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Using case study data to understand SES interactions: a model-centered meta-analysis of SES Framework applications

Abstract

Studying social-ecological interactions systematically is difficult when dealing with case study data. The methodological flexibility inherent in case studies facilitates the discovery of complex relationships between social and ecological variables; however, it also poses problems for knowledge accumulation given the diverse ways that variables are measured, as well as the descriptive approaches to causal inference that are typically employed. This article builds on the Social-Ecological Systems Framework (SESF) to systematically compare variable interactions among variables across numerous case studies. We adopt a "model-centered" meta-analysis of existing SESF case studies, in which the units of analysis are the causal explanations including sets of variables and their effects on outcomes (i.e., "models") constitute the unit of analysis. Our analysis included 30 studies and resulted in the formalization of 125 models. The analysis illustrates opportunities to assess interactions at different levels of detail using the data generated. The paper concludes by proposing strategies to advance the study and reporting of interactions in case studies to foster a better understanding of dynamics and outcomes of environmental sustainability.

Key words: SES interactions; SES Framework; meta-analysis; causal models; case study methods

1. Introduction: The study of interactions and the "reporting paradox" of case studies

Social-ecological outcomes are rarely explained by single variables, but rather result from interactions among a wide range of social, ecological and institutional factors [1]. Theory on social-ecological systems (SES) interactions is, however, rather limited and mostly anecdotal (see [2]–[4], for some exceptions). Most of our knowledge of SES governance tends to ignore the complex ways that explanatory (e.g., independent, mediating or moderating) variables interact with each other. Little systematic knowledge exists, for example, about the nesting of causal effects [5], the performance of institutions across different contexts [6]*, or configurations of variables that explain outcomes [7]–[9].

In this paper we attempt to make methodological progress in addressing the above gaps by exploring the possibility of synthesizing case study data into models of causal explanations. These can then be used to systematically study interactions at different levels of detail. We conceptualize interactions in two ways. First, we focus on "variable interactions" by exploring the co-occurrence of variables in models and how they are connected as pairs or chains of multiple causal factors. Second, we attend to a growing interest in dynamics to examine the variety of social and ecological processes that jointly mediate the impact of SES variables on outcomes. Finally, we also highlight patterns in the way case study scholars report SES interactions and propose potential strategies for improvement.

The study of variable interactions ("interactions" hereafter) involves a number of trade-offs. Simulation models (e.g., systems analysis), for instance, are amenable to analyzing interactions and feedbacks, but often face challenges in establishing the external validity of findings [10]*, [11]. Moreover, the construction of such models is quite demanding in terms of both quantitative and qualitative data. Regression analyses are also amenable to study interactions explicitly via interaction terms [12], [13], but pose challenges for interpreting findings and ensuring adequate statistical power with correlated predictors [14], [15]. Case study methods, meanwhile, provide powerful tools for uncovering and testing interactions; however, despite recent improvements (e.g.,[16]*, [17]*) these interactions tend to be obscured by deeply descriptive and relatively unstructured narratives. While there is a trade-off between the use of rich qualitative data and standardization, we believe there is room for improvement in the way case study findings are reported [18]*.

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Case study methods hold considerable promise as a powerful tool for developing and testing complex hypotheses (e.g., SES interactions), but face a “reporting paradox” that may hinder their contributions to the study of SES interactions: They are among the most (if not the most) widely used method in the environmental social sciences (ESS) [19]* and have unique advantages to assess complex phenomena, and yet the evidence for their conclusions is often under-reported. We believe this is an issue of transparency in how conclusions are reached rather than of rigor in the analyses, but sometimes it is difficult to tell. Variable definitions and measures are either lacking or imprecise, and inferences combine evidence-based and theory-based explanations indistinctively. In turn, knowledge from case studies is often neglected or not systematically exploited by other case studies or variable-oriented methods (e.g., SES modelling) because systematized interpretations of secondary data are almost impossible given the conditions mentioned above.

Meta-analyses of case studies (i.e., Qualitative Meta-Analyses, QMAs) have emerged in recent years in response to the above challenge, e.g., [19]*, [20]* ,[21]. QMAs are an effective way to move from case-oriented to variable-oriented research. That said, standard applications have to date provided little insight into the study of interactions [18]. We address this gap by implementing a “model centered” meta-analysis [19]*, [22]*, [23]. This approach focuses on the identification and formalization of causal explanations (i.e., models) advanced in published case studies. In contrast to previous applications of this approach (see [21]*, [23] for exceptions), our study focuses on the co-occurrence of variables in models rather than on testing the impact of individual explanatory variables on outcomes. We build on the Social-Ecological Systems Framework (SESF) developed by Ostrom [1], [24] to support the categorization and analysis of these variables. After an introduction of the SESF and some contextualization of our distinction between variable interactions and processes, we proceed with a brief overview of the data generated and ways of analyzing it at different levels of detail. Then we make some propositions about how to advance the study of interactions and processes in SES case studies and conclude with prospects for future research.

