A better understanding of social-ecological systems is needed for adapting fisheries to climate change

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ABSTRACT

Adaptation to climate change has traditionally been studied at the individual scale, with most studies focusing on specific adaptation actions and the potential of individuals to undergo such actions and reduce vulnerability to climate hazards. However, adaptation to climate change takes place at the broader scale of coupled social-ecological systems (SES), where decision making and adaptation policies are relevant. Despite the general need to understand adaptation in coupled systems, there is no evidence to date to the extent to which current adaptation and vulnerability studies are covering the full range of SES components. The present study contributes to this need by examining such coverage in applied studies of vulnerability, adaptation and SES sustainability in the field of small-scale fisheries. By means of a systematic review and comparison of case studies, we detected a gap between theory and implementation and a lack of consideration of several SES components in the adaptation and vulnerability literature. This gap is larger for the Interactions between social and ecological domains, and in the coverage of Related Ecosystems. By contrast, greater attention has been given to the Actors, Governance system and Resource unit components. On the basis of our findings, we propose a set of guidelines to better address adaptation in social-ecological systems by broadening the outlook of adaptation studies and policies, specifically by considering interactions, evaluating outcomes and integrating cultural and ecological variables.

1. Introduction

In the current Anthropocene era, human activity is considered to be the main influence on climate and the environment [1]. Climate change is a prominent sign of these human-driven changes to the global environment [1] and its influence on oceans is well known [2,3]. Coupled human and natural systems in oceans are frequently represented by small-scale fisheries, in which humans interact closely with nature in a very important way for many societies, providing social, cultural and economic benefits [4–7]. More so than in other fisheries, small-scale fisheries are expected to be impacted by climate change, with important implications for the livelihoods they sustain [8,9]. In the face of such impacts, small-scale fisheries must adapt to climate change; however, little is known about how humans and nature can adapt together [10].

The complexity of human-natural dynamics is best conceptualised with the framework of Social-Ecological Systems (SES) [11]. SES are understood as coevolutionary, interdependent and complex adaptive systems composed by social and ecological dimensions that interact continuously and at different scales in relation to sustainability [11]. Small-scale fisheries (SSF) are considered SES and although they are frequently conceived as complex and integrated systems [12], several times SSF SES studies do not apply the coupled adaptive systems theory and the SES framework on their approach. To synthesise knowledge using common language under the same frameworks and provide useful and effective solutions to real-world SES, scholars suggest that more attention should be given to better integrate the social and ecological domains [10,13].

Another utility of SES is the understanding of adaptation in complex systems. Under a resilience perspective, SES can respond to change by adapting or transforming [14]. In SES adaptation, the system tolerates unknown or unforeseen shocks by absorbing, accommodating, or embracing change [14]. However, in SES transformation, the system fundamentally reorganizes as a response to challenges that are impossible to address within a current SES state or regime [14]. In SSF, one way of transformation can be illustrated by fishers exiting the fishery.

Climate change adaptation is theoretically understood as the sum of adaptive capacity and adaptation actions [15,16]. Adaptive capacity can

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be defined as the ability of human actors and communities to respond to change and maintain human well-being over time [10,17]. The term is derived from the Vulnerability Assessment Framework [4], the most common framework used to study climate change impacts and adaptation [18,19]. Recently, adaptive capacity theory has been updated to propose six different and interrelated components (flexibility, socio-cognition, assets, learning, organization and agency) [20]. However, empirical studies on real-world SSF cases have not yet been published using this classification. Thus, applied studies that have operationalized the Vulnerability assessment, including adaptive capacity, are the potential candidates to identify the SES components that have been covered to date.

Adaptation actions comprise the second component of adaptation [15,16]. These actions have been studied in relation to resilience and network disciplines recently applied to SES from a broad theoretical basis [14,21]. Unfortunately, the resilience literature lacks an operational framework with specific components that are being quantified on SSF under climate change [22], and we are not able to systematically compare studies from this discipline. This is not new, and existing studies already point out that the disconnection between fields of research is a major challenge to understand adaptation in SES [13]. In this context, studies looking at fishers’ behaviour facing declining fisheries are potential candidates to evaluate which SES components have been covered in SSF case studies. Nevertheless, these studies are scarce, they focus on factors that drive actors to exit or remain in the fishery sector after impacts on catches or economic revenues.

