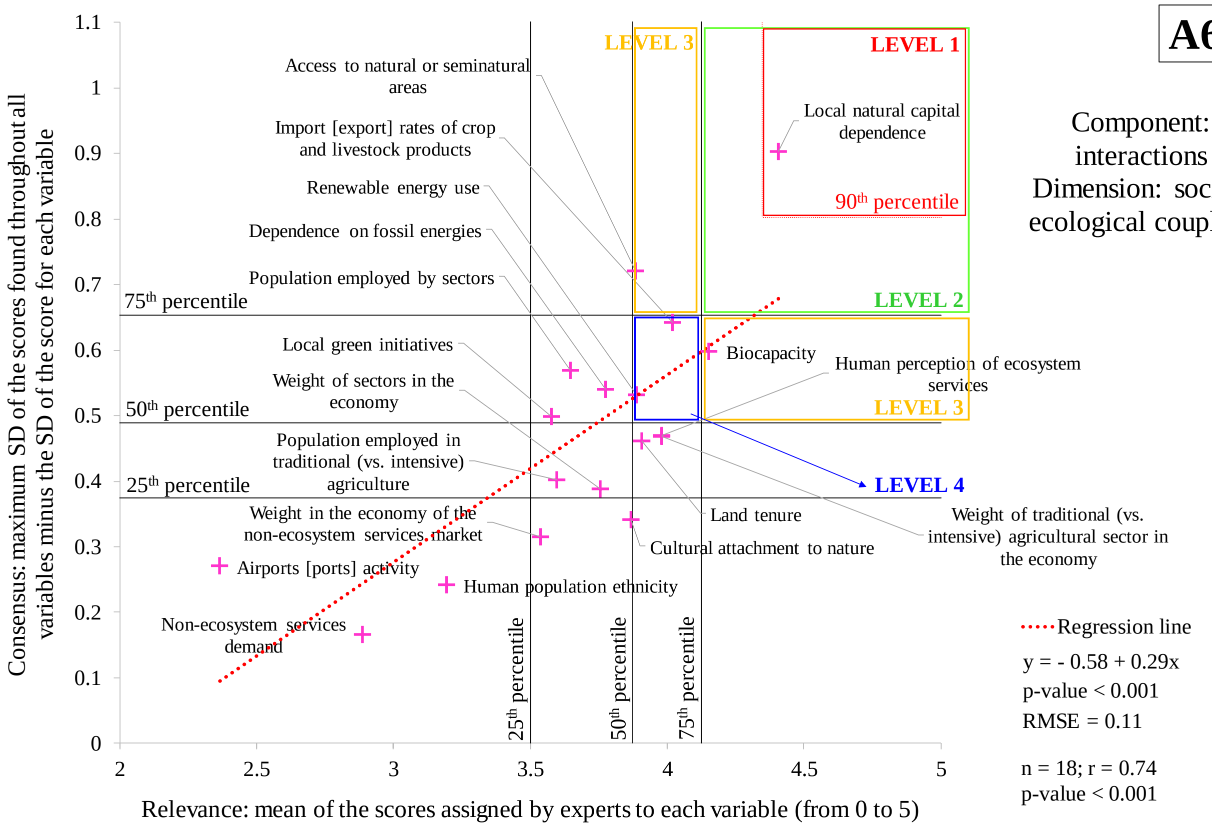
A6.13

Component: interactions
Dimension: human actions on the environment



A6.14