2. The SES Framework, theories and models.

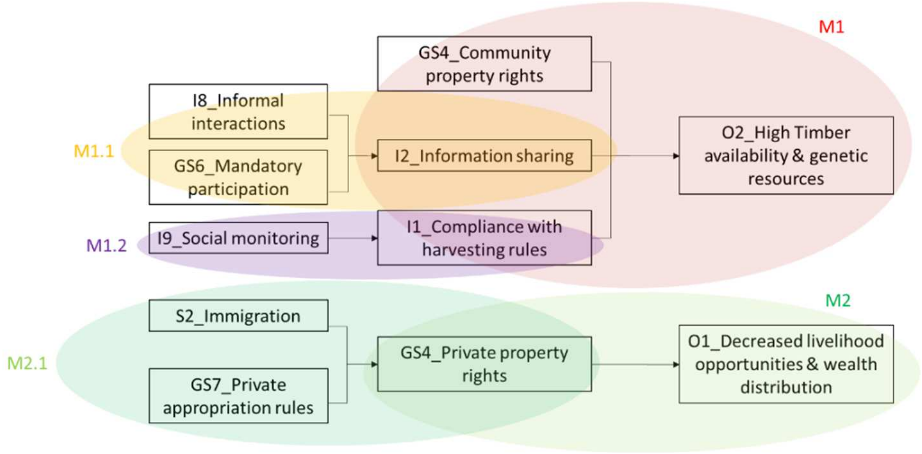
Elinor Ostrom and colleagues developed the SESF to improve how case study data is reported, and in turn facilitate cross-case comparisons and advance SES theory [1]. The SESF consists of six groups of variables that can be used to characterize the Actors, Resource System, Resource Units, Governance System, Interactions and Outcomes of SES (see Appendix). Scholars can thus use the framework to specify which variables constitute and characterize their cases, and/or which variables explain outcomes in the cases. Over the last 10 years scholars have applied the SESF to case studies of environmental governance and sustainability in a wide range of contexts. These applications have revealed a number of important methodological and conceptual concerns [25]–[27]. In particular, Partelow [27] highlights how case study scholars have neglected opportunities to systematically study interactions with the framework.

In our understanding, the SESF can inform the study of both interactions and processes. One the one hand the framework facilitates the mapping of variables that jointly explain outcomes (i.e., interactions). On the other hand, the framework can inform the study of processes by which actors develop and implement sustainable environmental governance [27]*. This is reflected in the “Interactions” component of the framework which we refer to as the “Process” component, which includes variables such as harvesting, monitoring, and conflict solving. These process variables theoretically mediate the effects of other framework variables of the framework as actors make decisions concerning the use and management of resources. Further the study of variable interactions and processes are not mutually exclusive. Here, we use the framework to map interactions among variables as they co-occur in explanations of social and ecological outcomes (models), but also pay attention to the existence of intermediate outcomes and the role played by the SESF process-variables (i.e., those included in the "Processes" component) in the models.

3. A model-centered analysis of SESF interactions with case study data

Our meta-analysis included 30 studies and resulted in the formalization of 125 models (see Appendix for methodological details and list of studies including annotated references). Each study contained between 1 and 14 models. A "model" is an explanation that includes a set of variables and an outcome. We coded models that reflected causal explanations as stated by the authors. A case study could contain multiple explanations per outcome and explain multiple outcomes. We focused on models that explained "final outcomes" as specified in the SESF, i.e., Social Outcomes (O1), Ecological Outcomes (O2) or Externalities (O3). We also coded "intermediate outcome" models, which explained variables included in the final outcome models (see Figure 1 and Appendix for an example). Finally, we developed narratives for each model. For example, M2 in Figure 1 would correspond to "Community property rights, rule compliance and effective information-sharing positively affect high timber availability and genetic diversity".

Figure 1. Final and intermediate outcome models from Oberlack [21]***.**



Note: M1 and M2 are final outcome models. M1.1, M1.2 and M2.1 are intermediate outcome models. "I2", "GS4", "O2" etc., is the nomenclature used in the SESF to refer to variables that characterize "Interactions" (i.e., here "Processes"), "Governance System", and "Outcomes". These models do not use variables from all the SESF components (e.g., there are no "Actor" or "Resource Unit" variables).