In addition, recent literature highlights the importance of social-ecological interactions (such as harvesting, information sharing, conflicts or deliberation processes) in coupled adaptive systems for fishers facing common dilemmas in SES [23]. Social-ecological interactions have been considered key components for adaptation and transformation in SES [14]. Despite this, it is not clear whether such interactions have been empirically analysed under Vulnerability assessments and the adaptation literature on SSF case studies. Furthermore, to our knowledge, there have not been any evaluations to the extent to which these disciplines have comprehensively covered SES components in SSF case studies. This is important as there could be a gap between what the SES framework and Vulnerability assessments state in theory and what applied case studies measure and consider in practice. In fact, theoretical frameworks must be tested and compared in order to be useful for decision-making purposes [24].

Based on the aforementioned gaps, this paper aims to contribute to the understanding of adaptation in social-ecological systems by systematically comparing empirical applications of SSF case studies under the SES framework. We focus on SES, Vulnerability assessments and adaptation actions research, which have all commonly been applied to SSF [4,25,26]. The main research question is: to what extent has research been undertaken to better understand climate change vulnerability and adaptation actions in small-scale fisheries, with the consideration of the full range of SES components?

To answer this question, we:

1) Review, summarise and compare the scientific literature concerning empirical case studies of real SSF within SES, vulnerability and adaptation studies.
2) Assess the geographical distribution of these studies and compare across research disciplines the degree of coverage of SES components and key variables, to identify mismatches and patterns.
3) Derive recommendations for further future understanding and analysis of climate change adaptation in SES.

2. Materials and methods

We first conducted an independent systematic literature search on exclusively SSF cases for each of the study disciplines considered: adaptation actions, Vulnerability assessments and operationalizations of SES framework. We then compiled a database of the variables measured in each case study, and translated those variables into the SES language (Table 1). The variables in each case study are any characteristic of the fishery system that is to be quantified. When the original studies performed their statistical analysis, they also recorded which variables were significant in relation to sustainability, vulnerability and adaptation. We documented these variables in order to get a deeper understanding of the information collected.

The SES framework coding shown in Table 1 is used in this work as the common SES language for case study comparisons, and is used hereafter in the text and subsequent figures. We used an updated version of the SES framework published by McGinnis and Ostrom [27], and modified by Blythe et al. [12]. We use the first-tier (also called sub-systems) and second-tier variable (also called components) coding to facilitate comparison across the different studies.

<table>
<thead>
<tr>
<th>Table 1 SES variables and coding. SES first-tier (in bold) and second-tier variables, taken from McGinnis and Ostrom [27] and Blythe et al. [12], with the coding we use in the remaining of the analysis.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Social, Economic and Political Settings</strong></td>
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<tr>
<td>Economic development</td>
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<td>Demographic trends</td>
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<td>Political stability</td>
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<td>Other governance systems</td>
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<td>Markets</td>
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<td>Media organizations</td>
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<tr>
<td>Technology</td>
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<tr>
<td><strong>Resource System</strong></td>
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<tr>
<td>Sector (e.g. small-scale fishery)</td>
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<tr>
<td>Clarity of system boundaries</td>
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<tr>
<td>Size of resource system</td>
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<tr>
<td>Human-constructed facilities</td>
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<tr>
<td>Productivity of system</td>
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<td>Equilibrium properties</td>
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<td>Predictability of system dynamics</td>
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<td>Storage characteristics</td>
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<td>Location</td>
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<td><strong>Governance System</strong></td>
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<td>Government organization</td>
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<td>Non-governmental organizations</td>
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<td>Network structure</td>
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<td>Property-rights systems</td>
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<td>Operational-choice rules</td>
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<td>Collective-choice rules</td>
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<tr>
<td>Constitutional-choice rules</td>
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<tr>
<td>Monitoring and sanctioning rules</td>
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<tr>
<td><strong>Resource Unit</strong></td>
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<td>Resource unit mobility</td>
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<tr>
<td>Growth or replacement rate</td>
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<td>Interaction among resource units</td>
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<tr>
<td>Economic value</td>
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<tr>
<td>Number of units</td>
</tr>
<tr>
<td>Distinctive characteristics</td>
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<tr>
<td>Spatial and temporal distribution</td>
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1 This modified version includes the variable “I11 – Differential powers”, that is not originally in McGinnis and Ostrom, 2014.
2.1. Systematic review

We conducted a systematic literature review including three types of relevant literature: a) studies in which a SES framework was used to conceptualise or diagnose sustainability in coupled systems (SES literature); b) studies applying the IPCC-derived Vulnerability assessment framework to assess vulnerability in coupled-systems, including at least the adaptive capacity of the social domain (Vulnerability assessment literature); and due to the lack of a general framework for adaptation actions c) studies addressing adaptation by the readiness of fishers to exit a declining fishery. We refer to this latter literature as Adaptation actions literature hereafter in the text.

