Environmental Science and Policy 107 (2020) 211–216

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Review

From concepts to comparisons: A resource for diagnosis and measurement in social-ecological systems

Michael Cox[a,*], Sergio Villamayor-Tomas[b], Natalie C. Ban[c], Graham Epstein[d], Louisa Evans[e], Forrest Fleischman[f], Mateja Nenadovic[g], Gustavo A Garcia Lopez[h], Frank van Laerhoven[i], Chanda Meek[j], Irene Perez Ibarra[k], Michael Schoon[l]

[a] Environmental Studies Program, Dartmouth College, USA
[b] Institute of Environmental Science and Technology, Autonomous University of Barcelona, Spain
[c] School of Environmental Studies, University of Victoria, Canada
[d] School of Environment, Resources and Sustainability, University of Waterloo, Canada
[e] Geography Department, University of Exeter, UK
[f] Department of Forest Resources, University of Minnesota, USA
[g] Nicholas School of the Environment, Duke University, USA
[h] Graduate School of Planning, University of Puerto Rico- Rio
[i] Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands
[j] Department of Political Science, University of Alaska Fairbanks, USA
[k] School of Social Work, Columbia University in the City of New York, USA
[l] School of Sustainability, Arizona State University, USA

ARTICLE INFO

Keywords:
Diagnosis
SESMAD
Social-ecological systems
Variable measurement
Variable repository

ABSTRACT

A central challenge facing the study the environmental governance is the lack of commonunderstanding of important concepts. Critical concepts such as social boundaries, property rights, and resource dependence are selected and measured inconsistently across research projects and field settings, producing results that are difficult to compare. This stymies the accumulation of scientific evidence regarding the most effective ways to address challenging environmental problems. As members of the Social-ecological systems meta-analysis database (SESMAD) project, we have addressed this challenge by developing a repository of variables associated with many of the most important concepts across a range of fields related to environmental governance. In this paper we describe the infrastructure behind the repository, the range of variables it includes, and how it can enable scholars across a range of fields to more systematically select and measure the variables to include in their analyses.

1. Introduction

There are diverse approaches for studying human-environment interactions, including conservation biology, institutional analysis and political ecology. Research across these fields involves many empirical factors that characterize complex, real-world settings (Agrawal, 2003; Liu et al., 2007). A central challenge facing these fields is the lack of a common understanding regarding the meaning of key concepts and the set of relevant variables (Pullin, 2015). For example, leadership, a key concept across multiple fields, has been viewed by some collective action scholars as occurring when actors make significant contributions to the provision of public goods (Glowacki and von Rueden, 2015). Alternatively, other scholars have equated leadership to certain positions, degree of influence in a community, or certain socio-demographic features like education or wealth (Meinzen-Dick et al., 2002; Villamayor-Tomas et al., 2014; Vedeld, 2000). While some studies point to the special skills of leaders to promote institutional development and adaptation (Meinzen-Dick et al., 2002; Olsson et al., 2004), others point to their privileged position to change rules to their own advantage (Andersson and Ostrom, 2008). Results from empirical studies on the importance of leadership are therefore mixed.

This lack of common understanding leads to inconsistent results in several ways (see Araral, 2014 and Cox et al., 2016a, 2016b for a broader discussion). First, in quantitative observational work, variable choice can be highly idiosyncratic. Standard protocols for describing why some variables and not others are included in empirical models

* Corresponding author.
E-mail address: michael.e.cox@dartmouth.edu (M. Cox).

https://doi.org/10.1016/j.envsci.2020.02.009
Received 11 July 2019; Received in revised form 5 January 2020; Accepted 11 February 2020
Available online 13 March 2020
1462-9011/ © 2020 Elsevier Ltd. All rights reserved.

generally do not exist in the literature. When hypotheses are included to motivate the variables that are included, this is usually not accompanied by a discussion of why many others were not included. Combining this with the plethora of variables that are known to be relevant can lead to challenges in the specification of empirical models. From a quantitative perspective, it leads to the likelihood of committing two analytical errors: (1) including variables that we should exclude, and (2) excluding variables that we should include. Including too many variables can rapidly erode statistical power, and lead to over-determination, multi-collinearity and post hoc theorizing of coincidentally significant results that cannot be reproduced. Including too few variables, meanwhile, can bias estimates of the effects of variables through endogeneity. Finally, when the reasons for variable choice are underdeveloped and thus not standardized, this can leave more room for confirmation biases to affect methods and results.

In addition to variable selection, the measurement of included variables can be idiosyncratic as well. When differences in findings are artifacts of varying measurement protocols, we cannot be sure that comparisons across study sites and projects are meaningful. Without comparable results, we cannot accumulate a core set of established facts, the hallmark of successful scientific research programs and sound policy advice (Pullin, 2012).