Of the 76 Final Outcome models, 26 include at least one intermediate model, for a total of 49 intermediate models. Most models analyze interactions and outcomes in the fisheries (41 models), forest (36) and water (33) sectors. Other sectors include marine areas, energy, land and pollution (15). The models include an average of 5 variables per model (~1.6 Actor, ~1.4 Governance System, ~0.7 Resource System, ~0.4 Resource Unit variables), with a range of 2 to 33 variables per model. The most frequent explanatory variables across the models are A5 "Leadership" and A6 "Norms/Social capital" (each were included in 25% of all models), and A1 "Number of users", A8 "Importance of resource", and GS5 "Operational Rules" (~20% each).

To illustrate the potential of the generated dataset, we synthesized the models at different levels of detail. We used a "Sankey" visualization (SankeyMatic®), a cross-frequency analysis, and a Formal Concept Analysis [28].

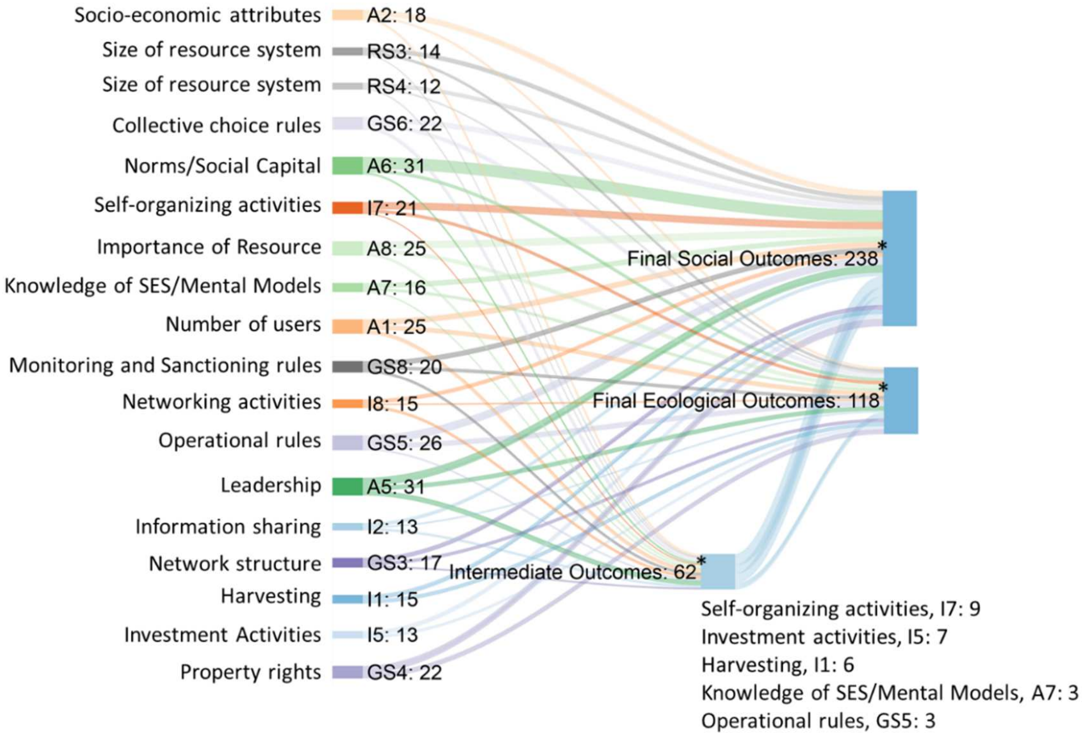
3.1. Exploring mediation: Final and intermediate outcome models

Figure 2 highlights how variables are distributed as they explain different types of outcomes. Some variables are more prone to act as “mediating variables” (“Intermediate Outcomes” in the figure) than others. As per our data, mediating variables (i.e., variables that appear as explained variables in intermediate models and as explanatory variables in final models) belong for the most part to the “Processes” component of the SESF, including I1 “Harvesting” (included as explained variable in 20% of the intermediate outcome models), I5 “Investment Activities”, and I7 “Self-organization Activities” (~ 13% each). Also, some variables are more frequently used to explain intermediate outcomes than others. For example, A5 “Leadership” is used as an explanatory variable in 38 models, 11 of which (29%) are intermediate outcome models. Alternatively, A6 “Norms/Social Capital” is used in 36 models, only 5 of which (14%) are intermediate outcome models. Finally, it is worth mentioning that some studies develop quite sophisticate explanations including several intermediate outcomes. For example, one case study shows how the robustness of community-based irrigation systems in Taos, Arizona, depends on the effectiveness of cooperative infrastructure maintenance and water allocation, which in turn depends on effective rule enforcement and the existence alternative sources of water [2].