We used Google Scholar for the systematic literature search and downloaded articles published through 2017. We used variations of three sets of keywords (Appendix A.1), with one set corresponding to each type of literature (SES framework, Vulnerability assessments and Adaptation actions). All potential target papers were screened in a two-step process. First checking the title and abstract to identify potential papers that meet our criteria: an empirical application of the SES framework, Vulnerability assessment or Adaptation actions literature on a real SSF case study with a qualitative and/or quantitative approach. Second, reading the paper in detail to verify they meet explicitly our criteria and for those that do, extracting all the variables measured. In this last step we also extract the statistically significant variables, when available in the source study. Additional relevant papers were identified under the same criteria from screening the reference lists of the remaining papers. This process led to the final identification of 331 potential studies in the first step. In the second step, most papers did not meet the criteria and as a consequence, the number of target papers was significantly reduced to 22 (36% SES, 46% Vulnerability assessments and 18% Adaptation actions). The studies included in this analysis are listed in Appendix Table A.2. Each empirical paper was coded and included in the database for the following analysis.

2.2. Data and analysis

The variables analysed by the collected studies were then translated to match the SES coding, in order to standardise them as SES components (Table 1). This standardisation is based on the definition of each variable as stated in each original paper and/or supplementary materials. The original variable names and the corresponding SES codes are included in Appendix Table A.3. Classification of the original variables into SES second-tier codes excluded some variables that did not match any of the second-tier SES categories. Regarding the Adaptation actions literature, we were able to identify statistically significant variables that explain the adaptation response from the original papers. These variables explain the fisher’s choice of remaining or exiting in the SSF activity after certain impacts. We refer to these variables as key variables hereafter in the text.

In the SES framework (Table 1), Interactions is a sub-system that includes the links between the rest of SES sub-systems and could have a key role between them. For example, II-Harvesting can link the Actors and the Resource Unit sub-systems by linking the A1-Number of relevant actors with the RU2-Growth or replacement rate of the resources. To better understand which Interactions components have been measured in the reviewed studies, and their purpose, we classified the Interactions components based on the following parameters: 1) the type of Interactions according to the SES coding, e.g. II-Harvesting; and 2) the SES sub-systems linked by the Interactions, e.g. Actors and Resource Unit. This enabled us to conceptualise the type of Interactions between several social-ecological sub-systems as a combination of SES components.

3. Results

We present the results of the cross-comparison of case studies in terms of 1) the geographical coverage of case studies 2) the coverage of the SES framework, including key variables and new second-tier variables which are not included yet in the SES framework, and 3) the interactions between sub-systems of the SES framework.

3.1. Spatial coverage of case study applications

Fig. 1 summarises the results in terms of the geographical coverage of case studies (Appendix Table A.4 to see the list of countries). Fig. 1 shows that the geographical coverage greatly differs across disciplines. SES applications have mainly been developed at community and site scales and most of these studies focus on the southern hemisphere (Fig. 1). Vulnerability assessments have a longer tradition- as a discipline which has resulted in a broader worldwide coverage (Fig. 1) with case studies ranging different countries around the world as well as covering country, site and community scales. However, adaptation action studies are concentrated in East Africa and South East Asia (Fig. 1), and they are mainly focused at individual, household and site scales.

Fig. 1 also shows the SES sub-systems which reviewed studies have been focusing on (bar plots). Surprisingly, although Vulnerability studies do not necessarily rely on SES theory, we find that they have been looking at a wide range of SES sub-systems. SES and Vulnerability assessments analysed cover a broader range of sub-systems than the Adaptation actions studies. While SES studies focus their analysis on Governance system and Actors, the Vulnerability assessments pay more attention to Actors. On contrast, Adaptation actions literature has been focusing on the Actors, Resource unit and Interactions subsystems mostly without any operationalization of Related ecosystems and Outcomes.