Addressing these challenges to produce consistent information across empirical settings poses an immense collective action problem as it requires researchers to coordinate their efforts to consistently define and measure concepts. Ostrom (2007, 2009) social-ecological system (SES) framework was ostensibly designed to address coordination problems in social-ecological research by providing scholars with a common language for empirical inquiry. A key part of Ostrom's argument was that a "diagnostic approach", based on the arrangement of variables along multiple tiers, would help scholars decide what mattered in a particular context. This was designed to help deal with the problems outlined above, particularly with respect to the plethora of relevant variables. This approach has been elaborated by others (Young et al., 2018), suggesting the development of a "diagnostic toolkit", but to date few resources are available that enable the diagnosis of SESs in the way that Ostrom envisioned.

Furthermore, although the SES framework provides a useful entry point for research and analysis, in a recent review of applications of the SES framework, Partelow (2018) highlights the lack of "general methods, guidelines or procedures", which has resulted in the continued use of inconsistent definitions, indicators and measures. As a result, Ostrom's framework has not contributed to advances in cumulative understanding as much as many had hoped (Thiel et al., 2015; Schlager and Cox, 2017).

In this paper we present an effort to address this suite of problems in the form of a repository of social-ecological variables, which could form the basis for a diagnostic, social-ecological toolkit. This was collectively developed by the authors to address challenges in selecting, defining and measuring a set of variables associated with well-established concepts relevant for the study of human-environment interactions, as well as providing tools for case comparison (https://sesmad.dartmouth.edu/variables). We developed the variables repository as a part of the social-ecological systems meta-analysis database (SESMAD) project, which built upon Ostrom's SES framework (Cox, 2014). The SESMAD project was originally developed to systematically code and compare large-scale commons (Ban et al., 2017; Davies et al., 2018; Fleischman et al., 2014). It has, however, also been applied to the study of small periodically harvested closures in Fiji (Jupiter et al., 2017) and supported a synthetic summary of important theories of natural resource governance (Cox et al., 2016a). While the variables we included were intended to support our specific project goals, we hope that it will be built upon and expanded by interested scholars. No similar repository exists to address the challenges of variable identification, definition, measurement for the study of human-environment interactions, although some similar efforts exist for specific fields or sectors: e.g. Salafsky et al. (2008) (http://www.conservationmeasures.org/); Wollenberg et al. (2007) and Chhatre and Agrawal (2009) (ifriresearch.net). Below we present our methods for constructing the repository, describe the variables it contains, how it can be used to implement Ostrom's diagnostic framing, and discuss its limitations and implications for future work.

2. Methods

Identifying and defining variables relevant to the study of human-environment interactions required several steps. The first of these was to identify scientific concepts across the relevant literatures. Scientific concepts reflect theoretically important ideas and narratives without explicit reference to measurement, whereas variables are associated with a well-defined range of possible values across a range of observations (Adcock, 2001). For this step, we first identified scientific concepts that can be used to operationalize Ostrom's SES framework (Ostrom, 2007) and related approaches of studying human-environment interactions (e.g., Binder et al., 2013). We used the SES framework as a starting point by including scientific concepts identified therein. We then looked for gaps by reviewing some of the critiques of the framework and related fields (Armitage, 2007; Clement, 2010), and added concepts associated with these critiques. For example, the SES framework has been criticized for its simplistic conceptualization of ecological systems (Epstein et al., 2013), and thus we reviewed concepts commonly considered in the fields of conservation science (Lovett et al., 2005) and resilience (Carpenter et al., 2001). We also drew on work from political economy and political ecology, which has emphasized the role of state policies, corporate actors and market forces (Robbins, 2011).

Second, we operationalized the concepts by creating well-defined variables (see Table 1). Creating variable definitions was a collaborative effort amongst co-authors. Individuals with backgrounds in relevant fields (e.g., common pool resources, political ecology, conservation science, resilience) took the lead in defining variables in their respective fields. To refine the variable definitions, we referred to key references and discussed each of the draft variable definitions in three in-person meetings as well as in a series of conference calls over two years. These discussions clarified varying interpretations of the variables and resulted in clearer descriptions.

In some cases, a single concept was operationalized into multiple variables. For example, studies criticizing Ostrom (1990) boundaries design principle have argued that in many systems, fuzzier social or geographic boundaries are needed to facilitate more flexible, ad hoc arrangements between participants (Cox et al., 2010). This indicates that two variables are needed to capture the operation of boundaries: their "clarity" in the mindsets of resources users and their "flexibility" in adapting rules regarding membership and access to fluctuations in resource condition or the user group (for example, seasonal availability of pastureland in rangeland systems, or demographic changes).