Variables also distribute differently depending on whether they explain Social and/or Ecological Final Outcomes. For example, A6 “Norms/Social Capital” is for the most part used to explain social outcomes, which range from the robustness of community-based natural resource management regimes and conflict (e.g., [29], [30]) to livelihood conditions (e.g., [31], [32]). Alternatively, A1 “Number of Users”, is used to explain social outcomes as well as ecological outcomes, which range from pasture cover and deforestation [33], [34], to fish stock conditions [35], [36]. Expectedly, variables associated to both social and ecological outcomes are involved in more complex explanations and a wider diversity of interactions than variables associated with just one type of outcome.

As a final note, the average number of variables used in Final Social Outcome and Final Ecological Outcome models is similar (7 vs. 6). However, explanations that rely on intermediate outcomes are mostly used to explain social outcomes (see link between “Intermediate Outcomes” and “Final Social Outcomes” in Figure 2). This potentially indicates that authors applying the SESF are more attentive to building their explanations when dealing with social outcomes.

Figure 2. Sankey© diagram of model-centered database by type of outcome.



Note: The figure includes only the SESF variables that are included in at least 10% of the 125 models. Lines represent the frequency of associations between the variables as they explain different outcomes. The numbers with an asterisk represent number of variables. The remaining numbers represent number of models. The central column includes both the variable name and its SESF code. The variables below the "Intermediate Outcomes" box are those that were included as intermediate outcomes in those models (only spelled out those that were included in at least 3 models).

3.2. Exploring moderation: pair-wise variable comparisons

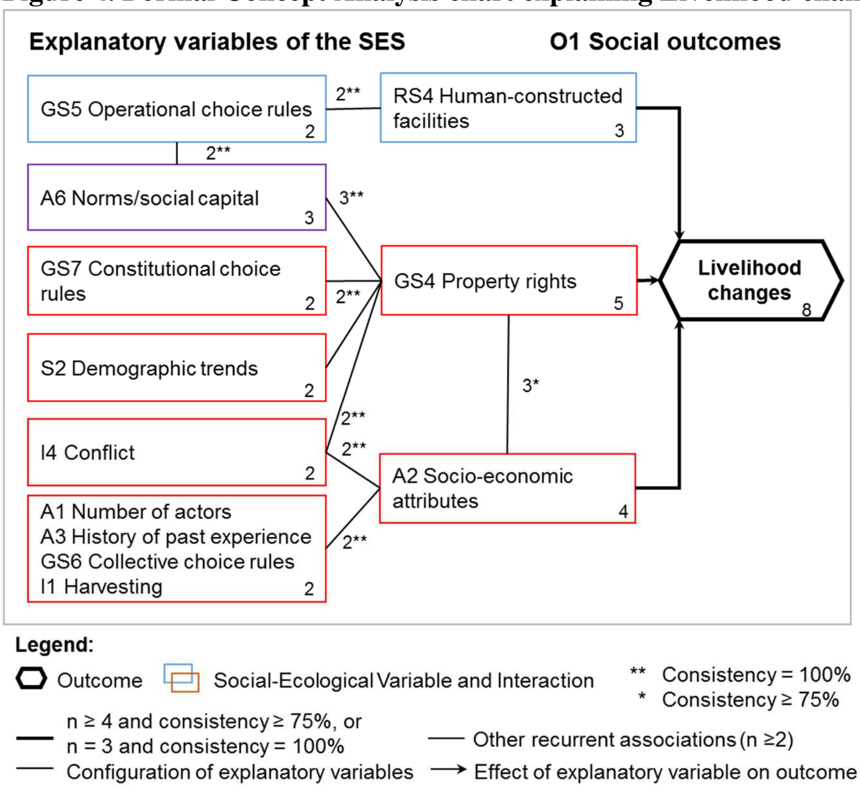
Figure 3 offers a more detailed look at the data by focusing on pairs of "Actor" variables as they explain positive vs. negative social outcomes (see note to the Figure for details about the calculations). According to Figure 3, some variables are more prone to interactions than others. For example, A5 "Leadership" is associated with mostly positive outcomes when it co-occurs in models with A1 "Number of users", A6 "Norms/Social Capital", A7 "Knowledge of SES/Mental models", or A8 "Importance of Resource"; however, it also tends to associate with negative outcomes when it interacts with A2 "Socioeconomic attributes", A3 "History of past experience" or A4 "Location". Alternatively, A6 "Norms/social Capital" tends to explain positive outcomes regardless of the variables it co-occurs with in the models, with the exception of A7 "Knowledge of SES/mental models. Variation in outcomes across pairs of co-occurring variables indicates the existence of moderation effects among the variables. A moderator variable affects the strength and/or direction of the relationship between two other variables, one of them being an outcome. A6 and A7, for example, co-occur in four negative Social Outcome models, all of which explain community-based natural resource management failures. Two of those models illustrate how a misfit between land users' understandings and the management needs of the SES perpetuates over time given the existence of strong social norms among the users [37], [38]. A third model illustrates the failed translation of new SES knowledge into new collective management measures given the lack of trust among resource users [29]. The fourth model shows how the rich SES knowledge of communities and their strong social capital cannot prevent the collapse of a community-based management regime that does not count on the recognition of government [39].

