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Harnessing expert-based information for learning and the sustainable management of complex socio-ecological systems

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ABSTRACT

Human-used and managed natural resources, such as watersheds, represent complex socio-ecological systems where learning from different knowledge sources is essential for sustainable management. Guided by the advocacy coalition framework, the paper presents a set of propositions that help explain the different functional uses of expert-based information, the network position of scientific experts, and learning within and between coalitions. Most importantly, the paper investigates common assumptions about the superiority of consensus-based institutions for integrating science into policy-making by examining two collaborative and two adversarial policy subsystems. The findings show that the scientists' centrality as coalition allies and opponents is lower in collaborative policy subsystems than in adversarial policy subsystems. The findings suggest a more hospitable setting for learning and sustainability in the management of natural resources in collaborative compared to adversarial subsystems. The paper concludes with suggestions for future research in sustainability and learning.

Trying to understand why some human-used natural resource systems are managed successfully while others are not is a core endeavor of many of the leading scholars in our field and in our time (Norton, 2005; Ostrom, 2009). These human-used natural resources, such as watersheds, typify complex socio-ecological systems (SESs) involving relationships and outcomes among an uncountable number of factors across temporal and spatial scales (Ostrom, 2009, p. 419). A challenge in managing SESs, or any complex system, is to learn from past experience and then to adapt accordingly (Simon, 1996). As such, one important ingredient in the sustainable management of complex SESs involves the integration of both expert and non-expert knowledge in learning at both the individual and group level (Clark, 2007; Dumreicher, 2008; Gleick, 2003; Rogers, 2006; Newig et al., 2008).

While learning and sustainable management are laudatory goals, both face nontrivial challenges. Both are hampered by humans' limited cognitive abilities and tendency to filter and distort stimuli (Simon, 1996). Both face coalition politics where allies compete against opponents over the future direction of policy (Sabatier and Jenkins-Smith, 1993). Both involve scientific and technical information when uncertainty and risks cloud the seriousness and causes of problems as well as the effects of plausible policy alternatives (Mazur, 1981). Subsequently, the process of working towards sustainable management of complex SESs involves designing institutional contexts where humans are most likely to overcome their cognitive limitations, deal fairly with opponents, and use scientific and technical information to harness learning and make decisions adaptively (Blackmore, 2007; Cortner, 2000).

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We investigate the role of experts and expert-based information from both theoretical and empirical perspectives. Theoretically, one of the most important premises of contemporary theories of the policy process is that most of the action involving policy formulation, implementation, evaluation, and learning occurs over periods of a decade or more among policy participants operating in policy subsystems, such as Colorado water policy, or in multiple, overlapping subsystems, as might be found in U.S. climate change policy (Redford, 1969; Baumgartner and Jones, 1993; Jones and Jenkins-Smith, 2009). Whereas SESs encapsulates resource systems, resource units, users, and governance systems, policy subsystems provide a narrower unit of analysis that focuses primarily on the political behavior within a governing system. More concretely, we structure our arguments by use of the advocacy coalition framework (ACF). In this manner, we are attempting to unpack the governing system aspect embedded within the frameworks employed by other scholars, such as Ostrom, and utilize the theories related to political behavior from the ACF to better understand this piece of the larger map used to study SESs.

Originally designed by Sabatier and Jenkins-Smith (1993, 1999), the ACF builds from a cognitively limited model of the individual to derive a theory of learning and coalition politics within policy subsystems. We present three different types of policy subsystems (unitary, collaborative, and adversarial) and the role of scientific experts and expert-based information in each. The role of scientific experts and expert-based information across different types of natural resource systems is important to explore because sustainability necessitates sharing resources and managing conflicts as well as managing scientific uncertainty (Blackmore, 2007; Cortner, 2000). Among our propositions, we argue that, as long as policy subsystems deal with scientifically and technically complex issues, sustainable SES management will not be attainable if scientists are principal allies to one coalition and opponents to another. The rationale is that, when scientists represent politically charged actors, their information will likely be exaggerated by their allies to bolster support for preferred policy decisions, or ignored by their opponents based on ideology and previously existing beliefs. While political allies and opponents persist regardless of the policy subsystem type, we hypothesize that scientists are less likely to be viewed as principal allies or opponents in collaborative compared to adversarial policy subsystems. Empirically, we examine the extent that scientists are viewed as important allies and opponents in two adversarial and two collaborative policy subsystems. The objective is to test conventional wisdom that collaborative institutions are more conducive to integrating science into policy (Heikkila and Gerlak, 2005; Lee, 1993; NRC, 1996). The adversarial policy subsystems are California marine protected area policy in 2002 and San Francisco Bay-Delta water policy in 1992. The collaborative policy subsystems are California and Washington watershed partnerships in 1999–2002 and San Francisco Bay-Delta water policy in 1997.

