An updated diagnostic social-ecological system framework for lobster fisheries: Case implementation and a sustainability assessment in Southern California

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Abstract

Fisheries exemplify the immense complexity of interactions in social-ecological systems (SESs). This complexity has created management challenges and raises concerns for the sustainability of our marine natural resource systems. The purpose of this article is two-fold: first, to contribute to the understanding of lobster fisheries as complex social-ecological systems, in particular the Southern California Spiny Lobster Fishery (SCSLF) case study. Secondly, to demonstrate a methodological approach for assessing component interactions in SESs that can be used to assess the sustainability of management approaches. We have systematically reviewed the literature on research trends in lobster fisheries and their SES characteristics. With this data, along with interviews and an author's first-hand experience as an alternate SCSLF Lobster Advisory Committee (LAC) recreational non-consumptive member, we updated and extensively defined the diagnostic social-ecological system framework for use in lobster fisheries. Subsequently, we use the SCSLF as a case example for how to implement the updated framework. With this classification we analyze the LAC, the stakeholder-comprised management group of the SCSLF, as a social-ecological action situation with the SES imbedded Institutional Analysis and Development (IAD) framework. Our results provide coherency and common metrics for more effective empirical utilization of the SES framework in lobster fisheries, which currently has mostly theoretical application. More generally, we find that research in lobster fisheries is focused on a few areas, limiting holistic SES knowledge. Lobster fisheries have many different characteristics and management approaches, none of which can be effectively generalized or transferred, including co-management, without contextual SES considerations. Furthermore, this analysis provides a sustainability assessment of how the LAC manages the SCSLF. The LAC and the SCSLF contain multiple SES components that have been associated with sustainable outcomes elsewhere, however the fishery still faces many obstacles such as how to adapt to future challenges. Our results contribute to developing a holistic methodological approach for operationalizing SES framework research into practical fisheries management.

Keywords

Lobster fisheries, SES framework, stakeholders, sustainability science, operationalizing, review

1.0 Introduction

The integration of human societies into the natural environment is a core driver of current global environmental change, and in few places is this more apparent than in the world's marine and coastal systems. The oceans and coasts of the world continue to experience rapid transformations through land use change, biodiversity loss, excessive extraction and general ecosystem degradation, exemplifying the immense impacts of increasing concentrations of human settlements and expanding exploitation of marine and coastal resources (Berkes et al., 2006; Halpern et al., 2008). Fisheries in particular demonstrate how the exploitation of these resources can cause significant changes to system functions and processes which may threaten the long-term sustainability of such resource systems globally (Berkes et al., 2006). Such human-induced changes also have important implications for the livelihoods (Checkley et al., 2013; Kittinger, 2013), cultural identities (Ernst et al., 2010; van Putten et al., 2013) , and the economic stability (Gourguet et al., 2013; Martinet et al., 2007) of those individuals and communities who rely on the use of these resource systems. The reciprocal social and ecological impacts of marine and coastal resource exploitation alludes to the point that both social systems and natural resource systems are embedded in complex social-ecological systems (SESs) (Ostrom, 2009, 2007).

The complexity inherent in SESs requires that their assessment consider a multiplicity of dimensions, including ecological characteristics as well as the quality and design of resource management institutions (Basurto et al., 2013; Ernst et al., 2013). Sufficient understanding of the various components of these complex systems, as well as the interactions within and between system components, is needed for the design and implementation of sustainable management approaches (Agrawal, 2003, 2001; Lange et al., 2013). Although many studies research human-nature interactions, the complexity of coupled SESs is not well understood (Liu et al., 2007; Ostrom, 2007). Ill-informed interventions due to e.g. a lack of knowledge types, can produce problems of ineffective and unsustainable management (Gutiérrez et al., 2011). As means to avoid this pitfall, case studies of SESs in particular can provide important insights into the context-specific nature of these management challenges, including developing knowledge about relevant system components and their internal interactions (Ostrom et al., 1999).

In this article, we demonstrate how complex SESs can be characterized and analyzed and how the results of such an analysis can be harnessed to inform improved management of natural resource systems. We do so by focusing our attention on lobster fisheries management as an exemplary research field, though the demonstrated approach is applicable to virtually all SESs. We begin by drawing on a comprehensive review of the existing academic literature on lobster fisheries, as well as consultative expert interviews with practitioners and academics, from which we update the well-known SES diagnostic framework to make it specifically applicable to lobster fisheries. We then apply the updated framework to a multi-use lobster fishery in the coastal region of Southern California, U.S.A, called the Southern California Spiny Lobster Fishery (SCSLF) to further elaborate the process of applying the updated framework to a real-world management case. The steps needed to elaborate the framework beyond the general characteristics of lobster fisheries to the specifics of a real-world management case, and the relationship between the two, are exemplified and discussed.

By applying the updated framework to the SCSLF, and utilizing data gathered from a survey conducted with stakeholder representatives, we undertake a demonstrative contextual SES component interaction analysis and sustainability outcome assessment of the case study fishery. We exemplify a methodological procedure for how to operationalize a more comprehensive case assessment, and our precursive analysis of the SCSLF Lobster Advisory Committee (LAC) serves to highlight how researchers and practitioners can utilize results from an updated SES diagnostic framework analysis to identify potential challenges relevant for the long-term sustainable management of multi-use SESs.

Results from our research feeds into the broader ambition for the diagnostic SES framework to provide a template for building cohesive data between SESs for collective inter-case analyses such as modeling interactions and outcomes across fisheries and testing theory, though we do not specifically pursue such an approach in this article. Beyond inter-fishery analyses, the general conclusions drawn from this work regarding the relationship between research and management (i.e. knowledge and action) are applicable to virtually any SES, terrestrial or marine, and thus contribute to filling an important research gap in SESs studies (Ostrom and Cox, 2010) and sustainability science more broadly (Kates, 2011; Wiek et al., 2012).

1.1 Lobster Fisheries and SES Research

Worldwide, lobster fisheries present resource systems that are largely common-pool in nature (Ostrom, 2007), relatively well researched, and are globally distributed in locations with very different historical (Davis and Wagner, 2006; Ernst et al., 2013) and social-institutional (Basurto and Coleman, 2010; Jennifer F. Brewer, 2012) settings. . The wealth and diversity of information regarding lobster fisheries generally provide quality case examples, in particular for elaborating on the process of moving from general SES component identification to diagnosing context-specific resource management systems. Focusing on distinctive contextual settings is important because such studies help support case-specific diagnosis of resource management problems while simultaneously contributing to integrated research approaches relevant to all SESs, and small-scale fisheries in particular (Kittinger et al., 2013). While research aimed at identifying SES components in fisheries is not uncommon (e.g. (Basurto et al., 2013; Ernst et al., 2013; Hearn, 2008)), there has been far less attention paid to developing an understanding of management configurations and social-institutional interactions, how they relate to the collective whole of SES characteristics, and how interactions within SESs affect the long-term sustainability of outcomes (Basurto and Coleman, 2010; Basurto et al., 2013; Gutiérrez et al., 2011; Kittinger et al., 2013). In particular, heuristics for moving from general SES component identification to such context-specific management case analysis is lacking. This is a particularly pressing issue given that policies for SES management have historically adopted a simplistic, blue-print approach by developing and implementing universal "solutions", panaceas, that have been largely unsuccessful in attaining sustainable outcomes due to their lack of sensitivity to context (Ostrom, 2007). To create contextually based solution options, solid foundations in research fields like sustainability science can help facilitate the production of sound research strategies for analyzing and integrating complex interlinked SESs while simultaneously providing normative grounds for utilizing such knowledge to promote and facilitate action conducive to sustainability (Clark and Dickson, 2003; Ostrom, 2007). This is particularly important for management of marine resources as they are immensely complex and thoroughly integrated with and impacted by a wide range of human activities (Berkes et al., 2006).

1.2 The Southern California Spiny Lobster Fishery

To demonstrate how general SES research can be adjusted to specific management contexts, we draw on the SCSLF as an exemplary case. The Southern California Spiny Lobster (*Panulirus interruptus*) is fished between Point Conception, California (northern boundary) and the US-Mexican border (southern boundary), (see *Figure 1*). The natural habitat of the Spiny Lobster ranges from Point Conception south beyond the US-Mexican border to Bahia Magdalena, Baja California, Mexico. Spiny lobsters are commonly found in rocky inter-tidal areas down to depths exceeding 73 meters. They reach sexual maturity between 3 and 9 years old, and spawning occurs yearly thereafter, usually spawning 2 to 3 times before they reach legal harvest size (Neilson and Barsky, 2011). Spiny lobsters do not have claws, but rather a spiny body and large tail for protection and mobility, respectively. Situated within the SCSLF boundaries is Los Angeles County, which witnessed the largest growth (in total number) of coastal population between 1970 and 2010 in the United States (NOAA, 2013). Coastal areas like those found in Los Angeles County contribute up to 81% of California's jobs and 86% of its economic output (Raheem et al., 2012). With California being the largest economy in the United States, these coastal areas represent a natural resource of central and growing social and economic, as well as ecological, importance.