Figure 3. Frequency analysis of actor variable dyads as they co-occur in positive and negative Final Social Outcome models.

	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1 Number of users	.	-5%	-7%	-6%	4%	6%	2%	9%	0%
A2 Socioeconomic attributes	-5%	.	-3%	-35%	-12%	15%	-10%	0%	0%
A3 History past experience	-7%	-3%	.	-23%	-6%	11%	-19%	3%	0%
A4 Location	-6%	-35%	-23%	.	-15%	5%	-8%	-10%	0%
A5 Leadership	4%	-12%	-6%	-15%	.	1%	1%	2%	0%
A6 Norms/social capital	6%	15%	11%	5%	1%	.	-23%	3%	0%
A7 Knowl. SES/mental models	2%	-10%	-19%	-8%	1%	-23%	.	-11%	0%
A8 Importance of resource	9%	0%	3%	-10%	2%	3%	-11%	.	0%
A9 Technology used	0%	0%	0%	0%	0%	0%	0%	0%	.

Note: the colors reflect differences in the frequency that each pair of variables appear together in positive vs. negative models. Red-colored cells indicate that each pair of variables appeared together in negative outcome models more frequently than in positive outcome models (in percentual points). Green-colored cells reflect the opposite. The intensity of the colors reflects magnitude of the difference (see also percentage points in grey). For example, A1 and A6 appear in 22 Positive Outcome models, and do it together in 4 of those models (18%); and they appear in 8 Negative Outcome models, and together in 1 of those models (12%). Thus, they appear 6% more frequently together in Positive Outcome than in Negative Outcome models (see 6% in the A1-A6 cell). By reading the figure along the columns one can observe how the positive vs. negative effects of an actor variable on social outcomes vary depending on the variables it co-occurs with in the models.

Figure 4. Formal Concept Analysis chart explaining Livelihood changes.



Note: Eight models explain the outcome of livelihood changes. The numbers refer to the frequency that pairs of variables co-occur in models and their associations with an outcome (here livelihood changes). For example, A6 "Norms/Social Capital" appears with GS4 "Property rights" in three models and with SG5 "Operational choice rules" in 2. A6 is in purple because it features both the red and blue groups of models/configurations.

3.3. Exploring configurations: Formal Concept Analysis

Figure 4 presents the results of a Formal Concept Analysis (FCA). FCA allows us to identify configurations of explanatory variables recurrently linked to outcomes. Here we used the models as proxies for said configurations. We first synthesized outcomes into a meaningful number and then aggregated the models that explained the same outcomes (see Appendix for details). As shown in the figure, models explaining Livelihood Changes (one of 6 types of Social and Ecological outcomes we identified) tend to fall into two main groups (see red and blue boxes). The red group explains livelihood changes as a function of Property Rights (GS4), Socio-economic attributes (A2) and a variety of other Actor, Governance System, and Interaction variables. The blue group traces livelihood changes back to the role of Human-Constructed Facilities (RS4) in combination with certain Operational Choice Rules (GS5) and Norms/Social Capital dynamics (A6). A6 is the only variable that features both groups of models. This is illustrated, for example, in a case study of Paraty fisheries in Brazil [40]. Here the sustained contribution of the fisheries to local livelihoods is explained as a function of the performance of informal management rules and social norms (A6, GS5) and the availability of local markets (RS4), but also as a function of the increasing salience of formal property rights over the fishing spots given the recent intrusion of industrial fishers (GS4).

4. Advancing the study of interactions in case studies

In this section we discuss lessons, recommendations and potential limitations drawn from applying the SESF to understand variable interactions. These are addressed to authors interested in improving the usability of the framework and in using case study methods to test and build theory on SES interactions. Extracting knowledge about causal relationships and interactions was challenging as many of the reviewed studies rely on the SESF mostly for descriptive purposes. In almost all the reviewed studies, the case descriptions included variables that were subsequently ignored in the explanations of outcomes. Descriptive applications of SESF may lead to confusion if readers understand that all variables included in the case descriptions are equally relevant to the case or have equal explanatory power. Clearly distinguishing scope conditions (i.e., used to describe the cases and draw the boundaries of explanations) from variables that explain outcomes seems like an important first step towards the systematic study of interactions. The SESF can easily be used to "map" both sets of variables.