3.2. Coverage of the SES framework

Fig. 2 compares the coverage of the SES framework at the second-tier variables level by different disciplines indicating current gaps and mismatches among them as well as key variables collected from the original Adaptation actions literature (data available in Appendix Tables A.6- A.7). This figure provides an idea of the extent to which SES, Vulnerability assessments and Adaptation actions studies have considered the full range of SES components. Overall, the most commonly studied sub-system across frameworks is Actors, with 100% of theoretical second-tier variables covered in SES studies, 88.89% in Vulnerability assessments studies, and 55.56% in Adaptation actions studies. By contrast, the least commonly studied sub-system in all empirical approaches is the Related Ecosystems (ECO), with no observations in SES and Adaptation actions studies, and with two out of second-tier variables covered in Vulnerability assessment studies. Interactions (I) and Outcomes (O) have also a very low coverage, especially in Vulnerability assessments and Adaptation actions studies. Interactions between the ecological and the social subsystems or the evaluation of outcomes after specific interventions can be crucial for climate change adaptation, and we see from our analysis that focus on these sub-systems is lacking in Vulnerability and Adaptation studies. Consideration of the full coverage of a SES differs across disciplines. As a consequence, 7 out of 57 of second-tier variables from the SES framework are still not addressed in empirical approach in any of these studies. We provide a detailed analysis of SES framework coverage below and discuss the results in different subsections focusing on each discipline.

3.2.1. SES coverage in empirical SES case studies

We found that 11 out of 57 second-tier variables in the SES framework were not addressed in any of the empirical SES case studies. The Related Ecosystems sub-system was not covered in any of these studies, and half of the Settings variables remain unexplored. Considering the sub-systems, we found that greater attention was placed on Actors, Governance system and Outcomes than on the other sub-systems (Fig. 2). We found an unbalanced coverage between the set of Resource system, Resource unit, Governance system, Actors,
3.2.2. SES coverage in vulnerability assessment studies

We found that 26 out of 57 theoretical SES variables are not included in any of the Vulnerability assessments empirical approach. In the Vulnerability assessments studies analysed in Fig. 2, the Interaction and Outcomes sub-systems were not widely studied. Interestingly, we found that Vulnerability assessments have operationalized Related Ecosystems to a further degree than the SES literature itself. Also, Vulnerability assessments have measured some Resource Unit variables that the other disciplines have not covered, such as RU3-Interaction among resource units.

3.2.3. SES coverage in adaptation actions studies

Only 11 second-tier variables out of 57 potential SES variables were addressed in the Adaptation actions literature. In this analytical discipline, the most-studied variables are part of the Actors sub-system, while the least-studied variables are in the Outcomes and Related Ecosystems sub-systems. Also, all of the variables applied in the Adaptation actions literature have also been explored in the Vulnerability assessments literature, and 72% of them are also covered in SES case studies. Despite the low number of SES variables covered in this literature, these studies illuminate key SES variables that allow us to better understand adaptation in SSFs. These key variables are indicated by the striped cells in Fig. 2. For example, according to the original study [25], depending on the scale that authors use in the analysis (country scale vs region scale), the infrastructure index which represents both human-constructed facilities and economic development is either positively and negatively correlated with exiting the SSF in the same study [25]. Authors explain in their original papers the potential reasons of these results, discussing levels of economic development and diversification, site-specific historical processes, the role of markets, technology and the government assistance. This information shows us the complexity of adaptation once different SES components and scales are integrated (see Appendix Table A.7) and calls for an interdisciplinary research to understand how adaptation works in different case studies.