Third, we entered a formal description of the variables into the variables table in the SESMAD relational database (https://sesmad.dartmouth.edu/manual/pages), and specified each variable's relationship to other objects in this database, namely the studies and theories tables, as well a set of empirical tables describing the cases coded into SESMAD. The SESMAD theories table contains theories (https://sesmad.dartmouth.edu/theories) that have been published in academic fields that study human-environment interactions (Cox et al., 2016b). To express these theories, we linked them to the variables that are used to capture their narrative arguments. Additionally, when appropriate, variables are linked to the studies that were used to inspire their definition and specification (https://sesmad.dartmouth.edu/studies).

Once the variables were entered, we tested them by coding their values for five test cases, which were also entered into the SESMAD database and subsequently published (Cox, 2014; Epstein et al., 2014;

Table 1
Information included about each variable in the repository. The component type category is based on the subsystems of a social-ecological system as identified by Ostrom (2007). In the SESMAD database, resource units and resource systems were combined into one larger category, environmental commons. Further information can be found on the SESMAD website. See Appendix A for a discussion of the themes a variable can be assigned to. The final column presents an example of values for the Actor Group Boundary Clarity variable from the database. This is mostly inspired from Ostrom (1990) second design principle, which discusses the importance of such boundaries.

Field	Description	Values for Actor Group Boundary Clarity variable
Type/ Measurement scale	Whether the variable is measured at the (1) interval, (2) ordinal, (3) categorical, or (4) open-text level.	Ordinal
Component Type	What type of SES subsystem (i.e.actor, governance system, environmental commons) the variable describes.	Actor
Theme	What broad thematic category (e.g. institutions) the variable belongs to.	Institutions
Question	What question is posed to the user when they are measuring the variable for a case.	Are there clear rules that are followed about who is and who isn't a member of this group?
Select options	The range of values that the variable can take on.	1 No boundaries 2 Somewhat unclear boundaries 3 Clear boundaries
Unit	For interval variables, the unit of measurement.	(not applicable)
Role	Records whether the variable describes components with a particular role (e.g. commons users)	Commons user
Importance	Describes the theoretical importance of the variable	As Ostrom (1990) states: "So long as the boundaries of the resource and/or the specification of individuals who can use the resource remain uncertain, no one knows what is being managed or for whom. Without defining the boundaries of the CPR and closing it to "outsiders," local appropriators face the risk that any benefits they produce by their efforts will be reaped by others who have not contributed to those efforts."
Definition	Provides a basic definition of the variable and defines the values it can take on.	No boundaries indicate an entire lack of common understanding regarding group membership. Unclear boundaries indicate that some of the members of this group are aware of who is and who isn't a member, and there is some enforcement of any rules associated with membership. Clear boundaries indicate that the great majority of the members of this group are aware of who is and who isn't a member, and there is strong enforcement of any rules associated with membership."
Sector	Records what sector(s) (e.g. fisheries) the variable is associated with, if it is specific to a particular sector	All

Fleischman et al., 2014; Epstein et al., 2014b; Villamayor-Tomas et al., 2014; Evans et al., 2014). Testing the variables facilitated further refinement of definitions and explanations, and allowed us to identify additional variables necessary for fully coding each case (i.e. reflecting the body of scientific empirical evidence explaining environmental and social outcomes in each case).

The variables repository thus consists of the variables table in the SESMAD database along with this table's connections to several other tables, as well as the front-end interface accessible via the SESMAD website. Through this website users can filter the variables table and view pages for individual variables, which list their attributes (Table 1), as well as which studies, theories and cases they are associated with, providing further guidance to users on their importance, motivation, and measurement protocols.

To showcase the range and utility of the variable repository for this paper, we analyzed the variables and their definitions in several ways. We summarized the variables by the measurements they use and the components they describe. We also summarized the number of times variables related to the governance system, environmental commons, and actor components appeared in the theories related to academic fields that we explored.

3. Results

To date we have identified and defined 177 variables in the SESMAD database to achieve the goals of the SESMAD project. All variables and their definitions and references are available on the SESMAD website: https://sesmad.dartmouth.edu/variables. Each is defined by values assigned across a set of fields in the SESMAD database variables table (Table 1).

For the purposes of comparative analysis and given the available empirical data, most variables were measured at the ordinal and categorical scales, rather than at the interval scale or as qualitative text variables (Fig. 1).