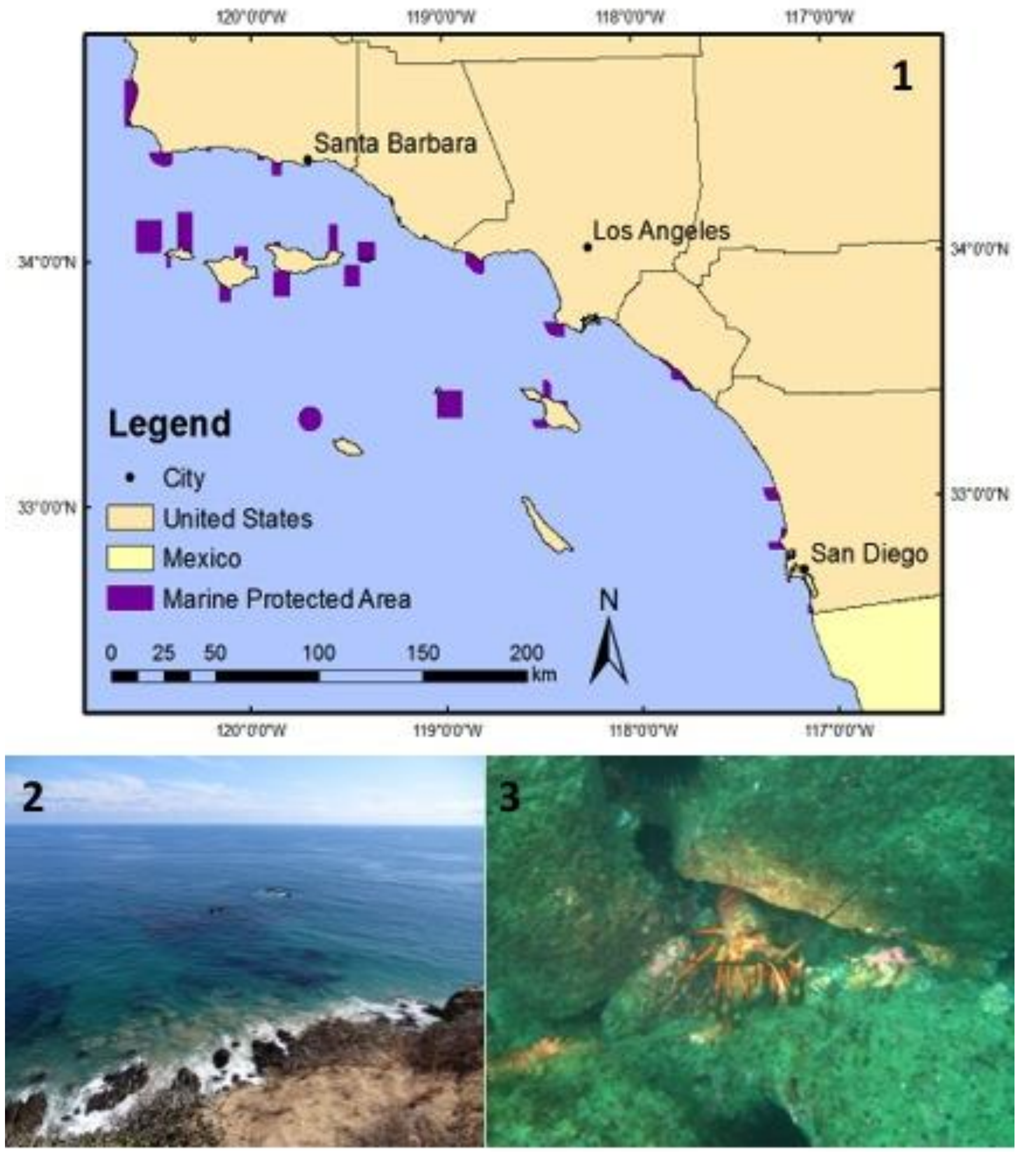

Figure 1. (1) The larger photo shows the full extent of the SCSLF boundaries from Point Conception, CA to the US-Mexican border. (2) A typical coastal view off the Southern California coast into Spiny Lobster habitat. (3) A Spiny Lobster in its natural rocky habitat.

1.3 The Lobster Advisory Committee

The SCSLF involves a complex social-institutional dynamic and a unique, historically evolved stakeholder management approach to collectively manage the fishery, namely through the LAC. The Marine Life Management Act, passed in the California Legislature in 1999, mandates that all marine fisheries in California prioritize the conservation, restoration and sustainable use of marine resources through the adoption of sustainable Fishery Management Plans (FMPs) for each fishery (California Department of Fish & Wildlife, 2001). FMPs must include all relevant stakeholders to the fishery and be founded on good science. The California Spiny Lobster was listed fifth in priority of 109 fisheries in California to develop a sustainable FMP (ibid). This was largely due to the fact that lobsters are assumed to be long-lived and one of the most exploited fisheries in California (California Department of Fish & Wildlife, 2001; Neilson and Barsky, 2011).

Simultaneously, landmark legislation was passed in California to create a statewide network of Marine Protected Areas (MPA) to protect marine ecosystems and marine life populations (Saarman and Carr, 2013). Each section of the state was responsible for designing and implementing MPAs through a stakeholder engagement process. While the implementation of the MPA network was eventually, though arguably, effective in the Southern California section, the organizational process of incorporating diverse and conflicting stakeholder interests, science advisors, and government oversight was seen as 'poorly balanced' and collaborative efforts were experienced as 'very low' in a post-process survey (Fox et al., 2013). Largely in response to the reflections on the MPA process, the LAC was formed (see *Figure 2)*, by the California Department of Fish and Wildlife (CADFW) in 2012, to form a fishery management plan to manage the SCSLF. The LAC consists of primarily the same stakeholders engaged in the MPA process and is intended to provide a more fairly balanced and collaborative stakeholder management process.

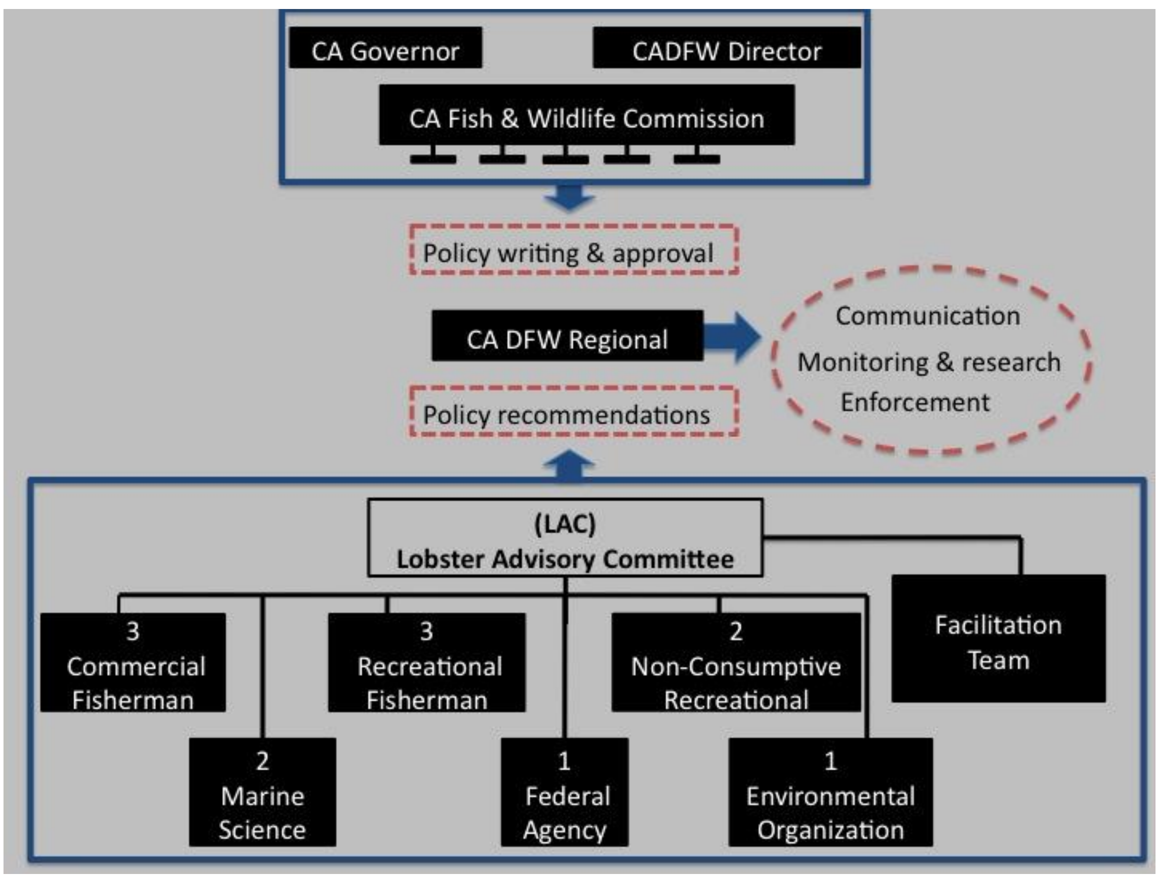

Figure 2. The LAC stakeholder representative composition and CADFW governance network structure. The LAC consists of 12 voting members and one alternate (not displayed) for each stakeholder group, making 18 total representatives. The number indicates the amount of representatives in each stakeholder group. The facilitation team organizes, facilitates discussion and consults decision-making on the LAC, but has no voting or authoritative power on decision-making. The LAC is overseen by the CADFW regional office who provides communications, monitoring, research and enforcement for the fishery at the regional level.