3.2.4. New variables for SES adaptation

After matching the original variables from Adaptation actions and Vulnerability studies with the SES code, we identified a set of variables that did not match the SES Framework. Based on these results and taking advantage of the flexibility of the SES framework [26], we propose incorporating 6 additional second-tier variables for future climate change adaptation studies focused on SES: Actor’s perceptions (A10), Habitat characteristics (RS9), Ecosystem characteristics (RS10), Interaction between resource systems (RS11), Human-Environment activities (I12) and Linkage to other SES (I13). By incorporating these variables, we believe we will better understand the complex dynamics of coupled adaptive SES under adaptation processes such as social responses to social-ecological impacts. Some of these variables may convey important information about a system’s adaptive capacity and vulnerability. For example, A10-Actor’s perceptions is relevant, as previous studies have found that a pessimistic perception of predicted fish abundance in 5 years is positively correlated with exiting the fishery [28]. The RS9-Habitat characteristics and RS10-Ecosystem characteristics have been described in the Vulnerability assessments as essential components to evaluate the dynamics and capacity of the fisheries to respond under social-ecological climate change [4]. The analysis of RS11-Interaction between resource systems can identify the connectivity among resource systems in order to avoid social conflicts due to competing concerns [29], which is a key adaptive capacity domain for climate change adaptation [16,30]. Also, Vulnerability literature has showed that the I12-Human-environment activities such as the human impact index can measure the exposure to climate change of SSFs [44]. Finally, the I13-Linkage to other SES such as the portfolio of industrial to small-scale fisheries is one of the key flexibility components for social adaptive capacity [30,31]. Appendix Table A.8 details these variables and the proposed coding.
Fig. 2. Results of the Frameworks comparison. The SES framework is used as common language for the comparison between disciplines in which each segment is a sub-system and each cell is a second-tier variable. The percentage values below each segment indicate the quantity of second-tier variables covered per sub-system. The data used to create this figure is available in the Appendix Tables A.6-A.7.

3.3. Interactions

Fig. 3 shows the results of our analysis on Interactions sub-system. Nine out of these 11 components have been studied in SSFs. The different colours indicate the six different combinations of social-ecological sub-systems identified as interacting with each other. The most frequent type of combinations studied in the literature and evaluated here are those between Actors and Resource unit (A-RU), and those between Actors and Governance system (A-GS). Within the first category, I1-Harvesting is the most frequent studied variable. Within the second category, a broad array of Interactions is used, including I11-Differential powers, I2-Information sharing, I3-Deliberation processes, I4-Conflicts and I8-Networking activities (Fig. 3). We also identified two Interactions linking second-tier variables within sub-systems. In Actors, I2-Information sharing and I7-Self-organizing activities happen between actors. In the Governance system, I11-Differential powers and I6-Lobbying activities are Interactions within governance. Finally, only one paper has focused on Actors - Resource system (A-RS) and Actors - Resource unit - Governance system (A-RU-GS) combinations. For these Interactions, the variables that link the sub-systems are I1-Harvesting and I9-Monitoring activities. Appendix Table A.9 details these variables and the sub-systems they link.

4. Discussion

Adaptation in social-ecological systems involving fisheries has been studied from the perspective of different research disciplines, but adaptation policy in marine systems is still lagging behind probably as a consequence of the lack of applied studies under adaptation frameworks in marine systems [32]. In this study, we have shown how different disciplines have covered the full range of SES components and that much is already known about SES, Vulnerability and Adaptation in small-scale fisheries. However, a new focus on complex SES must emerge as a complementary approach to the traditional Vulnerability and Adaptation focus on individuals. We argue that the use of the SES framework to understand coupled human-natural systems can improve our capacity to understand vulnerability and adaptation to design effective policy solutions by converging the multiple disciplines under the same framework and language. We summarise our findings in terms of lessons learnt, in order to guide climate change adaptation practice in social-ecological systems.

1 Increase the number and the geographical coverage of adaptation studies

Climate change impacts occur at the global scale [2,3] and affect livelihoods in different directions and with dissimilar intensities according the specific context [8,25]. While Vulnerability assessments are being developed in many regions [8], Adaptation actions have only been developed in specific regions, and evidence is scarce [33]. Adaptation actions studies in the face of climate change will be critical for the most vulnerable livelihoods, but there is limited evidence of adaptation actions in many areas [34]. Social-ecological components as the Social, Economic and Political Settings are key aspects that should be considered carefully for understanding the effect of adaptation in
context-specific cases [25]. We encourage future research to apply the SES thinking over SSFs case studies in order to understand the diversity of relationships between SES components and adaptation outcomes. Furthermore, we expect to obtain a better transference of knowledge from case study applications and relevant contributions for climate change adaptation literature, decision-making and policy.