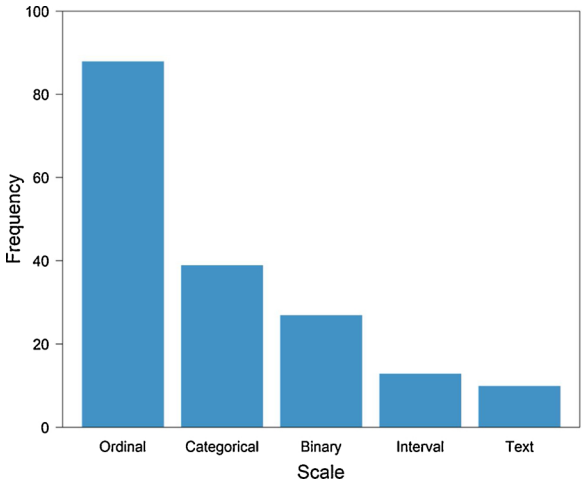

Fig. 1. Distribution of the measurement scale for the SESMAD variables.

Most of the variables describe how people (i.e., actors) use and govern environmental commons (e.g., natural resources, pollutants, protected areas). There are more variables reflecting social characteristics (actors and governance systems) than biophysical characteristics of the commons (Fig. 2). Our interpretation of this is that it reflects the dominance of social science in the literatures we examined.

Different fields made disproportionate use of variables associated with the three main components (Fig. 3). This result is not necessarily reflective of the overall theoretical approach in the fields (e.g. conservation biology), as we selected those theories that pertained to natural resource and environmental governance.

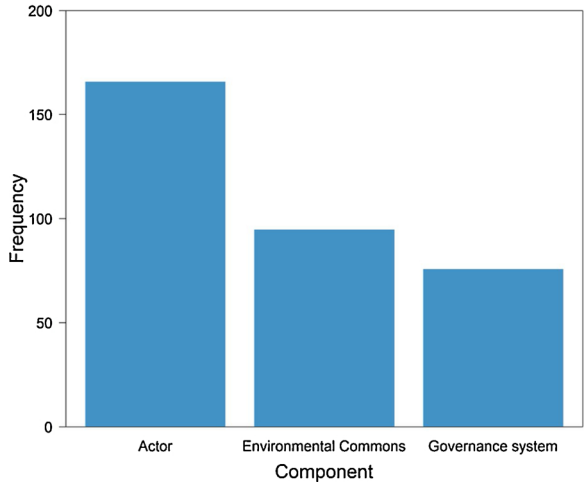

Fig. 2. Frequency count of the number of variables classified in each component.

4. Using the repository: diagnosis and measurement

4.1. Variable choice and diagnosis

The repository of variables (https://sesmad.dartmouth.edu/variables), while not exhaustive, reflects the number and diversity of concepts and variables that have been introduced in the study of human-environment interactions. As we have discussed, this diversity presents a great analytical challenge, to which Ostrom's diagnostic framework was an attempted solution.

Here we describe how the variables repository represents an attempt at helping users diagnose the important factors to consider in their systems and avoid the errors discussed in the introduction. Specifically, users can use the fields available in the variables table, as outlined in Table 1, to help determine which variables are relevant to a specific research question, environmental problem and system type. Several of these fields breaks the list of variables up into helpful subgroups, with subgroups being more or less relevant to different empirical contexts. These distinctions reflect the diagnostic approach that Ostrom argued for: we likely want to ask different questions of different component types, or within component types, for example (government agencies, natural resource users), and the structure of the database reflects this approach.

For example, if an analyst is examining the significance of institutional arrangements, they can look up the variables categorized under the "institutions" theme (see Appendix A for a description of variable themes). This would include the Actor Boundaries example included in Table 1. Or if they were interested in relationships between institutions and the environment, they could look up variables assigned to the "Institutional-biophysical linkage" theme, including the Governance Knowledge Use variable, a categorical variable that records whether scientific and/or local knowledge is used to manage a commons.

Additionally, the variables are broken up by component (actor, commons, governance system), reflecting the structure of the SES framework. If a researcher wanted to focus solely on patterns associated with environmental commons without regard to governance, they could focus on the variables that describe the commons alone, such as the presence of natural boundaries and the mobility of resource units. The role field further specifies the role that a component can play in a system. The most commonly used role in the database is for actor groups that use a commons. Several actor-specific variable most meaningfully apply to this type of actor group. For example, the actor group commons boundary variable from Table 1 was developed in reference to commons user groups, and so this variable is assigned to this role.

Additionally, if a user is studying a particular environmental sector, they can filter the variables table to examine whether there are variables pertaining to this sector that they should look at. The primary sector that has been enabled in the repository to this point is the study of marine protected areas (Ban et al., 2017; Davies et al., 2018). For example, the repository includes variables describing the extent to which an MPA protects biological connectivity and helps conserve migratory species, which are issues in the discourse on MPA governance.