1.4 Research foundations

Given the complexity of coastal and marine SESs, the integration of SES research into the field of sustainability science is necessary for achieving the ambitious goals of enhancing the effectiveness of positive outcomes through interactions within the research-management nexus (Miller et al., 2008). In turn, scholarship in sustainability science has been linked, referenced and or defined as research in social-ecological systems (Agrawal and Chhatre, 2011; Folke et al., 2005; Lange et al., 2013; Perrings, 2007). Sustainability science aims to influence a transition towards sustainability by developing a comprehensive understanding of complex systems through problem-driven, action-oriented interdisciplinary research that embraces a pluralistic methodological approach (Jerneck et al., 2010; Kerkhoff, 2013; Perrings, 2007). Conducting SES research is therefore vital for further principle development of interdisciplinary approaches to, and collaborations between, research and management aimed at achieving sustainable outcomes. Furthermore, applying a SES-based diagnostic framework in sustainability science research to analyze management challenges and take steps towards achieving sustainable outcomes in fisheries and other resource systems helps facilitate the incorporation of disparate epistemological and theoretical viewpoints inherent in transdisciplinary research collaborations with non-academic actors (Lang et al., 2012). Sustainability science is fundamentally grounded in a praxis of rigorous empirical research that combines theory and practice while also maintaining commitment to sound epistemological foundations (Wiek et al., 2012).

2.0 Analytical Framework: Inheriting a SES research agenda

The diagnostic SES framework was originally developed by Nobel Laureate Elinor Ostrom and colleagues in response to the insufficient conceptualization of complex system components and interactions in resource management studies. Additionally, the framework was intended to bring workable and transdisciplinary-oriented foundations to research aimed at addressing the problematic practice of developing and implementing one-size-fits-all 'solutions' to resource management problems. The diagnostic SES framework, at its roots, emerged out of a critique of streams in game theory which over-simplistically conceptualized human decision making in resource management, leading to both insufficient outcomes in policy approaches and a generally pessimistic outlook for the prospects of human society's capacity to sustainably manage common-pool resources, most notably captured in Garrett Hardin's 1968 (Hardin, 1968) Tragedy of the Commons. The SES diagnostic framework, introduced by Ostrom (2007) and shown in *Figure 3*, was a hugely influential step for distilling variables and interactions from a wide swath of empirical natural resource management research cases from around the world as a means to assist the systematic assessment of SESs in any given context. This framework is essentially a "systematic analytical tool to work through and categorize complexity," (Basurto et al., 2013, p.1375).

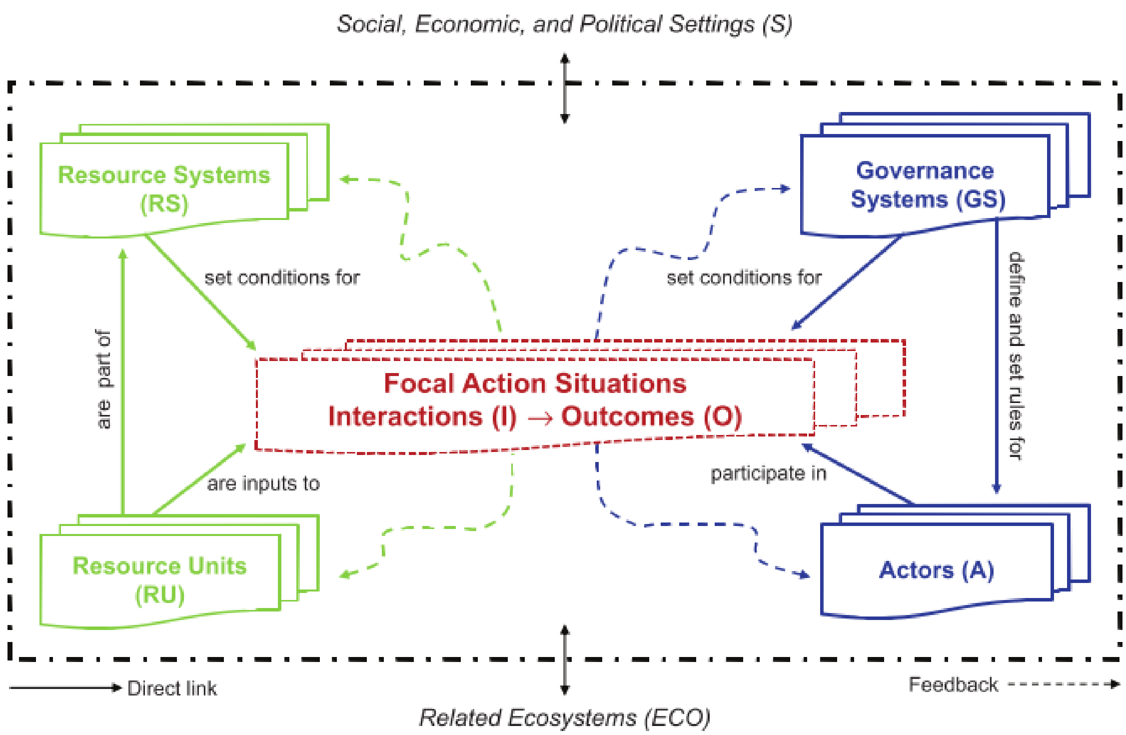

Figure 3. A diagnostic social-ecological system (SES) framework with first-tier variables, including interactions and outcomes through 'action situations'. Second-tier variables and sub-sequent tier variables, fall under first-tier groups and can be expanded further to contextualize a specific SES. The depth of tier variables fall across a gradient of analytical relevance from collectively aggregated to case specific. Adopted from (Ostrom, 2011a).

The diagnostic framework in particular is meant to facilitate the identification, categorization and organization of relevant variables necessary for understanding resource management processes and outcomes. The framework begins to classify an integrated human-environment system through the four initial first tier variables: Governance System (G), Resource System (RS), Resource Units (RU) and Actors (A). Subsequent variable tiers identify specific sub-system variables relevant at different scales and levels within the specific SES. For example, in this study these subsequent tiers are updated for classifying lobster fisheries generally, and then specifically used to classify the SCSLF. As the diagnostic SES framework merely provides a means to identify variables and structure data collection in an SES, acting as a sort of checklist, an analysis of how variables interact requires a complementary but different methodological approach. The Institutional Analysis and Development (IAD) framework shown in *Figure 4* is the political science predecessor, rooted in game theory and imbedded within the SES framework (McGinnis and Ostrom, 2014), which aims to achieve understanding of interactions through defining specific action situations in the SES and assessing them with evaluative criteria. An action situation is defined by the following seven criteria: (1) sets of actors, (2) sets of positions actors fill in context of situation, (3) set of allowable actions for actors in each position, (4) level of control that individual or group has over an action, (5) outcomes associated with combinations of actions, (6) amount of information available to actors, (7) costs and benefits associated with actions and outcomes (Ostrom and Cox, 2010). In this study our action situation is the LAC in the SCSLF and our evaluative criteria are focused on sustainability, as elaborated further below.

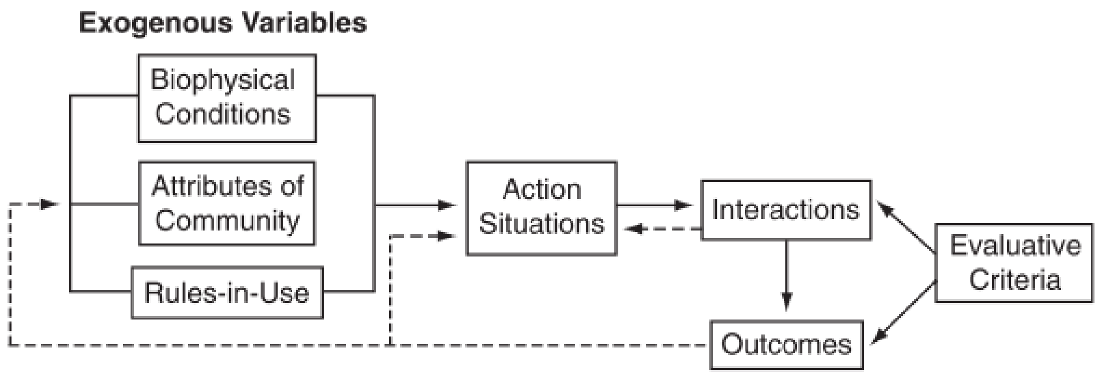

Figure 4. The Institutional Analysis & Development (IAD) framework, used to assess and evaluate the interactions between variables in an action situation. Adopted from (Ostrom and Cox, 2010).

3 Methods

3.1 Foundations for updating the SES framework for lobster fisheries

As means to update the diagnostic SES framework for lobster fisheries as a collective whole, a systematic literature review was conducted of an initial 140 publications, from the peer-reviewed literature database Scopus, containing research and/ or discussion on various aspects of SESs in lobster fisheries. The database search string[1] and article selection were guided by the question, "Does this article focus on aspects of social-ecological systems or social-institutional dynamics in a lobster fishery?" The original cohort of articles was refined to 19 focal publications through systematic review and exclusion in relation to the study focus. In addition to providing the foundation for updating the framework to be specifically utilized in lobster fisheries, this information

[1] The Scopus search string was: TITLE-ABS-KEY((lobster* AND fisher*) AND (management OR system* OR platform* OR framework* OR committee* OR governance OR board* OR stakeholder*) AND (social OR ecological) OR (SES))

also provided insights related to trends in the research foci, how it was conducted, and on specific information relating to lobster fishery case studies. This information included specific fishery social-institutional settings, threats, and current status, as well as additional collective characteristics. Though utilized for updating the framework, the comprehensive results of this literature review are not fully reported in this article, but can be accessed in the supplementary material, *Appendix B*. Also, to further support specific fisheries knowledge and methodological construction of updating the framework, expert and consultative interviews were conducted with five leading researchers and practitioners within the broader field[2].