2. Integrate the ecological dimension into adaptation studies

In this review, we found that the empirical studies evaluated have paid little attention to ecosystems and ecological dynamics (e.g. interactions among resource units, spatial and temporal distribution, climate patterns). Despite this evidence, we know that covering this range of social-ecological components is not always possible due to data, time, budget and human resources availability. However, gaps and potential key components need to be identified in order to conduct efficient and accurate climate change adaptation research. In addition, we suggest that the Resource system sub-system must be broadened from the human-utility conception towards acknowledgment of ecological functions and services. In this line, the inclusion of ecological components into the SES framework has been recommended [35] as well as the interdisciplinary network approach to resolve ecological and human-nature dilemmas [36,37]. Our analysis contributes to fulfil this gap by proposing the inclusion of specific variables related to habitats and ecosystems in the current SES framework such as RS9-Habitats characteristics, RS10-Ecosystem characteristics and RS11-Interactions between resource systems (Appendix Table A.8). Furthermore, this work highlights the lack of SES studies that focus on the interactions between species in the same or different ecosystems. We suggest that consideration of interactions between target and non-target species can improve our understanding of ecological dynamics.

3. Incorporate social and cultural factors in adaptation studies

Adaptation actions studies include factors that explain the reasons why people decide to enter or exit fisheries, such as tradition, necessity or job satisfaction. Although the Actors sub-system is one of the most widely covered in terms of first-tier variables, some of the second-tier variables within this sub-system should be studied in greater detail, particularly in the socio-cultural domain. The key variables collected from the literature of Adaptation actions reveal that variables included in the socio-cultural domain such as preference, perception and number of occupations in households are important to exit or remain in the SSF sector. Many socio-cultural factors such as education, family tradition in fisheries, cultural dependence [26], people’s beliefs, cooperative behaviour [38], wealth, being born in the community, the length of co-management arrangements [39] and kinship aspects [40] can play a key role on the decision to exit a SSF. By contrast, economic and material values are generally considered the most important factors in the literature [25]. Also, a gender perspective is needed to inform a complete understanding of what climate change adaptation of a SSF means for ecological and social domains [41]. Consistent with the literature [42].
our analysis shows that further studies addressing adaptation actions should integrate the broad range of cultural, social and human aspects of SES that have recently been underused. To contribute to this point, we propose the A10- Perception second-tier variable to be included in the current SES framework according to Adaptation actions literature that shows its relevance facing impacts on fisheries (Appendix Table A.8). Here, we propose an analysis based on qualitative data to understand the complexity behind individuals, groups and governance systems [42]. Also, well-designed participatory processes and the identification of marginalized social individuals and collectives from areas of power and equity can be a resourceful tool to link specific interventions with winner and losers [43]. In these regards, the multi-dimensional components of social wellbeing can provide deep insights if they are integrated from a climate change adaptation perspective [44,45].

4 Consider interactions between sub-systems and scales

Whitney et al. [10] suggest that a greater effort should be placed on Interactions sub-system such as I9- Monitoring activities and I10- Evaluation activities (Fig. 1) over time and across scales. Furthermore, Torres-Guerra et al. [46] highlight the importance of the Social, Economic and Political Settings (Fig. 1) and their consequences on collective action, and Daw et al. [25] empirically show how a multiscale approach is crucial for understanding SES and their complexity for adaptation actions (Appendix Table A.7). In this line, a scale of operationalisations varies among disciplines and case studies. While Vulnerability assessment has not been applied to household and individual scale, Adaptation actions literature lacks at community and country scale.

Regarding Interactions, the Adaptation literature has focused on I11- Harvesting only, ignoring other Interactions components. Although studies examined from the Vulnerability and SES literature cover more SES Interactions than those from the Adaptation literature, there are still remarkable gaps in this field, including: a) the disconnection between Related Ecosystems and Settings with the rest of the SES sub-systems, b) the small number of links between sub-systems that have been considered in any discipline and, c) the small number of Interactions second-tier variables analysed so far in those literatures. Our findings suggest that incorporating the Interactions components between SES sub-systems and across scales that have not been previously tested in Adaptation actions studies would allow these recommendations to be fulfilled. In order to contribute with this gap and based on the results of our analysis, we propose an extension of the current SES framework with I12- Human-Environment activities and I13- Linkages to other SES second-tier variables which were not explicitly considered in the framework to date. Also, focus on the analysis of the interactions as they relate to Outcomes in the face of climate change could provide fruitful insights. In this regard, we suggest a network approach as a useful way to fill some of the gaps identified here, such as enhancing the connectivity between the social and ecological dimensions or addressing interactions among nested scales by building blocks, multiplex networks and networks modelling analysis [14,36,37].