Finally, the description of the theoretical importance of each variable and references therein can point scholars to related variables to consider for their research question. Scholars can also refer to the theories we formalized (Cox et al., 2016a), to examine the roles that variables play in these theories, and review which studies have

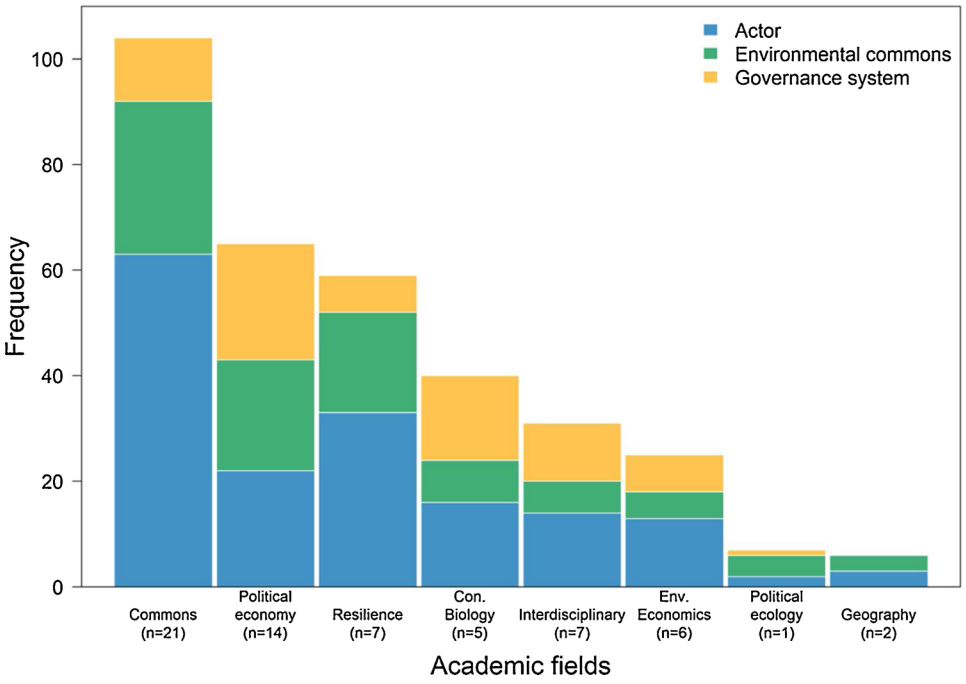

Fig. 3. Number of times variables related to the governance system, environmental commons, and actor components (characteristics and interactions) appear in the theories related to academic fields that we explored. Commons refers to the field of commons studies, con. biology means conservation biology, and env. economics means environmental economics. The number after each field indicates the number of theories we included (see Cox et al., 2016a).

described the importance of these theories. For example, the boundaries of an actor group are an important part of Ostrom's design principles theory and framing for community-based natural resource management. An analyst examining this variable may well want to examine variables associated with Ostrom's other design principles to ensure a coherent analysis.

4.2. Measurement

The variables repository provides scholars with ideas and options for measurement. For each variable, users can see a description of how it can be meaningfully measured, and, via the connection between variables and empirical cases in the database, can examine the contexts in which the variables have been previously measured to help ground their understanding of the variable. Moreover, each time that a variable is measured in a SESMAD case, case authors are encouraged to provide an explanation for why they assigned the variable the value that they did. Thus, each variable page comes with a set of empirical values and explanations for these to help guide the user in their own research and measurement. If the user wants further background, they can refer themselves to the studies that are linked to most variables, possibly in support of an independent literature review.

A central decision here is what measurement scale to use when operationalizing a concept. We operationalized most variables at the ordinal and categorical scales rather than interval scale or as text fields. Our original motivation was to facilitate the production of comparable data across cases. Interval data are more precise and text fields allow for flexibility, but both can be difficult to measure comparably. For example, we measured group size as an interval variable (number of members in a group), but then confronted the fact that how we measure group size and various types of heterogeneities will be different for different types of actor groups (natural resource users, countries that sign international treaties, governmental agencies). A number that is "large" in some contexts may be considered small in others. Similarly, how we measure the size of a natural resource system varies across resource sectors (e.g. a large forest is not the same area as a large marine protected area).

Ultimately we have tried to strike a balance between providing too much and too little guidance in regards to measurement. Our intention was not to find the only way to measure variables, but rather to be transparent about the different ways a variable is measured in the cases we analyzed. Indeed, other research projects may require more detailed text and interval data and measurements. In this case, users can add their own variables to the database, which then increases its value to future projects.