3.2 Updating the SES classification framework for lobster fisheries

An updated version of the original diagnostic SES framework developed by Ostrom (2009) and adjusted by Basurto and colleagues (2013) was developed for the specific classification of lobster fisheries. Development of the framework started by adopting all of the available variables, first and second tier, from both the Ostrom (2009) and Basurto (2013) SES frameworks and assessing them for relevance to lobster fisheries as understood through the aforementioned literature review and interviews. The Social, Economic, and Political settings, as well as the Related Ecosystems, were not updated from the original framework and therefore not included in the adjusted framework presented below. Additional second, third, fourth, fifth and sixth tier variables were added to the framework and are shown in *Table 1.* Nearly all additionally added and existing variables were defined and referenced to a case study or theoretical discussion in relation to its relevance, shown in Appendix *A.1-A.4*. To increase clarity and avoid confusion, only updated framework components from this study were used to classify the SCSLF. Additionally, a separate interaction analysis using the SES embedded IAD framework was conducted for this study, negating the need for the original framework section. The related ecosystems remain the same, and while important as indicated by concerns in the literature review, they were beyond the scope of the study focus and not updated or used to classify the SCSLF.

Table 1. Updated social-ecological system classificatory framework for lobster fisheries.

Governance System	**Resource System**
GS1 Governance Policies	RS1 Sector
GS1.1 Marine Protection Area (MPA) policies	RS1.1 Lobster (Species)
GS1.2 National sanctions	RS2 Clarity of system boundaries
GS1.2.1 Endangered species policies	RS2.1 Recruitment Sourcing
GS1.3 Spatial Zoning	RS2.1.1 Within governance system boundaries
GS2 Organizations/Institutions	RS2.1.2 Outside of governance system boundaries

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Xavier Basurto, PhD. Assistant Professor of Sustainability Science. *Marine Science and Conservation at Duke University*. Durham, NC. USA
Michael Cox, PhD. Assistant Professor. *Environmental Studies, Dartmouth College*. Hanover, NH. USA
Ingrid van Putten, PhD. Researcher. *CSIRO*. Hobart, Tasmania.
Sarah Sikich, MSc. Science & Policy Director, *Heal the Bay*. Los Angeles, CA. USA

GS2.1 Government organizations
GS2.1.1 National Level
GS2.1.2 Regional level
GS2.1.3 Local Level
GS2.1.4 Support Enforcement
GS2.1.5 Support Funding
GS2.1.6 Restoration efforts
GS2.2 Nongovernment organizations
GS2.2.1 Environmental Organizations
GS2.2.2 Research Organizations
GS2.2.3Social/ Welfare Organizations
GS2.2.4 Restoration efforts
GS3 Decision making structures
GS3.1 Network structure
GS3.1.1 Vertical
GS3.1.2 Horizontal
GS3.1.3 Transparency
GS3.2 Management Strategy
GS3.2.1 Co-management
GS3.2.1.1 Consultive
GS3.2.1.2 Collaborative
GS3.2.1.3 Delegative
GS3.2.2 Adaptive management
GS3.2.3 Self-governance/ Community-based
GS3.2.4 Stakeholder Involvement
GS3.2.4.1 Committee/ Council
GS3.2.4.2 Open forum/ comment
GS3.2.4.4 Research Involvement
GS3.2.5 Multiple outcome recognition & planning
GS4 Rules & Regulations
GS4.1 Constitutional Rules
GS4.2 Collective Choice Rules
GS4.3 Operational Rules
GS4.4 Commercial Resource Regulations
GS4.4.1 Input controls
GS4.4.1.1 Season
GS4.4.1.2 Licenses/Permits
GS4.4.1.3 Equipment/Gear allowed
GS4.4.1.4 Harvestable Size Limits
GS4.4.1.5 No berried females
GS4.4.1.5.1 V-Notch
GS4.4.2 Output controls
GS4.4.2.1 Total Allowable Catch (TAC)
GS4.4.2.2 Individual Transferable Quotas (ITQ)
GS4.4.3 Access
GS4.4.3.1 Shared exclusive territory
GS4.4.3.2 Individual spot ownership
GS4.4.3.3 Open
GS4.4.4 Decision Rules
GS4.5 Recreational Resource Regulations
GS4.5.1 Input Control
GS4.5.1.1 Harvestable Size limits
GS4.5.1.2 Licenses
GS4.5.1.3 Trap soak time
GS4.5.1.4 Equipment/ Gear allowed
GS4.5.1.5 Season
GS4.5.2 Output Controls
GS4.5.2.1 Daily limit
GS4.5.2.2 Season limit
GS5 Monitoring
GS5.1 Social
GS5.2 Biophysical
GS6 Sanctions
GS6.1 Graduated Sanctions

RS2.2 Zoning Districts/ Marine Protected Areas
RS2.3 International Waters
RS3 Size of resource system
RS3.1 Carrying capacity
RS4 Human-constructions
RS4.1 Human access structures
RS4.2 Artificial Habitat
RS5 Productivity of system
RS5.1 Stock Status
RS5.2 Biophysical Properties
RS6 Equilibrium properties
RS7 Predictability of system dynamics
RS8 Storage characteristics
RS9 Location

Resource Units

RU1 Resource unit mobility
RU1.1 Recruitment
RU 1.2 Nocturnal movement
RU2 Growth or replacement rate
RU3 Interaction among resource units
RU3.1 Reproduction
RU4 Economic dynamics
RU4.1 Economic Value
RU4.1.1 Live
RU4.1.2 Frozen
RU4.2 Market Predictability
RU4.3 Market Diversity
RU4.4 Recreational Value
RU5 Cultural value
RU5.1 Indigenous/ Subsistence Value
RU5.2 Recreational value
RU6 Number of units (Harvestable Population)
RU6.1 Legal Harvest Rate
RU6.2 Illegal, Unreported, Unregulated (IUU) fishing
RU7 Distinctive Characteristics
RU7.1 Molting
RU7.2 Artificial female markings
RU7.3 Tail V-notch
RU8 Seasonal and Temporal distribution
RU8.1 Seasonal migration

Actors

A1 Number of actors
A1.1 Commercial
A1.2 Recreational
A1.3 Non-consumptive recreational
A1.4 Indigenous peoples, subsistence harvesting
A1.5 IUU actors
A2 Socioeconomic attributes of actors
A2.1 Socioeconomic resilience
A2.1.1 Insurance Availability
A2.2 Operating Costs
A2.2.1 Replacement/ Renewal Rates
A3 History of use
A3.1 Crisis
A3.2 Duration
A4 Location
A4.1 Ports/ Harbors/ Built Infrastructure
A4.2 Beaches/ Non-built/ natural access
A5 Leadership/entrepreneurship
A6 Norms/social capital
A6.1 Spatially based
A6.1.1 Clubs/ Organizations/ Chapters
A6.2 Non-spatially based
A6.2.1 Online format, publications
A7 Knowledge of SES/mental models

	A7.1 Traditional Ecological Knowledge (TEK) A7.2 Western Science & Management Knowledge (SMK) A7.3 Local Ecological Knowledge (LEK) A7.4 Knowledge Sharing/ Social Learning A8 Importance of resource A8.1 Economic dependence A8.2 Cultural dependence A9 Technology used A9.1 Homogeneity A9.2 SCUBA for commercial gear recovery

3.3 Surveying the Lobster Advisory Committee in the SCSLF

The LAC stakeholder representatives of the SCSLF were surveyed to provide data towards our exemplary assessment of sustainability in the fishery through its social-institutional setting. The 20 question online survey was initially disseminated on February 4th, 2014 and sent to all 18 LAC members. Questions pertained to management dynamics, functionality and effectiveness of the social-institutional arrangement. All questions were answered in a Likert scale format along with an additional comment box for voluntary elaboration. This data was used for the case specific interaction analysis within the IAD framework, leading to the precursive sustainability assessment of the SCSLF. As the assessment of the SCSLF undertaken in this article was intended for the purpose of demonstrating a holistic methodological protocol, our results do not intended to provide a fully comprehensive and definitive assessment of the LAC, and the data analysis and outcomes should be viewed with this in mind.

3.4 Classifying the SCSLF as a SES

The updated lobster fishery SES classification framework was applied to the SCSLF to demonstrate its use empirically and to provide additional data for the sustainability interaction analysis assessment with the IAD framework. This was done by identifying and matching data from the SCSLF to the framework classification variables, shown in *Table 2*. This was accomplished through document analysis, survey responses and author's first-hand experience as an alternate LAC recreational non-consumptive member. Classification of a variable may be 'Yes or No', or 'Low, Medium, or High', or specific data relevant to the framework variable. The classification depth or specificity was not exceeded beyond these metrics in this application.

3.5 Assessing sustainability through variable interaction analysis in the SCSLF

The LAC, a part of the 'delegative co-management' component of the SCSLF SES, was classified as an 'action situation' in the IAD framework. The survey data of the LAC along with the results of the framework classification of SCSLF are interacting sets of data, of which the dynamics within the LAC as a social-institutional 'action situation' between multiple variables in the framework were assessed. The interactions of the seven action situation criteria (see section 2.0) in the LAC with internal and external variables for each were identified through analysis of the survey data, SCSLF framework classification, and document analysis. The LAC was analyzed at a singular point in time when this research was conducted, with the variables present at the time included. The changes to the fishery's management approach as a result of the LAC will not be implemented into the fishery until 2015, and were not included in this study.