Component: interactions
Dimension: social-ecological coupling



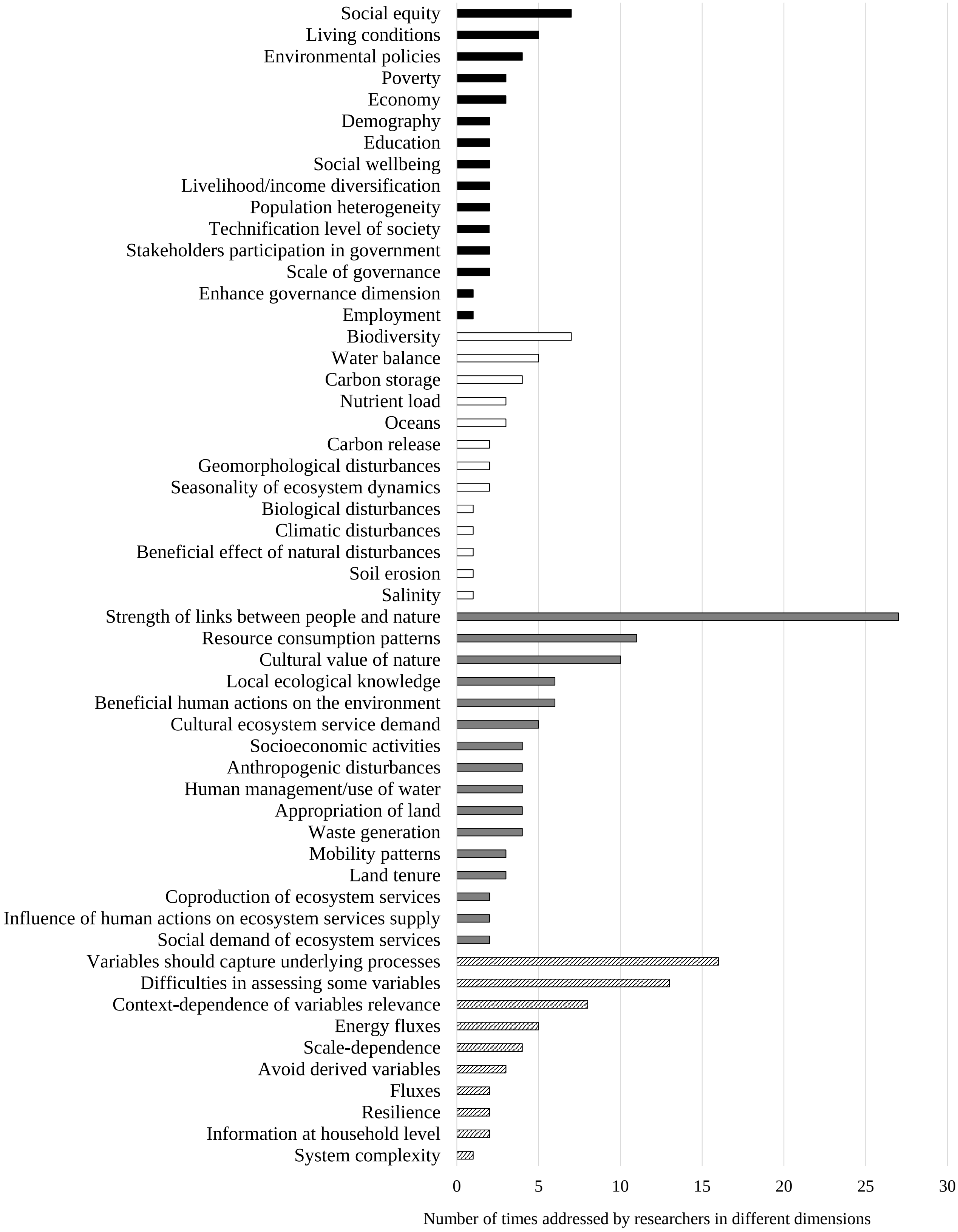
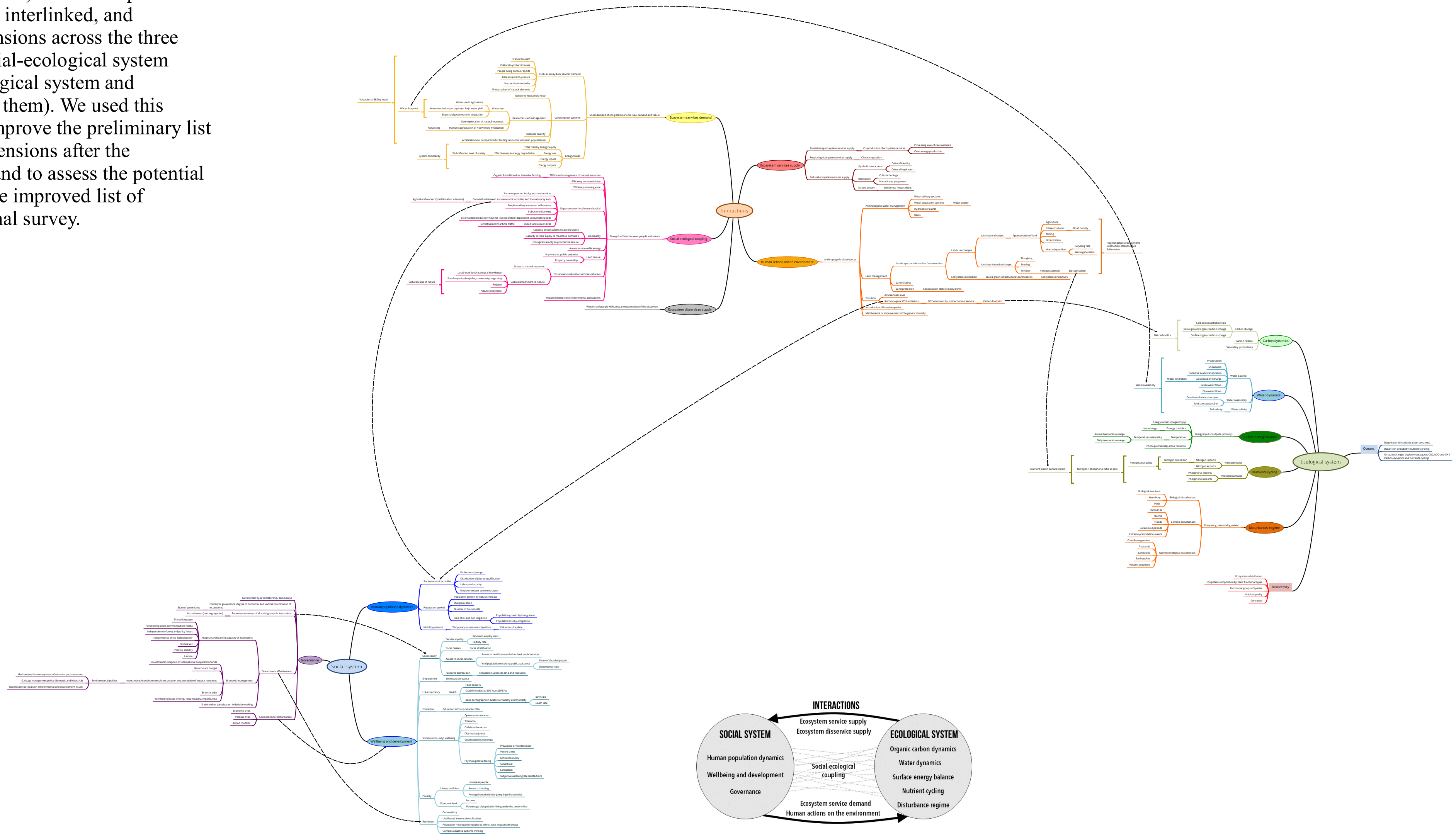