5 Apply the SES Framework in Climate Change Adaptation research

Literature claims that interventions that ignore nature and culture can reinforce poverty [47]. Based on our analysis, we can see now the SES framework offers a balance between complexity, operability and flexibility that make it very useful for scholars to investigate human-nature complex adaptive systems under climate change. Our analysis shows that the structure of the SES framework embraces complexity when it covers Actors, Governance system and Settings, as well as the Resource unit, Resource system and Related ecosystems on real case studies. Interactions are the articulations of this framework and the specific place designed for Outcomes highlights the diversity of approaches and the capacity to evaluate interventions such as those related with climate change adaptation. The integration of new social-ecological aspects by different authors during last years is a clear example of its flexibility. The possible level of specification in the variables (1st-tier, 2nd-tier, etc.) and the application on different scales and case studies show the operability of this tool.

In addition, the underlying goal of the framework is to accumulate and synthesise knowledge from multiple disciplines and standardise languages to provide cutting edge research questions, efficient policy communication and solve real-world dilemmas, such as climate change adaptation in SSF. Thus, we recommend to understand climate change adaptation in SSF by exploring the seven resilience principles [48] using the SES framework mindset and looking at how the different SES components behave under different principles and case studies.

5. Concluding remarks

With the goal of understanding climate change adaptation in coupled human-natural systems (“what we know, don’t know and need to know”), this paper identifies, describes and compares some of the different disciplines used to assess small-scale fisheries facing climate change under the lens of social-ecological systems. A general gap across disciplines whereby little attention has been given to the role of the ecological side of SES and to the interactions between components. Cultural, human and social factors have also been poorly studied, despite evidence regarding their important role in adaptation.

Mismatches between frameworks indicate a lack of knowledge transfer from one research area (e.g. SES and Vulnerability assessments) to others (e.g. Adaptation actions), as well as the poor worldwide case study coverage for Adaptation actions and SES literature so far. We have also found that applied studies in Vulnerability assessments and Adaptation actions do not cover the full range of SES components. To solve this ideally, we propose that the whole SES and the diversity of second-tier variables should be addressed using the standardised SES terms and that a special effort should be made to integrate disciplines and approaches. In this line, studies should balance the social and ecological domains of SES and carefully consider the role of socio-cultural aspects that enable or threaten adaptation processes. Furthermore, interactions between SES components should be better measured and understood within and across first- and second-tier variables. Also, evaluations before-after interventions are strongly recommended under the SES framework. Finally, focus should be placed on variables that have not been studied in detail so far in the context of climate change adaptation, but have been largely developed under the SES framework.

For many cases, following these recommendations and covering all the SES components may be unfeasible and ticking all the SES components should not be a priority over ensuring that data collected are of the highest quality possible. In this regard, we suggest that future studies could either target particular aspects of the SES framework in greater detail, or, those with the budget/capacity, can do a robust assessment of the full SES framework for specific case studies.

We recommend potential pathways to address future climate change adaptation research on fisheries. Primarily, from a participatory approach, we recommend to strengthen the nexus science-society-policy, where synergies can arise and researchers can greatly benefit from citizen science, stakeholder consultations and well-designed participatory processes. Secondly, from a scholar perspective, we recommend to explore the intersection between the case study conditions, SES components and Resilience principles empirically to identify key converging points and address climate change adaptation in SSF. For both approaches, network analysis can be a promising tool to assess SES. And finally, we strongly recommend a combination of these two previous options when conditions make it possible.

We argue in this study that the SES framework could be better applied to the understanding of climate change adaptation in SSF and beyond. Lessons learned from this analysis can be used as: 1) a guideline for future research, 2) a practical tool for transferring knowledge about
climate change adaptation of SES and 3) needed information to be incorporated into adaptation policy design and facilitation. 

CRediT authorship contribution statement

Diego Salgueiro-Otero: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing - original draft, Writing - review & editing. Elena Ojea: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing.

Declaration of competing interest

None.

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Appendix A. Supplementary data

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