4 Results

4.1 Social-ecological system characteristics of lobster fisheries: Review results

The fishery characteristics, as a result of the conducted literature review, provide a summarized guide to building an understanding of the various lobster fisheries and their potential collective characteristics across the world. While this information is not claimed to be inclusive of all relevant data or lobster fisheries, achieving an overview of the many similarities and differences within the lobster fishery sector added valuable insights for updating the diagnostic SES framework for lobster fisheries. Many fisheries have undertaken similar management approaches and achieved drastically different fishery outcomes, and some have developed stable or healthy fisheries through entirely different approaches. The differences in fishery characteristics among all of the fisheries express the need for contextualized assessments and management plans. These specifics, grouped by fishery, are in *Appendix B*.

4.2 Updating the SES framework for the broader classification of lobster fisheries

The updated diagnostic SES framework for general lobster fisheries includes 153 components, compared to the original Ostrom (2009) framework which contains 37 components in first and second tier variables. To capture the diversity of lobster fisheries generally, the updated framework has been elaborated beyond second tier variables to include third, fourth, fifth and sixth tier variables that are relevant to at least one lobster fishery system, identified through the analyzed case studies within the literature review. Definitions and/ or a lobster fishery case study containing and justifying each framework component are shown in *Appendix A.1-A.4*.

4.3 The specific classification of the SCSLF as a SES

The updated framework for lobster fisheries collectively was applied to classify the SCSLF as a social-ecological system specifically. Exemplary results are displayed below in *Table 2*[3], with the classification data or indicator within the SCSLF displayed when present in the right column. The classification shows that the SCSLF has a well-developed and defined governance system including complex decision making structures and defined rules and regulations. Focal governance of the system is given to

[3] Full classification results by can be accessed in *Appendix D*.

the stakeholder-comprised LAC. The resource system of the fishery is extensive and not entirely well understood. Influential factors in the resource system include a network of Marine Protected Areas and its existence in international waters. The different interactions actors exhibit in the fishery are well understood, but data on amounts and their impacts on the system are not available (except for the commercial sector). There is a diverse array of system knowledge that is shared between stakeholders in varying degrees and settings. The resource unit, the lobster species *Panulirus interruptus*, is fairly well understood and stable both ecologically and economically. Recruitment dynamics are not well understood. The classification of the SCSLF has additionally shown considerable data gaps regarding many interactive system components.

Table 2. Selected framework components and the classification data of the SCSLF, as well as those used within the subsequent IAD framework analysis. The full classification can be viewed in *Appendix D*.

Selected Framework Components	*Southern California Spiny Lobster Fishery*
Governance System	
GS3 Decision making structures	
GS3.1 Network structure	--
GS3.1.1 Vertical	Yes
GS3.1.2 Horizontal	Yes
GS3.1.3 Transparency	Medium
GS3.2 Management Strategy	--
GS3.2.1 Co-management	Yes
GS3.2.1.3 Delegative	Yes
GS 3.2.2 Adaptive management	Yes
GS3.2.3 Self-governance/ Community-based	--
GS3.2.4 Stakeholder Involvement	Yes
GS3.2.4.1 Committee/ Council	Yes
GS3.2.4.2 Open forum/ comment	Yes
GS3.2.4.3 Research Involvement	Yes
GS3.2.5 Mult. outcome recog. & planning	Unknown
GS4 Rules & Regulations	Yes
GS4.1 Constitutional Rules	Yes
GS4.2 Collective Choice Rules	Yes
GS4.3 Operational Rules	Yes
GS4.4 Commercial Resource Regulations	Yes
GS4.4.1 Input controls	Yes
GS4.4.1.1 Season	October-March
GS4.4.1.2 Licenses/Permits	Limited ~150, ~$50 - $100,000 USD per
GS4.4.1.3 Equipment/Gear allowed	Baited Traps only
GS4.4.1.4 Harvestable Size Limits	Minimum 8.255 carapace length.
GS4.4.1.5 No berried females	Unofficial
GS4.4.3 Access	--
GS4.4.3.1 Shared exclusive territory	No
GS4.4.3.2 Individual spot ownership	Unofficial
GS4.4.3.3 Open	Yes
GS4.4.4 Decision Rules	No
GS4.5 Recreational Resource Regulations	Yes
GS4.5.1 Input Controls	Yes
GS4.5.1.1 Harvestable Size limits	Minimum 8.26 cm carapace length.

GS4.5.1.2 Licenses	Yes, no limit. ~$35 USD/yr. ~30,000
GS4.5.1.3 Trap soak time	Yes, 24 hours
GS4.5.1.4 Equipment/ Gear allowed	Hoop traps, out of water. Hands only, in water. SCUBA allowed.
GS4.5.1.5 Season	October-March
GS4.5.2 Output Controls	Yes
GS4.5.2.1 Daily limit	Yes, 7 per person per day.
Actors	
A1 Number of actors	--
A1.1 Commercial	~150
A1.2 Recreational	+30,000
A1.3 Non-consumptive recreational	Likely high but unknown.
A1.4 Indigenous peoples, subsistence harvesting	None
A1.5 IUU actors	Unknown
A2 Socioeconomic attributes of actors	--
A2.1 Socioeconomic resilience	Unknown
A2.1.1 Insurance Availability	Yes
A2.2 Operating Costs	Commercial costs, high. Recreational, low.
A2.2.1 Replacement/Renewal Rates	Yearly recreational license renewals. Case-based commercial license transfers.
A7 Knowledge of SES/mental models	--
A7.1 Traditional Ecological Knowledge (TEK)	Low
A7.2 Western Science and Mgmt. Knowledge (SMK)	Medium, social and ecological.
A7.3 Local Ecological Knowledge (LEK)	High
A7.4 *Knowledge Sharing/ Social Learning*	Medium
A8 Importance of resource	High
A8.1 Economic dependence	High
A8.2 Cultural dependence	Unknown
Resource System	
RS2 Clarity of system boundaries	Not well understood.
RS2.1 Recruitment Sourcing	Not well understood.
RS2.1.1 Within gov. system boundaries	Yes
RS2.1.2 Outside of gov. system boundaries	Yes
RS2.2 Zoning Districts/ Marine Protected Areas	Yes, extensive MPA network within RS.
RS2.3 International Waters	Yes, USA and Mexico.
Resource Units	
RU4 Economic dynamics	Yes
RU4.1 Economic Value	High.
RU4.1.1 Live	~ $14.90 - $39.70 USD per kilogram
RU4.1.2 Frozen	--
RU4.2 Market Predictability	No data.
RU4.3 Market Diversity	Mostly export to Asian markets.
RU4.4 Recreational Value	Yes, but no data.

4.4 Interactions in the SCSLF SES: Evaluating the LAC through the IAD framework criteria

Evaluating the LAC as an action situation with the IAD framework requires defining the scope and depth of the variables to be included. The LAC demonstrates an action situation where the fishery's policy choices are made, which also incorporates many identified variables in the SES classification framework that interact with each other, including but not limited to: the number of actors (*A1)*, delegative co-management (*GS3.2.1.3)*, stakeholder involvement (*GS3.2.4)*, knowledge of SES/mental modes (*A7)*, network structure (*GS3.1)*, rules and regulations (*GS4)*, socioeconomic attributes (*A2)*, and importance of resource (*A8)*. This data was grouped into the seven action situation criteria categories in *Table 3*, with the data categorized as either an internal (within the LAC) or external (within the SES) variable in each criterion. In the case of the LAC, the internal interactions of the committee are primarily explored, although certain external variables also have a significant influence.

Table 3. Defining the LAC as an action situation through the seven IAD framework criteria**.**

IAD "action situation" criteria	**External variables**	**Internal variables**
1) Sets of actors	~150 commercial actors A1.1 +30,000 recreational actors A1.2 Unknown non-consumptive actors A1.3 No indigenous population A1.4 Unknown (IUU) fishing A1.5	18 LAC stakeholders (1 alt. per group): 3 commercial 3 recreational 2 marine science 2 non-consumptive 1 governmental 1 environmental
2) Sets of positions actors fill in context of situation	----	LAC stakeholders assume the role of communicating in the best interest of their stakeholders and the sustainability of the fishery (LAC Charter, 2012).
3) Set of allowable actions for actors in each position	Refer to: Rules and regulations GS4. Extensively defined and monitored for the commercial sector. The recreational and non-consumptive sectors are well defined but not well monitored. Recreational value RU4.4 and cultural dependence A8.2, are not well understood or have no data.	The LAC members' role is to provide advice, feedback, and recommendations regarding the issues and actions to develop the fishery management plan (FMP). Additionally to address and put forth key issues from the interested parties (stakeholders).
4) Level of control that individual or group has over an action	In relation to rules and regulations GS4, transparency of the network structure GS3.1 and collective choice rules GS4.2 are present within the fishery.	Stakeholder involvement GS3.2.4 and the delegative co-management structure are present in the SES and control group actions inclusively.
5) Outcomes associated with combinations of actions	Adaptive management GS3.2.2 and monitoring GS5 are present. Multiple outcome recognition and planning GS3.2.5 is unknown currently.	Primarily explored through the survey questions.
6) Amount of information available to actors	Norms and social capital A6. Organized commercial chapters are at various harbor locations to discuss fishery issues. Online blogs and publications are open access.	Primarily explored through the survey questions.
7) Costs and benefits associated with actions and outcomes	Primarily explored through the survey questions.	Primarily explored through the survey questions.