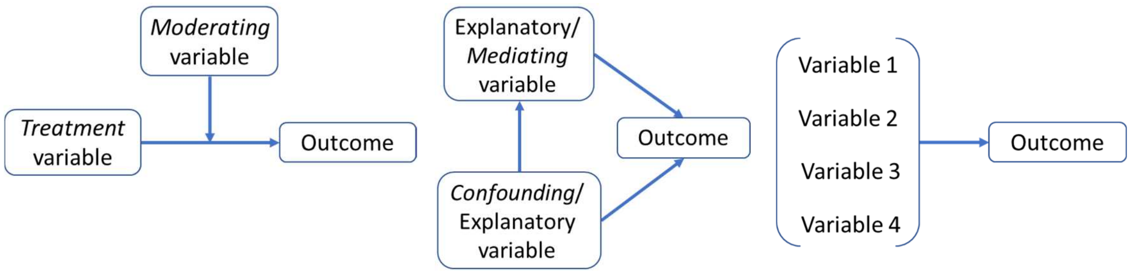
Second, the "Processes" component of the SESF is rarely examined as such, leaving a critical gap in our understanding of the processes that underlie environmental sustainability. As noted in section 2, authors implicitly use the "Processes" component variables as intermediate outcomes, i.e., as variables that mediate the impact of explanatory variables on final outcomes; however, they do not call those variables "intermediate outcomes" or treat them distinctively from other variables of the SESF. In our view, using the "Processes" component variables explicitly to organize explanations (i.e., group explanations as they speak about the same or different processes) may not only clarify the role of those variables and enhance the utility of the framework [27] but also help scholars better articulate their causal analyses . It is unclear to us whether inattention to the distinctiveness of the "Processes" component is due to confusion about what it refers to, and/or how to use those variables. Our analysis shows that thinking about processes and using the variables as intermediate outcomes in explanations has some promise. Advancements in this direction can also benefit from the terminological and methodological improvements made by land-use scientists to identify causal pathways (e.g. [41], [42]), as well as from advancements in the use of process tracing in case studies [43], [44].

Despite the methodological difficulties, we were able to identify a large number of variable interactions that can be further tested and theoretically developed. Although many studies mention their interest in interactions and highlight a general understanding that causal explanations involve interaction effects, the vast majority of studies do not clearly report how explanatory variables relate to each other. That said, many studies also include sufficient information to nest intermediate outcome models into final outcome models. Thus, the lack of reporting about types of interactions may not be due to a lack of data but simply insufficient attention. There is already well-established theory about how variables interact; see for example the distinction between moderating, mediating and confounding variables (Figure 5 and [45]*).

Structuring case study narratives along this distinction is a small step that could pave the way for further testing and theory building on interactions.

The above suggests some ideas about how case study scholars could approach the study of interactions. First, approaches should vary with the type of case study and research question at hand. Critical, comparative and longitudinal case studies are good for theory testing [46], and therefore likely amenable to the "treatment variable" or the "moderating variable" approaches (see Figure 5). In critical case studies, theory specifies a clear set of propositions about how explanatory variables affect outcomes, as well as the conditions within which the propositions are believed to be true. The "treatment" approach would explore whether changes in the explanatory variable ("treatment") affects the outcome given the proposed set of conditions. The "moderating variable" approach would capture how changes in one or several of the conditions affects the impact of the explanatory variable/s on the outcome. A similar logic applies in ("most similar") comparative studies or longitudinal studies, where the variables that change across cases or over time, can be understood as treatment or moderating variables. Alternatively, unique or inductive case studies [46] are prone to exploratory analysis and theory building [47]*, and therefore amenable to the identification of configurations of variables that affect outcomes or sophisticated models that involve nesting of explanations (i.e., models) through mediating or confounding variables.

Figure 5. Three approaches to study interactions



A complementary strategy that is well adapted to unique/inductive case studies are graphical representations, e.g., in the form of flow charts that formalize causal chains (see Figure 1 and [2]). This formalization could provide readers with a quick summary of the main findings. Additionally, formalization may encourage case study scholars to be transparent and rigorous about the variables they use in their causal claims and to reveal gaps in whether and how they substantiate those claims.