5. Conclusions: limitations and further development

Our effort to identify and define variables in order to facilitate comparative research and theory development has several limitations. First, while we define variables, we do not provide instructions for data collection and inference regarding the values of each variable, nor do we develop specific guidelines for selecting variables, beyond what the structure of database provides as just described. Guidance for such variable selection and data collection would be useful, including outlining methods such as key informant interviews, survey instruments, secondary data collation, and meta-analysis.

Second, in part due to the lack of anything resembling a sampling frame for relevant concepts, the database does not provide an exhaustive list of all concepts or variables that could explain human-environmental interactions and outcomes. Rather, the database now constitutes the best approximation of such a sampling frame. The identification and definition of variables drew on some of the most well-established fields of research related to sustainability and includes insight from ecology through a range of social science subfields. However, the repository does still to some extent reflect the backgrounds and interests of the interdisciplinary team involved. This publication aims to address this limitation by introducing the variables repository and inviting other scholars of human-environment interactions to partake in identifying, defining, and refining concepts and variables. This also raises an additional limitation of the database: access to editing privileges in the SESMAD website faces a moderate barrier to entry given the rules applied by the institutional host (Dartmouth College). To address this, we anticipate establishing a publicly available, structured wiki-type resource that will facilitate greater participation by scholars to add and define variables, including options and details of how they could be measured. Additional variables can expand beyond the academic fields we have initially focused on, add further theories, and provide sector-specific variables (e.g., variables that apply only for forestry systems). In the meantime, we ask interested scholars to contact the team directly to discuss collaborations around adding and refining the set of concepts, variables and theories elaborated in the database to date.

Finally, we recognize that our aim to provide a standardized set of metrics (concepts, variables and values) privileges more positivist scientific traditions. The variables repository and SESMAD database are intended to leverage the decades of detailed empirical work into environmental problems and wealth of case-study research in environmental governance. Given a rich empirical foundation there is a genuine need for mechanisms that enable evidence building and comparative analysis for further theory development and policy.

However, this is not to dismiss the importance of constructivist and more interpretivist research methodologies. We contend that the repository of variables, relationships and associated theories should still be an asset to scholars of this persuasion, enabling them to position their research in relation to others. Furthermore, critiquing and deconstructing key concepts and variables and refining their definition and application remains a vital contribution in this area. The database provides a transparent trail through careful documentation of metrics and their definitions, but also allows for concepts to be contextualized and updated through the use of multiple variables and their links to theoretical contestations. It is important to create a dialogue across these philosophical and conceptual divides that takes critiques seriously and attempts for transparency in the arguments made. We believe this transparency is furthered by publicly viewable resources, such as our variables repository, that makes epistemological commitments visible. Identifying variables and specifying definitions is a first step towards creating a common understanding, or at least clarity of meaning and disagreement.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Basic: A basic variable describes essential and basic background information for a component.

Biophysical: Biophysical variables describe just that: important biophysical properties, largely of environmental commons, that are not captured by a more specific theme.

Causation: A variable with this theme describes issues of causality, which is a complex subject. Most basically this theme is associated with variables that describe different types of causation and different types of causes of environmental problems.

Context: contextual variable relates the component with which it associated to the social and/or ecological setting of a particular interaction and/or case.

Ecosystem services: Variables associated with this theme describe factors that affect or describe the provision of important ecosystem

services by a natural resource.

Enforcement: Enforcement involves several different processes, including monitoring for violations of rules, sanctioning violators, and conflict resolution mechanisms involved in this process. Variables that relate to any of these processes should be attached to this theme.

External: Variables with this theme relate a component to processes external to the case with which the component is associated.

Heterogeneity: Variables with this theme describe important ways in which the member of an actor group differ from each other.

Incentives: This theme is associated with variables that are not directly related to institutions and rules, but which still play a role in affecting the incentives that commons users have to ameliorate or exacerbate the commons they use.

Institutional-biophysical linkage: This is a sub-theme of the institutions theme, and describes those variables that ask about the relationship between a set of institutions and a biophysical aspect of a commons.

Institutions: Variables with this theme describe the social institutions (rules, property rights) that are used to organize and direct human behavior. It does not include monitoring and enforcement of these institutions, as these are associated with the Enforcement theme.

Knowledge and uncertainty: Variables with this theme describe levels of knowledge that actor groups have regarding a commons, as well as factors that affect how much uncertainty there is in the status and dynamics of that commons.

Leadership: Leaders play an important role in commons management, most traditionally by providing for public goods needed to organize commons users. But there are other possible roles, and variables associated with this theme can relate to any role that a leader might play in an interaction.