The survey responses were diversified, as there was at least one response from each stakeholder group. We received responses from 8 of the 18 possible LAC stakeholder representatives, which we consider sufficient for the context and scope of this analysis. Those stakeholder representatives who responded include: 1 commercial, 2 recreational, 1 non-consumptive, 2 environmental, 1 governmental and 1 marine science representative. The degree of positive (when stakeholders tend to agree with the statement) and negative (when stakeholders tend to disagree with the statement) agreement among responses between stakeholder groups to the survey questions are presented below in *Figure 5.* Question responses indicating a high level of agreement, either positive or negative, indicate more uniform responses between the stakeholder groups to the given question and thus may signal internal consensus regarding the issue. Statements located towards the middle of the figure, with scattered responses across the Likert scale, indicate diverse responses across the stakeholder groups in the given statement and thus signify potential points of contention within the LAC that are in need of further scrutiny. The original long-forms of the stakeholder survey questions can be found in *Appendix C.*

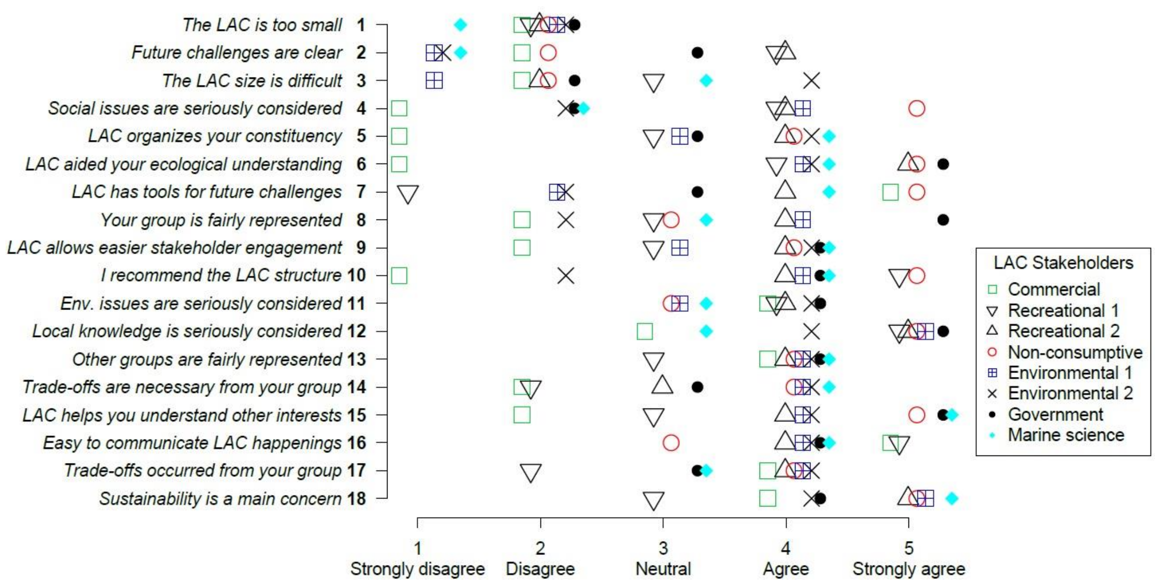

Figure 5. The 18 survey question responses from stakeholders on the LAC in a Likert scale. The questions (short-form version) are ordered in terms of their clustered responses on the Likert scale from left to right. Answers clustered to the left (top) indicate negative agreement and answers clustered to the right (bottom) indicate positive agreement. Answers scattered across (middle) the Likert scale, indicate less uniform consensus among the answers. The individual stakeholders that represent each response are indicated with the varying symbols.

As a supplement to the Likert scale survey responses, additional text commentary was submitted as an option when the stakeholders felt the need to expand on their Likert response or provide general feedback in relation to the survey statement. The surveyed stakeholders submitted more than 3,000 words of additional text commentary. Beyond relevance to the individual questions, this information was qualitatively assessed in relation to two general attitudes of the stakeholders, ‘attitudes in reflection of the LAC process’ and ‘attitudes in reflection of engaging with the other stakeholders’ in *Table 4*. Although there were many negative comments regarding the processes, the majority of comments reflected a neutral or positive attitude towards both perspectives. There was variance in the attitudes of the additional commentary, but most of the comments were constructively mannered. Direct examples of selected and categorized stakeholder commentary are shown in *Table 4*, with the full set of the additional commentary available (see Partelow (2014)).

Table 4. Open-ended commentary as part of the survey responses from stakeholders. The commentary was classified as either positive, negative or neutral in regards to the LAC process or to other stakeholders more broadly.

Topic	Stakeholder attitude	Selected direct comments from stakeholders
Regarding the LAC process	Positive	“Especially pleased with the flexible and adaptive nature of the LFMP framework. There is no reason it would not work in the future.” *“The proactive nature of the process is refreshing.”* *“I think the size was great, enough folks to represent viewpoints across sectors”.* “At this time, we the changes we have agreed upon, the chances of a failure of any kind in the fishery is highly unlikely.”
	Negative	*“The make up of the current LAC will not be able to accomplish anything moving forward. Its widely understood that [other interests] wield a large stick in this forum, and have funding to further their views.”* *“The LAC seemed more structured to deal with immediate challenges.”* *“Fisheries management plans should never consider one reference to sustainability as a main concern. All references to time plans should be considered with equal significance.”* *“I am not certain if the discussions and recommendations will amount to change in regulations to ensure sustainability.”* *“There would be some serious disagreements on how to move forward if there was a serious need to alter the fishery.”*
Regarding other stakeholders	Positive	*“There were some difficulties but overall the group worked well together.”* *“Ultimately, every LAC appointee came to the table with the common desire for a healthy fishery.”* *“Facilitated meetings over 18 months allowed me to see the complexity of each stakeholder group. Even years of reading about it could not do that.”* *“Selection of representatives was 90% successful in gathering people invested in collaboration to meet mutual goals.”* *“We worked very well together. I was able to find common ground with each and every person on the LAC.”*
	Negative	“We are more divided now than at the start of this thing.” “With professional facilitation I believe more can be accomplished.”

5 Discussion

5.1 The results and functionality of the IAD action situation assessment of the LAC

Using the IAD framework, which is an embedded and integral aspect of the diagnostic SES framework (McGinnis and Ostrom, 2014), frames the LAC as an action situation. Because an action situation is a sub-system of variables in a given SES (such as the LAC in the SCSLF), the LAC cannot be analyzed entirely as a separate entity from the larger SES. Internal (within the LAC) and external (within the SES) variables will affect both the LAC and the SES outcomes. From a methodological perspective the LAC must be classified with both internal and external variables, and the IAD framework assumes an embedded role in the SES framework's analytical process for assessing these interactions and outcomes.

The LAC is defined into the seven action situation criteria above in *Table 3* and we can unpack the IAD framework's functionality through clarifying the role of internal and external variables in each criterion. The *sets of actors (1)* are internally defined as the LAC members and externally defined as the larger stakeholder groups they represent. There is a direct link in this criterion between the internal action situation LAC members and the external SES actor groups. Identifying the dynamics of the interactions (e.g. spatial/ temporal, communication, self-organization, leadership, etc.) between the internal LAC members and large external stakeholder groups is vital for a valid outcome assessment with the framework. The additional criterion, including the *sets of positions (2)*, *allowable actions (3)*, *level of control (4)* and *amount of information available to actors (6)*, define the situational context for how interactions will proceed and lead to certain outcomes in the LAC and in the SCSLF SES. As the LAC's role is to provide a sustainable fishery management plan, which in return affects the outcomes in the SCSLF SES, the different possible combinations of interactions must be defined. The remaining IAD criterion, the *outcomes associated with combinations of actors* (5) and the *costs and benefits associated with possible actions (7)*, frame these possibilities for the outcomes analysis.

Defining the desired outcomes of an action situation and in an SES more broadly are vital for categorizing which interactions lead to successful or desirable outcomes. This holds for any SES action situation. As the possible amount of interactions and outcomes are often exhaustive in large scale SESs, defining outcomes can guide how to approach an interaction assessment. For example, in this study we defined evaluative sustainability criteria to assess outcomes and designed a survey for LAC members to assess their agreement on the possibility of achieving those outcomes. The survey results displayed in *Figure 5* show the level of positive or negative agreement regarding the ability to achieve defined sustainability criteria and general LAC functionality. Undertaking and analyzing such a survey can provide indispensable insights into potential points of contestation or collaboration within a resource management system, and the results can guide further inquiries regarding the need for and possibility of achieving sustainable outcomes in any SES.

5.2 Evaluating sustainability in the SCSLF: The IAD framework analysis

There are many possible evaluative criteria to analyze sustainable outcomes, but there are no well supported, generalized or defined evaluative criteria that identify or assess causal characteristics that associate with sustainable outcomes in complex social-ecological systems (Agrawal, 2003; Ostrom and Cox, 2010). In aims to support these causal characteristics, we grouped certain system components and survey responses that define the seven IAD action situation criteria in the LAC into outcome characteristics associated with sustainability. We take into consideration various evaluative criteria associated with sustainability as proposed by Gibson (2006; Gibson et al., 2005), McGinnis (2011) and Ostrom (2011b).

Those variables present in the SCSLF associated with the sustainability criteria are presented as possible key factors for achieving sustainable outcomes for the future of the fishery[4]. This study has identified five components that may positively identify with achieving sustainability and sustainable outcome characteristics in the SCSLF, including: (i) delegative co-management with the LAC, (ii) stakeholder involvement, (iii) the accumulated and shared knowledge within the SES, (iv) an interlinked and semi-transparent governance structure, and (v) extensive control rules that are regulated with high compliance. While there are no direct causal characteristics associated with sustainability in SESs, these linkages attempt to further associate certain system characteristics with defined sustainability criteria. These identified components do not necessarily determine sustainable outcomes within the fishery, but rather provide a guide for reevaluation of the current management structure within the SCSLF and for management practitioners in other fisheries. Similar approaches could and should be adopted in the assessment of the sustainability of other natural resource SESs as they help towards developing an understanding of context-specific sustainability criteria and whether specific system components related to management of a given SES are conducive to fulfilling these criteria.