Finally, and related to the above, there are the empirical strategies used to make inferences about interactions and about causal relationships more generally. For 72 (60%) of the models in our data, we could not find sufficient information about the strategies used by the authors to draw causal inferences. The remaining models were split between those relying on counterfactual analysis (23 models, mostly from comparative studies) and those relying on process tracing (30). Also, a few authors were careful to distinguish between theory-based and case-based claims (see [16] for a quite unique example, that was nevertheless excluded from our meta-analysis due to its reliance on secondary data) Although these findings are somewhat less relevant for the purpose of this paper, it still reveals an important gap in the way case study data is reported.

5. Conclusions and further steps

In this study we examined the potential of combining a "model-centered" meta-analysis of case study data and the SESF to systematically assess SES interactions. In that process, we also evaluated whether and how case study scholars study SES interactions. As we illustrate, it is possible to synthesize SES case study knowledge into complex causal explanations (or models) that can in turn be analyzed using different techniques. Even high-level analyses (like those carried here via Sankey© diagrams) can result in new insights about variable configurations that can in turn be used for further testing and refinement (e.g., via the study of pair-wise interactions, Formal Concept Analysis).

As we also illustrate, case study scholars are interested in socio-ecological interactions but are not very systematic in studying or reporting them. Progress in the systematic study of interactions, as well as applications of the SESF and model-centered meta-analyses, would benefit from some degree of formalization by case study scholars about the nature and degree of the interactions presented. This should not be incompatible with thick case study narratives if scholars are transparent about the choices made in the formalization process. Thick narratives allow for deep understanding of causal relationships and prevent reductionistic explanations of phenomena. Reporting those narratives along with visual representations or variable-oriented hypotheses provides a balanced approach for understanding social-ecological phenomena.

Overall, this study demonstrates the value of exploring methodological tools to move SES theory beyond an over-simplified "variable-to-outcome" approach, towards the analysis of bundles of interacting variables on outcomes. The SESF can be useful in that process, particularly if it is used not only to organize case descriptions but also to map explanatory variables and their effects. The data generated, in turn, may shed new light on the potential of the SESF as a heuristic to build and test new SES theory (i.e., on interactions). Similarly, the "models centered" approach is an opportunity to close the methodological gap between case studies (of which there are many) and the new SES theories we desire to build from the studies (of which there are few), as well as between case studies, statistical analysis and simulation models of SES interactions. Despite the current momentum of multi-methods research, little systematic knowledge exists on how to use case study data to design statistical and simulation models (see for exceptions, [48], [49]*. Standardizing the way case study data are reported is one way to start filling that gap. In turn, the data generated through model-centered reviews can support and make more transparent the design of statistical and simulation models.

This study has limitations that should be addressed in future endeavors. First, we did not code for specific relationships among variables within the models. Although this was the result of a lack of information in the examined studies, it was also related to the lack of knowledge about how to organize the data generated. Collaboration with a data management/cyber infrastructure expert would have helped. Second, we took the author's statements about causal relationships at face value, even in studies where the inference strategy used by the authors was not clear. Next steps in this endeavor should include uploading the models into an online platform so both the authors of the studies and other scholars can validate, test and further specify the models (see SESMAD, SES library or the ESSN platform for potential candidates[i]). Third, in this manuscript we left out a detailed analysis of the indicators used by the authors to measure variables. Such an analysis would provide a more nuanced understanding of the empirical insights shown in section 3. Fourth, our overview of analysis strategies is by no means comprehensive. Further research shall tackle a review of other techniques to study SES interactions in case studies (e.g., Qualitative Comparative Analysis), with particular attention to the combination of said techniques and data visualization techniques. Finally, this study builds on and informs a positivistic view of case study methods, which may not fit all SES contexts and research purposes. Case study methods are methodologically and epistemologically very plural and this is one of their main assets. Progress that respects this plurality can only improve the way we do science.

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- This paper considers the biophysical components of the SES framework. It finds that the mixture of case-based (inductive) and rule-based (deductive, theoretical) reasoning associated with socially-oriented investigations of SES is lacking on the ecological side, which relies upon induction alone. The paper shows, through an instructive case study, how the addition of ecological rules can provide a more nuanced description of the interactions that contribute to outcomes in social-ecological systems.

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- A central challenge facing the study the environmental governance is the lack of common understanding and measuring of important concepts. This stymies the accumulation of scientific evidence and the development of new SES theory on interactions. In response, the article introduces a repository of variables associated with many of the most important concepts across a range of fields related to environmental governance.

[18] S. M. Alexander *et al.*, "Qualitative data sharing and synthesis for sustainability science," *Nat. Sustain.*, vol. 3, no. 2, pp. 81–88, Nov. 2019.

- The authors argue that qualitative data present untapped opportunities for sustainability science and discuss practical pathways to facilitate and realize the benefits from sharing and reusing qualitative data. They also discuss practical, ethical and epistemological challenges and outline enabling conditions and suggest actions for researchers, institutions, funders, data repository managers and publishers.