Outcomes: This theme is attached to variables that deal with any outcomes that are produced by the actions of relevant actors in an interaction.

Resource renewability: Variables associated with this theme deal with the ability of a natural resource to be highly productive and renewable.

Social capital: Social capital captures the processes that enable the members of an actor group to work effectively together. Variables associated with this theme describe factors that affect or in some way express the level of social capital among members of a group.

Spatial: Variables associated with the Spatial theme describe important spatial patterns or dynamics, such as the spatial heterogeneity of a commons, or whether or not a user group resides within a particular commons.

Technology: This theme is attached to variables that consider the role that technology and infrastructure have in affecting commons outcomes.

References

Adcock, R., 2001. Measurement validity: a shared standard for qualitative and quantitative research. Am. Polit. Sci. Rev. 95, 529–546. https://doi.org/10.1017/S0003055401003100.

Agrawal, A., 2003. Sustainable governance of common-pool resources: context, methods, and politics. Annu. Rev. Anthropol. 32, 243–262.

Andersson, K.P., Ostrom, E., 2008. Analyzing decentralized resource regimes from a polycentric perspective. Policy Sci. 41, 71–93.

Araral, E., 2014. Ostrom, Hardin and the commons: a critical appreciation and a revisionist view. Environ. Sci. Policy 36, 11–23. https://doi.org/10.1016/j.envsci.2013.07.011. Interrogating The Commons.

Armitage, D., 2007. Governance and the commons in a multi-level world. Int. J. Commons 2, 7–32. https://doi.org/10.18352/ijc.28.

Ban, N.C., Davies, T.E., Aguilera, S.E., Brooks, C., Cox, M., Epstein, G., Evans, L.S., Maxwell, S.M., Nenadovic, M., 2017. Social and ecological effectiveness of large marine protected areas. Glob. Environ. Change 43, 82–91. https://doi.org/10.1016/j.gloenvcha.2017.01.003.

Binder, C.R., Hinkel, J., Bots, P.W.G., Pahl-Wostl, C., 2013. Comparison of frameworks for analyzing social-ecological systems. Ecol. Soc. 18, 26.

Carpenter, S., Walker, B., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: resilience of what to what? Ecosystems 4, 765–781. https://doi.org/10.1007/s10021-001-0045-9.

Chhatre, A., Agrawal, A., 2009. Trade-offs and synergies between carbon storage and livelihood benefits from forest commons. PNAS 106, 17667–17670.

Clement, F., 2010. Analysing decentralised natural resource governance: proposition for a "politicised" institutional analysis and development framework. Policy Sci. 43, 129–156.

Cox, M., 2014. Understanding large social-ecological systems: introducing the SESMAD project. Int. J. Commons 8, 265–276.

Cox, M., Arnold, G., Villamayor-Tomas, S., 2010. A review of design principles for community-based natural resource management. Ecol. Soc. 15.

Cox, M., Villamayor-Tomas, S., Arnold, G., 2016a. Design principles in commons science: a response to "Ostrom, Hardin and the commons" (Araral). Environ. Sci. Policy 61, 238–242. https://doi.org/10.1016/j.envsci.2016.03.020.

Cox, M., Villamayor-Tomas, S., Epstein, G., Evans, L., Ban, N.C., Fleischman, F., Nenadovic, M., Garcia-Lopez, G., 2016b. Synthesizing theories of natural resource management and governance. Glob. Environ. Change 39, 45–56.

Davies, T.E., Epstein, G., Aguilera, S.E., Brooks, C.M., Cox, M., Evans, L.S., Maxwell, S.M., Nenadovic, M., Ban, N.C., 2018. Assessing trade-offs in large marine protected areas. PLoS One 13, e0195760. https://doi.org/10.1371/journal.pone.0195760.

Epstein, G., Vogt, J.M., Mincey, S.K., Cox, M., Fischer, B., 2013. Missing ecology: integrating ecological perspectives with the social-ecological system framework. Int. J. Commons 7, 432–453.

Epstein, G., Meek, C., Ibarra, I.P., Schoon, M., 2014. Governing the invisible commons: ozone regulation and the Montreal Protocol. Int. J. Commons 8 (2), 337–360.

Epstein, G., Nenadovic, M., Boustany, A., 2014b. Into the deep blue sea: Commons theory and international governance of Atlantic Bluefin Tuna. Int. J. Commons 8, 277–303.

Evans, L.S., Ban, N.C., Schoon, M., Nenadovic, M., 2014. Keeping the 'Great' in the Great Barrier Reef: large-scale governance of the Great Barrier Reef Marine Park. Int. J. Commons 8, 396–427.