5.3 The LAC's structure as a unique approach to fisheries co-management

As co-management occurs when stakeholders and managers work together to improve the regulatory process (Gutiérrez et al., 2011), the evaluated effectiveness of this process in the LAC alludes to its ability to raise the many collective concerns of stakeholders regarding the fishery and to provide the means for productive discussion through facilitated dialogue. Continuous evaluation and adaptation of a stakeholder

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[4] A more elaborate presentation and discussion of the sustainability assessment is available (see Partelow (2014).

involved management plan is considered necessary to adjust to system feedbacks and continually updated social-ecological knowledge (Folke et al., 2005). Although the survey in this study indicated considerable critical and often negative feedback regarding the approach the LAC uses to manage the fishery (see *Table 4*), the ability of the LAC to bring these discussions to a public forum with facilitated dialogue can potentially benefit the fishery as it allows for identification and resolution of emergent management challenges, for example those indicated by the statements with a high level of disagreement in *Figure 5*.

It is unlikely any fishery management committee will be successful without addressing challenges and trade-offs, but such challenges provide the opportunity to contextually adapt and work with relevant stakeholders to continuously improve the social-ecological sustainability of the fishery. The potential of the LAC's structure to facilitate the necessary links which make it feasible to avoid traditional top-down management panaceas is significant, and further provides the foundation for a transparent collaboration which can lead to a contextually adapted, responsive and desirable management scenario. The research approach demonstrated in this article, specifically the analysis of the LAC action situation, can facilitate the identification of points of agreement and disagreement within a resource management committee like the LAC, and thus help target efforts to reduce points of conflict between stakeholders while exploiting synergistic relationships conducive to sustainable management.

5.4 Improving management in the SCSLF and LAC

To improve management within the SCSLF and the LAC process, a few key considerations can be made as a result of our analysis. It is not directly apparent to stakeholders if the LAC is intended to manage the fishery into the future or how the management of the fishery will respond to future challenges. It is critical that management plans are adaptive and quick to respond to challenges affecting the fishery's sustainability, which is affecting the livelihoods of commercial fisherman, a deeply embedded cultural identity within coastal communities, and ecological functionality of the marine ecosystem in Southern California. Defined and transparent mechanisms for how to proceed with future management in the SCSLF are shown to be needed.

Furthermore, it is generally acknowledged that the LAC process was well accepted among stakeholders, but that a more equitable focus in the LAC on the different priorities between the stakeholders can to be improved. This includes the role of how different knowledge types were brought into the process as a mechanism for supporting sound decision-making. Scientific perspectives were included as a stakeholder but also as a consulting service to the LAC process. The role science played in the LAC process as either a stakeholder or foundational decision support tool was unclear in relation to local in-the-field knowledge, and appeared to affect how stakeholder decisions were made around ecological fishery sustainability and appropriate management rules.

Additionally, there was a large amount of local in-the-field knowledge present among stakeholders. The way this type of knowledge was presented and affected decision-making in relation to scientific knowledge should be considered further.

The SCSLF thus far seems to have avoided a tragedy of the commons situation that is characteristic of common-pool resource systems (Basurto and Ostrom, 2009), but this outcome is not static. As common-pool resource systems are characterized by high subtractability (each resource unit removed reduces the amount available to the next user), and high excludability (ability to control who is accessing the resources) (Ostrom, 2005), there are still challenges to be faced in the SCSLF for effectively regulating these attributes. In the commercial fishing sector of the SCSLF, both challenges are addressed through limiting access with formal licenses and informal harbor associations as well as setting trap usage limits to control resource extraction. The primary unknown common-pool challenges in the fishery are recreational fisherman. Although there are formal license controls and mandatory catch reporting, there is minimal data on the total amount of fisherman/users and how many lobster/resources they are actually extracting from the system. The impacts of recreational users present challenges for adequately addressing high subtractability and excludability common-pool resource challenges in the SCSLF, which need to be addressed in the fishery's management to more adequately encompass these known attributes of the fishery.

5.5 Research trends and SES characteristics across multiple reviewed lobster fisheries

5.5.1 Collective lobster fishery characteristics

The lobster fishery characteristics derived from the literature review show the need for contextual, place-based management solutions that involve management practitioners in their design and implementation. The review revealed both successfully managed and poorly degraded lobster fisheries due to various causes, with no trends indicating success factors for sustainable fisheries. This further supports the need to avoid generic science-based prescriptions, and to rather explore contextual interactions at the case specific SES level. To highlight a few examples, although the Marine Stewardship Council (MSC) certification played a role in two of the reviewed fisheries (see (Ernst et al., 2013; Pérez-Ramírez et al., 2012)) through securing federal funding and management support as well as increasing economic market stability for the fisheries, the contextual settings that enabled this to occur within these cases is not replicable in all other fisheries due the historical backgrounds, national-to-local governing arrangements, and country specific economic drivers. In addition, similar control rules (e.g. season, size limits) in fisheries with similar ecological characteristics but differing social-institutional settings or actor community attributes has created different outcomes, supporting the need to avoid generic management approaches. As differing rule configurations and management approaches have demonstrated contrasting outcomes between fisheries, contextualized management approaches that involve stakeholders, rather than transferring a successful management approach from one fishery to another, is necessary. The generalization of management approach explanations may reflect a lack of in-depth contextual understanding of how and why the social-institutional settings have formed the given outcomes or function accordingly. The approach adopted in this article offers a step-wise example of how such context-specific analyses can be undertaken and should be viewed as applicable to virtually all natural resource SESs.

5.5.2 Research trends and co-management across multiple lobster fisheries

It is evident that the SES research field focusing on lobster fisheries is over-looking and overly-generalizing co-management approaches, although such approaches have become central to normative natural resource policy models (Jennifer F Brewer, 2012; Gelcich et al., 2007). In regards to generically recognized co-management approaches, this study further recognizes differing types of co-management based on fishery participation research from McConney and Baldeo (2007). The concept of co-management can vary greatly in meaning as there are over 130 co-managed fisheries worldwide in countries with varying developmental states, ecosystems, and fishing sectors (Gutiérrez et al., 2011). Despite such diversity, there remains minimal focus on understanding the relevant social-institutional structures and arrangements behind co-management approaches. Understanding these arrangements can contribute significantly to how and what degree stakeholders are included in the process (Crona and Hubacek, 2010; Lange et al., 2013). This also indicates that concerns over generalized panacea type approaches still exist and that integrating stakeholders into management remains a challenge in many fisheries. Strengthening the need to address this issue, Gutierrez and colleagues (2011) have recognized that community based co-management arrangements with certain characteristic such as strong leadership, social cohesion and self-enforcement often demonstrate sustainable outcomes in fisheries. Contextually defined, designed and researched management approaches need to be considered in collaboration with the necessary practitioners and stakeholders in complex SESs in order to avoid social-ecological traps and aim towards achieving sustainable outcomes (Cinner, 2011; Kittinger et al., 2013; Steneck et al., 2011). Again, the step-wise movement from updating the diagnostic framework based on general SES characteristics to its application in a specific SES resource management context demonstrated in this article can help facilitate the identification of those criteria which may support sustainable management of natural resources, including those related to successful co-management.

5.6 Utilizing the social-ecological system diagnostic framework in research

The diagnostic SES framework can be used in different ways for different purposes related to assessing and understanding management pathways in a fishery or other resource system. Time sequences, as demonstrated by Basurto (2013), can provide valuable insights towards understanding specific system changes between two definitive points in time or in intervals. Also, adopting selective event classification to analyze a system in response to a disturbance, such as a tsunami event as demonstrated by Ernst (2013), can illustrate impacts as well as the resilience of a system (Schoon and Cox, 2012). Using the framework to analyze the presence of sustainability criteria for a fishery, as done by Hearn (2008), will help to correlate sustainable outcomes to certain variables or interactions in a system. Although there is an absence of specific rules that typify any specific system as long-lasting or sustainable (Agrawal, 2003, 2001; Ostrom and Cox, 2010), research efforts that aim to collectively aggregate empirical data through uniformed frameworks, metrics and definitions may aid towards a better understanding of certain system characteristics and interactions that associate with sustainable outcomes between systems, which can then better inform policy and practice (Agrawal, 2003; Liu et al., 2007; Ostrom, 2007).

While the recognition and use of the Ostrom (2009, 2007) diagnostic SES framework has been widely accepted and incorporated into fisheries research (Basurto and Nenadovic, 2012; Basurto et al., 2013; Cinner et al., 2013), empirical application of the framework and the use of common metrics and definitions within research on comparable systems is largely absent. In social-ecological system research on lobster fisheries, only two studies from an initial 140 used the framework empirically as shown through the literature review in this study. Within fisheries as a larger sector, Basurto (2013) provides definitions and an updated framework for classifying benthic small-scale fisheries as SES's. Many of their definitions and framework components were relevant to lobster fisheries and provided very useful base-component metrics in which specific sub-systems and sub-variables could be developed for lobster fisheries generally, and the SCSLF specifically. Many systems may overlap with numerous applicable and relevant SES framework components, and research that aims to collectively aggregate these components between systems may help to achieve coherency and comparable data between similar systems within SES research (Agrawal, 2003; Basurto and Nenadovic, 2012; Cinner et al., 2013; Hunt et al., 2013; Ostrom and Cox, 2010).