[19] T. K. Rudel, "Meta-analyses of case studies: A method for studying regional and global environmental change," *Glob. Environ. Chang.*, vol. 18, no. 1, pp. 18–25, 2008.

- This paper introduces the idea of model-centered meta-analysis, a method for analyzing and summarizing the findings from the case studies. It illustrates the method through a meta-analysis of local studies of forest cover change in Mexico, and discusses how the method can produce credible, insightful findings about global environmental change.

[20] M. Roggero, A. Bisaro, and S. Villamayor-Tomas, "Institutions in the climate adaptation literature: A systematic literature review through the lens of the Institutional Analysis and Development framework," *Journal of Institutional Economics*, vol. 14, no. 3. pp. 423–448, 2018.

- This article presents a systematic review of the adaptation literature, assessing the consideration adaptation scholars give to different elements of the Institutional Analysis and Development framework. Results show a strong focus on collective choice and on adaptation by public actors, with an emphasis on rules in use and social interactions. Research gaps include operational and constitutional choice, private adaptation, physical interactions and biophysical conditions.

[21] C. Oberlack, L. Tejada, P. Messerli, S. Rist, and M. Giger, “Sustainable livelihoods in the global land rush? Archetypes of livelihood vulnerability and sustainability potentials,” *Glob. Environ. Chang.*, vol. 41, pp. 153–171, 2016.

- This study presents a meta-analysis of case studies and applies formal concept analysis to analyze the configurations of factors and processes that generate different livelihood outcomes in large scale land acquisition (LSLA) situations. The results show that LSLAs affect rural livelihoods through a small set of archetypical configurations such as enclosure of livelihood assets, elite capture, or competitive exclusion.

[22] C. Ragin, *Redesigning Social Inquiry: Fuzzy Sets and Beyond*. Chicago : University of Chicago Press, 2008.

- This study aims to explain barriers to collective adaptation to environmental changes via a meta-analysis of 26 selected case studies. It is one of the few studies that adopt the model-based meta-analysis. The study finds 21 archetypical patterns and shows that reported problems in adapting collective action under climate change arise from attributes of actors and pre-existing institutions rather than biophysical characteristics.

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[26] E. Schlager and M. Cox, “The IAD Framework and the SES Framework: An Introduction and Assessment of the Ostrom Workshop Frameworks,” in *Theories of the policy process*, Routledge, 2018, pp. 225–262.

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- This article systematically reviews the literature applying and developing the SESF and discusses methodological challenges. The discussion reflects on how the SESF is historically related to commons and collective action research. The discussion also covers a reflection on the so far unexploited potential of the "Interactions" component of the Framework to make SES theory move forward.

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[32] B. Ernst *et al.*, “Sustainability of the Juan Fernández lobster fishery (Chile) and the perils of generic science-based prescriptions,” *Glob. Environ. Chang.*, vol. 23, no. 6, pp. 1381–1392, Dec. 2013.

[33] F. D. Fleischman, N. C. Ban, L. S. Evans, G. Epstein, G. Garcia-Lopez, and S. Villamayor-Tomas, “Governing large-scale social-ecological systems: Lessons from five cases,” *Int. Jounal Commons*, vol. 8, no. 2, pp. 428–456, 2014.

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- This paper provides a basic rubric for the conduct of empirical research in the environmental social sciences field. Current literature displays a healthy diversity of methods and techniques, but lack of consistency in the way in which research in this area is done. Basic types of research designs and methods are covered, as are criteria for evaluating these methods. Attention is paid also to the study of variable interactions.

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- This study illustrates how to study interactions in institutional analysis. It assesses via Hierarchical cluster analysis and Qualitative comparative analysis the alignment between drought adaptation institutions and types of irrigation systems in Spain. As shown, the "Asian" type shows more diverse adaptation paths than the "American" type. Also, "specific adaptation" institutions are more relevant during droughts, whereas "generic adaptation" institutions are so both during and in the aftermath of droughts.

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[49] N. R. Magliocca *et al.*, "From meta-studies to modeling: Using synthesis knowledge to build broadly applicable process-based land change models," *Environmental Modelling and Software*, vol. 72. Elsevier Ltd, pp. 10–20, 01-Oct-2015.

- This paper explores how meta-studies can support the development of process-based land change models (LCMs) that can be applied across locations and scales. They conclude that meta-studies best support the conceptualization and experimentation phases of the model development cycle, but cannot typically provide full model parameterizations.

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[i] SESMAD : https://sesmad.dartmouth.edu/; SES-Library: https://seslibrary.asu.edu/; ESSN: https://essnetwork.net/.