Fleischman, F.D., Ban, N.C., Evans, L.S., Epstein, G., Garcia-Lopez, G., Villamayor-Tomas, S., 2014. Governing large-scale social-ecological systems: lessons from five cases. Int. J. Commons 8, 428–456.

Glowacki, L., von Rueden, C., 2015. Leadership solves collective action problems in small-scale societies. Philos. Trans. Biol. Sci. 370, 20150010. https://doi.org/10.1098/rstb.2015.0010.

Jupiter, S.D., Epstein, G., Ban, N.C., Mangubhai, S., Fox, M., Cox, M., 2017. A social–Ecological systems approach to assessing conservation and fisheries outcomes in fijian locally managed marine areas. Soc. Nat. Resour. 1–16. https://doi.org/10.1080/08941920.2017.1315654.

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C.L., Schneider, S.H., Taylor, W.W., 2007. Complexity of coupled human and natural systems. Science 317, 1513–1516. https://doi.org/10.1126/science.1144004.

Lovett, G.M., Jones, C.G., Turner, M.G., Weathers, K.C., 2005. Conceptual frameworks: plan for a half-built house. In: Lovett, G.M., Turner, M.G., Jones, C.G., Weathers, K.C. (Eds.), Ecosystem Function in Heterogeneous Landscapes. Springer, New York, New York, NY, pp. 463–470. https://doi.org/10.1007/0-387-24091-8_24.

Meinzen-Dick, R., Raju, K.V., Gulati, A., 2002. What affects organization and collective action for managing resources? Evidence from canal irrigation systems in India. World Dev. 30, 649–666. https://doi.org/10.1016/S0305-750X(01)00130-9.

Olsson, P., Folke, C., Berkes, F., 2004. Adaptive comanagement for building resilience in social–ecological systems. Environ. Manage. 34, 75–90. https://doi.org/10.1007/s00267-003-0101-7.

Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge, MA.

Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. PNAS 104, 15181–15187.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325, 419–422.

Partelow, S., 2018. A review of the social-ecological systems framework: applications, methods, modifications, and challenges. Ecol. Soc. 23. https://doi.org/10.5751/ES-10594-230436.

Pullin, A.S., 2012. Realising the potential of environmental data: a call for systematic review and evidence synthesis in environmental management. Environ. Evid. 1, 2. https://doi.org/10.1186/2047-2382-1-2.

Pullin, A.S., 2015. Why is the evidence base for effectiveness of win–win interventions to benefit humans and biodiversity so poor? Environ. Evid. 4, 19. https://doi.org/10.1186/s13750-015-0045-4.

Robbins, P., 2011. Political Ecology: A Critical Introduction. John Wiley & Sons.

Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H.M., Collen, B., Cox, N., Master, L.L., O'connor, S., Wilkie, D., 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conserv. Biol. 22, 897–911. https://doi.org/10.1111/j.1523-1739.2008.00937.x.

Schlager, E., Cox, M., 2017. The IAD framework and the SES framework: an introduction and assessment of the Ostrom workshop frameworks. In: Weible, C., Sabatier, P. (Eds.), Theories of the Policy Process, 4th edition. Westview Press, Boulder, CO.

Thiel, A., Adamseged, M.E., Baake, C., 2015. Evaluating an instrument for institutional crafting: how Ostrom's social–ecological systems framework is applied. Environ. Sci. Policy 53, 152–164.

Vedeld, T., 2000. Village politics: heterogeneity, leadership and collective action. J. Dev. Stud. 36, 105–134.

Villamayor-Tomas, S., Fleischman, F.D., Ibarra, I.P., Thiel, A., van Laerhoven, F., 2014. From Sandoz to Salmon: conceptualizing resource and institutional dynamics in the Rhine watershed through the SES framework. Int. J. Commons 8, 361–395.

Wollenberg, E., Merino, L., Agrawal, A., Ostrom, E., 2007. Fourteen years of monitoring community-managed forests: learning from IFRI's experience. Int. For. Rev. 9, 670–684.

Young, O.R., Webster, D.G., Cox, M.E., Raakjær, J., Blaxekjær, L.Ø., Einarsson, N., Virginia, R.A., Acheson, J., Bromley, D., Cardwell, E., Carothers, C., Eythórsson, E., Howarth, R.B., Jentoft, S., McCay, B.J., McCormack, F., Osherenko, G., Pinkerton, E., van Ginkel, R., Wilson, J.A., Rivers, L., Wilson, R.S., 2018. Moving beyond panaceas in fisheries governance. PNAS 115, 9065–9073. https://doi.org/10.1073/pnas.1716545115.