It bears mentioning that the SES diagnostic framework is often misunderstood in how it is used and applied to a case study for analysis (Basurto et al., 2013), and is typically applied to specific sectors such as commercial fisheries. All of the variables in the updated general lobster fisheries framework are most likely not applicable to all other lobster fisheries, which is not necessarily a limiting factor for exploring additional variable components in the SES. It can be difficult, due to constraints on e.g. time, finances, etc., to delve deep into all relevant variables that can be identified within an SES when using an extensive diagnostic framework ontology. Specific interaction analyses like the LAC action situation analyzed in this article may provide more relevant and tangible research foci, leading to more salient, contextually developed conclusions towards case specific management implications. Furthermore, use of the SES framework on lobster fisheries has almost exclusively been limited to commercial-actor dominated systems. The implications of non-commercial actors in fisheries generally are poorly understood and far less frequently researched (Hunt et al., 2013). Applications of the framework to recreational-actors or indigenous peoples dominant fisheries may be limited within the normalized use of the framework due to the existence of differing system dynamics regarding governance and actors in these non-commercial contexts. For example, recreational catches may generally be lower in percentage of total catch than commercial catches in most fisheries, but may contain significantly more users that can attribute an unknown amount of cultural identity and value, economic impact, local ecological knowledge, and management challenges to the fishery (Hunt et al., 2013; Schuhbauer and Koch, 2013; Sharp, 2005).

5.7 Reflection on using a diagnostic SES approach in the SCSLF

We acknowledge that there are many methodological approaches to analyzing SESs (see Binder et al. (2013)) and fisheries management, and believe it is beneficial to reflect and highlight the insights a diagnostic approach has provided in our exemplary case. Our diagnostic case study application has revealed the diversity of interacting social-institutional components in the SCSLF, but more importantly has provided insights to previously lesser-known interacting components that were given less focal importance as key drivers of change or value in the SES. In the SCSLF these included recreational user dynamics and impacts, unknown aspects of the ecological system functionality, and the importance of different commercial input control rules. A diagnostic classification has allowed for a systematic sifting through of these components and allocation of time for the analysis assessment of available data for each component. The flexible nature the diagnostic approach promoted a reflexive identification of interacting system components, in line with its vision to aid in generating theory within and across cases. Within the SCSLF, we have demonstrated an analysis of the contribution of different stakeholder perspectives regarding the potential for pursuing more sustainable outcomes for the fishery. It has been shown that in the fishery the institutional capacity for addressing these challenges is present, but that an adaptive capacity for addressing system change into the future is still ambiguous among the managers and stakeholders. Additionally, it has now been recognized that lesser-known but integral components of the SCSLF need to be further assessed.

5.8 Operationalization and coherency of the SES diagnostic framework for improved management

Operationalizing the diagnostic SES framework in lobster fisheries seeks to shift the applicability of the framework beyond research and into use for the practical management of the fishery. However, there are many challenges and difficulties for practitioners in understanding and trying to implement social-ecological system-based thinking (Aaron MacNeil and Cinner, 2013; Kittinger et al., 2013; Ostrom and Cox, 2010).

Through this study, initial classification of the SCSLF revealed significant data gaps such as recruitment sourcing, market stability, and impacts from consumptive and non-consumptive recreational users. Initial roadblocks for practitioners would be to address these data gaps, and the framework provides the means to help identify them (Cinner et al., 2013). While identifying data gaps is important, an understanding of the interactions between certain management techniques and tools may be necessary for attaining desired outcomes in the fishery. These interactions require an in-depth empirical understanding of interacting components (Aaron MacNeil and Cinner, 2013; Aswani et al., 2013), of which case studies at the regional may provide the most appropriate research design.

This study has provided an example of how to approach research on interacting SES components by examining the LAC through the use of the IAD framework. Research providing well-supported correlations between management approaches and outcomes may provide more tangible references for practitioners to base fishery management decisions on (Aswani et al., 2013; Cinner et al., 2013; Degnbol and Mccay, 2007). Further insights from the literature review and interviews suggest the need for the development of a ‘practitioners guide’ for understanding and using the framework for practical applications in management. Insights for developing the foundations of such a guide may be aided through a more integrated SES understanding and increased consideration of research methodologies designed for operationalizing research outcomes into practical management. This includes for example trans-disciplinary research approaches and methods designed to incorporate practitioners into research processes and implementation. Attempts have been made by Partelow (2015), in line with the research in this article, to conceptually operationalize SES framework research into practical fisheries management with the inclusion of stakeholders. In *Figure 6* below, a conceptual heuristic approach for developing operational research is shown which also serves to visualize the general approach adopted throughout this article.

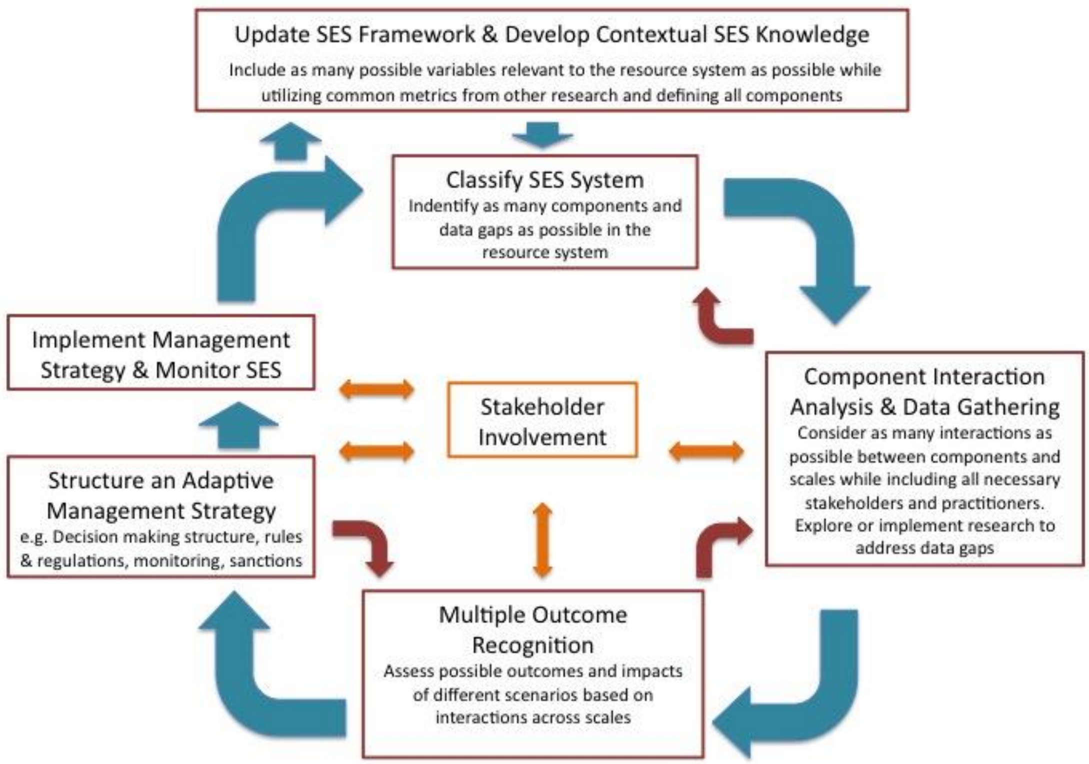

Figure 6. A heuristic conceptual approach for operationalizing the SES framework for practical fisheries management, adopted from Partelow (2015). Key components of the framework include stakeholder involvement, multiple outcome recognition, SES classification and interaction analyses. The larger blue arrows represent the conceptual methodological flow and the smaller red arrows represent system feedbacks.

6 Conclusion

A diagnostic social-ecological system framework for the classification of lobster fisheries has been developed and thoroughly defined through a systematic literature review on social-ecological system research in lobster fisheries and interviews with academic experts and practitioners. By defining additional framework variables through the results from the literature review, and incorporating components and definitions from other relevant SES research frameworks, incremental steps were made towards identifying and utilizing common metrics for inter-fishery or related SES research and data comparisons. The literature review indicated that there are many differing research approaches, focal areas, social-institutional settings, and management techniques used concerning lobster fisheries, and this is likely the case for all natural resource management systems. There is also a strong emphasis on addressing sustainability and taking governance perspectives in the research. To demonstrate the application of an updated diagnostic SES framework to a real-world management case, the updated lobster fishery framework developed through the literature review and interviews was applied to the SCSLF to exemplify how classifying the fishery system components aids in identifying data gaps, illustrates the complexity of interactions, and demonstrates the necessity for understanding such interactions to more effectively implement management practices that are conducive to sustainable outcomes.

The contributions and insights from this study have cumulated towards operationalizing research into practical management in lobster fisheries and related marine and coastal natural resource systems. These contributions include a summarized review of lobster fishery characteristics and lobster fishery SES research, an updated and defined diagnostic framework for classifying a lobster fishery as a SES, an instructive contextual interaction and outcome analysis of the SCSLF LAC for improved management, and over-all a demonstrated holistic methodological approach for research in social-ecological systems. In addition, key recommendations for further research were presented for research focused on social-ecological systems in lobster fisheries and related natural resource systems. It is hoped that the outcomes of this study support the perspective that the abolition of negligent marine resource exploitation can be achieved with thoughtful science and conservation based natural resource management that acknowledges and takes into consideration the complexity and place-based diversity of the communities and ecosystems that we all depend on.

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