Figure A6.15. Extended version of Figure 4 in the manuscript. Featured topics addressed by respondents related to potential biases and gaps in the list of variables identified from comments and suggestions in the final survey. Black, white and gray bars represent the social system, ecological system and interaction components, respectively, while stripped bars reflect issues that are transversal to the whole conceptual framework. (See also these topics in the conceptual map of Appendix 7).

Appendix 7. Conceptual map with keywords annotated from comments and suggestions provided by respondents in both surveys (zoom in to see in detail). The concepts are shown hierarchically interlinked, and structured into dimensions across the three components of a social-ecological system (social system, ecological system and interactions between them). We used this conceptual map to improve the preliminary list of variables and dimensions after the preliminary survey, and to assess the potential biases and gaps in the improved list of variables after the final survey.



Appendix 8. Survey results.

Please click here to download file 'appendix8.xlsx'.

Appendix 9. Acknowledgement to survey respondents.

We gratefully acknowledge the participation in the preliminary survey to:

Last name	First name	Institution/Department	Area of expertise
Açma	Bülent	Anadolu University - Department of Economy (Turkey)	Social sciences Sustainability Science Environmental management / Territorial planning
Balvanera	Patricia	Universidad Nacional Autónoma de México - Instituto de Investigaciones en Ecosistemas y Sustentabilidad (Mexico)	Biophysical sciences Sustainability Science Environmental management / Territorial planning Biodiversity Science Ecosystem services Social-ecological systems
Bentley-Brymer	Amanda	University of Idaho - Rangeland Center (USA)	Social sciences Environmental management / Territorial planning
Brown	Dan	University of Michigan - Graham Sustainability Institute (USA)	Sustainability Science Environmental management / Territorial planning Remote sensing
Chapin	Terry	University of Alaska Fairbanks - Institute of Arctic Biology (USA)	Sustainability Science
Ellis	Erle	University of Maryland Baltimore County - Geography & Environmental Systems (USA)	Biophysical sciences Sustainability Science Environmental management / Territorial planning Remote sensing Biodiversity Science
Escribano-Velasco	Paula	Andalusian Center for the Assessment and Monitoring of Global Change – University of Almería (Spain)	Environmental management / Territorial planning Remote sensing
Fabricius	Christo	Nelson Mandela University - Sustainability Research Unit (South Africa)	Sustainability Science

García-Nieto	Ana Paula	Mediterranean Institute of marine and terrestrial Biodiversity and Ecology (France)	Ecology
Garcia-Valdecasas	José Ignacio	University Carlos III de Madrid – Department of Social Sciences (Spain)	Social sciences
Gibout	Christophe	Université du Littoral Côte d'Opale (France)	Social sciences
Golland	Ami	Stockholm University - Stockholm Resilience Centre (Sweden)	Sustainability Science Electronic engineering
Hernandez-Zamorano	Isaac Rhodart	Universidad Nacional Autónoma de México - National School of Higher Studies Morelia (Mexico)	Enviromental Science
Hevia	Glenda Denise	Centre for Studies on Marine Systems, CESIMAR - CCT CENPAT- CONICET (Argentina)	Environmental management / Territorial planning Biodiversity Science Avian breeding biology
Hinton	Jennifer	Stockholm University - Stockholm Resilience Centre (Sweden)	Social sciences Sustainability Science
Ignatov	Alex	Russian University of People's Friendship - R&D Center PhytoEngineering LLC (Russia)	Sustainability Science Biodiversity Science
Leitão	Pedro J.	Technische Universität Braunschweig - Department of Landscape Ecology and Environmental Systems Analysis (Germany)	Remote sensing Biodiversity Science
Locatelli	Bruno	University of Montpellier - Forests and Societies research unit - CIRAD (France)	Sustainability Science
Martin	Romina	Stockholm University - Stockholm Resilience Centre (Sweden)	Sustainability Science
Martinez-Harms	Maria Jose	Pontifical Catholic University of Chile – Department of Ecology (Chile)	Sustainability Science Environmental management / Territorial planning Biodiversity Science

Martin-Lopez	Berta	Leuphana University of Luneburg - Institute for Ethics and Transdisciplinary Sustainability Research (Germany)	Sustainability Science
Nagendra	Harini	Azim Premji University - School of Development (India)	Sustainability Science Remote sensing Biodiversity Science
Narducci	Jenna	Boise State University – Department of Geosciences (USA)	Environmental management / Territorial planning
Niquil	Nathalie	French National Centre for Scientific Research - Institut écologie et environnement (France)	Biodiversity Science Ecology
Noss	Reed	Florida Institute for Conservation Science (USA)	Environmental management / Territorial planning, Biodiversity Science
Pandey	Rajiv	Indian Council of Forestry Research &Education (India)	Vulnerability and Adaptation in Social-ecological systems
Pardo	Mercedes	University Carlos III de Madrid - Sociology of Climate Change and Sustainable Development (Spain)	Social sciences
Rodríguez	Jon Paul	Instituto Venezolano de Investigaciones Científicas - Centro de Ecología (Venezuela)	Biodiversity Science
Romero-Calcerrada	Raúl	King Juan Carlos University – Faculty of Legal and Social Sciences (Spain)	Environmental management / Territorial planning Remote sensing
Ruggeri	Daniela	University of Cagliari - Dipartimento di Ingegneria Civile, Ambientale e Architettura (Italy)	Environmental management / Territorial planning
Vallet	Améline	AgroParisTech – CIRED (France)	Biophysical sciences Social sciences

… and to 25 additional researchers who anonymously filled the preliminary survey

We also gratefully acknowledge the participation in the final survey to:

Last name	First name	Institution/Department	Area of expertise
Baró	Francesc	Autonomous University of Barcelona - Institute of Environmental Sciences and Technologies (Spain)	Sustainability Science Environmental management / Territorial planning
Berbery	E. Hugo	University of Maryland - Earth System Science Interdisciplinary Center (USA)	Climate Sciences
Blenckner	Thorsten	Stockholm University - Stockholm Resilience Centre (Sweden)	Biophysical sciences Sustainability Science Biodiversity Science
Blum	Alfredo	Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente (Uruguay)	Social sciences Sustainability Science Environmental management / Territorial planning
Castro	Antonio J.	University of Almería - Department of Biology and Geology (Spain)	Biophysical sciences Social sciences Sustainability Science
Ceausu	Silvia	Aarhus University - Department of Bioscience (Denmark)	Environmental management / Territorial planning Biodiversity Science
Couvet	Denis	Muséum National d'Histoire Naturelle (France)	Biodiversity Science
Felipe-Lucia	María	Helmholtz Centre for Environmental Research - Centre for Integrative Biodiversity Research (iDiv) (Germany)	Biophysical sciences Social sciences Sustainability Science Environmental management / Territorial planning Biodiversity Science Ecosystem services
Filatova	Tatiana	University of Twente - Department of Governance and Technology for Sustainable Development (The Netherlands)	Social sciences Sustainability Science Environmental management / Territorial planning
Fischer-Kowalski	Marina	University of Natural Resources and Life Sciences Vienna - Institute of Social Ecology (Austria)	Social sciences Sustainability Science
Furman	Eeva	Finnish Environment Institute | ymparisto - Centre for Environmental Policy (Finland)	Social sciences Sustainability Science Environmental management / Territorial planning Biodiversity Science

Garcia del Amo	David	Autonomous University of Barcelona - Institute of Environmental Sciences and Technologies (Spain)	Sustainability Science
Geijzendorffer	Ilse	Tour du Valat - Research Institute for the conservation of Mediterranean Wetlands (France)	Biophysical sciences Sustainability Science Environmental management / Territorial planning Biodiversity Science Ecosystem services
Ifejika Speranza	Chinwe	Universität Bern - Centre for Development and Environment - Institute of Geography (Switzerland)	Sustainability Science
López-Rodríguez	María D.	University of Almeria - Andalusian Center for the Assessment and Monitoring of Global Change (Spain)	Sustainability Science
Luque	Sandra	National Research Institute of Science and Technology for Environment and Agriculture - UMR TETIS Territoires, Environnement, Télédétection et Information Spatiale (France)	Biophysical sciences Sustainability Science Environmental management / Territorial planning Remote sensing Biodiversity Science
Macchi	Leandro	CONICET - Instituto de Ecología Regional (IER) - Universidad Nacional de Tucumán (Argentina)	Sustainability Science Biodiversity Science
Mahecha	Miguel	Max Planck Institute for Biogeochemistry - Department of Biogeochemical Integration (Germany)	Biophysical sciences Sustainability Science Remote sensing Biodiversity Science
Martinez-Harms	Maria Jose	Pontifical Catholic University of Chile – Department of Ecology (Chile)	Sustainability Science Environmental management / Territorial planning Biodiversity Science
Munday Seguel	Daniel	Economic Commission for Latin America and the Caribbean (Chile)	Environmental management / Territorial planning
Onaindia	Miren	University of the Basque Country – Department of Plant Biology and Ecology (Spain)	Biophysical sciences Environmental management / Territorial planning Biodiversity Science

Ozán	Ivana	CONICET - Instituto de Geociencias Básicas, Ambientales y Aplicadas de Buenos Aires (Argentina)	Social sciences Geoarchaeology
Piñeiro	Gervasio	Universidad de Buenos Aires - Facultad de Agronomía (Argentina)	Biophysical sciences Remote sensing
Requena	Juan Miguel	Boise State University - Department of Biological Sciences (USA)	Remote sensing Biodiversity Science
Roche	Philip	National Research Institute of Science and Technology for Environment and Agriculture IRSTEA - Lands Department (France)	Remote sensing Biodiversity Science
Rosales Benites de Franco	Marina	Federico Villarreal National University - Biological Sciences (Peru)	Biodiversity Science
Saldivar	Americo	Universidad Nacional Autónoma de México – Faculty of Economy (Mexico)	
Volk	Martin	UFZ-Helmholtz Centre for Environmental Research - Department of Computational Landscape Ecology (Germany)	Biophysical sciences Sustainability Science Environmental management / Territorial planning Biodiversity Science
Watmough	Gary	The University of Edinburgh - School of GeoSciences (UK)	Sustainability Science Remote sensing

… and to 30 additional researchers who anonymously filled the final survey