This paper consists of two parts. The first part is theoretical, where we summarize the ACF and present propositions about the functional uses of scientific experts and the role of expert-based information in policy subsystems. The second part is empirical, where we apply one proposition about the extent that scientists are important allies or opponents in adversarial versus collaborative policy subsystems.

1. Part 1: Presenting an ACF theory of experts and expert-based information in policy subsystems

1.1. *Premises of the advocacy coalition framework*

The ACF builds its theories and hypotheses from five premises (Sabatier and Jenkins-Smith, 1999, pp. 118–120). Three of the ACF's premises parallel the foundations underlying sustainable management of complex SESs. First, scientific and technical information plays a central role in learning, politics, and policy change. The idea is that most policy subsystems involve complex interactions of an uncountable number of factors that defy understanding from common sense, intuition, or unsystematically recorded observations. As a result, policy participants rely on scientific and technical information throughout the policy process, from shaping problem definitions to advocating a policy proposal. Second, understanding the processes of policy change and outcomes requires long-term time perspectives. The ACF posits that outcomes from policy decisions cannot be understood in short-term time perspectives but necessitates a perspective of a decade or more. Third, as discussed, the ACF recognizes that policies do not occur within a single government agency or a single organization but within policy subsystems. Policy subsystems are semi-autonomous decision-making networks of policy participants that focus on a particular policy issue usually within a territorial boundary. Policy subsystems are complex systems and can be thought of as nested and interdependent with other policy subsystems (Fenger and Klok, 2001; Jones and Jenkins-Smith, 2009) as well as a subset specifically focused on the political behavior and outcomes from the governance system of a broader framework used to analyze the sustainability of SESs (Ostrom, 2009).

The fourth and fifth assumptions of the ACF hint at the challenges facing sustainable management of SESs. For the fourth, the ACF assumes that the relevant set of subsystem actors include all people attempting to influence subsystem affairs, which encompass officials from all levels of government, non-government actors, consultants, scientists, and members of the media. Broad participation is a necessity in a political system founded on the normative principles of a representative democracy and where expertise is diffuse among government and non-government actors as well as scientists and consultants. But broad participation also produces disagreement and raises legitimacy issues regarding the extent that people participating truly represent members of the public who are not (Dryzek, 2001). The continuation of disagreement and lack of legitimacy of subsystem affairs can threaten the long-term stability of processes and policies. Finally, policies and programs are best thought of as translations of beliefs and, therefore, embedded with emotion, implicit causal theories, and normative priorities. Whereas sustainable management views policies as objects of experimentation (Norton, 2005), the ACF views policies with normative and emotional connotations that actors are rarely willing to test experimentally.

Along with its five premises, the ACF incorporates a model of the individual as boundedly rational with limited abilities to process external stimuli and, thus, to learn from experiences (Simon, 1996). The ACF actor selects and interprets incoming stimuli based on a complex belief system (Lord et al., 1979; Munro and Ditto, 1997; Munro et al., 2002; Peffley and Hurwitz, 1985). Central to the actors' belief system are policy core beliefs, which span the substantive and geographic breadth of a policy subsystem. The subsystem-relevancy of policy core beliefs make them ideal for binding coalitions together over extended time periods. The ACF also assumes that actors remember losses more than gains and, therefore, exaggerate the power and maliciousness of opponents, a cognitive state called the ''devil shift'' (Quattrone and Tversky, 1988; Sabatier and Jenkins-Smith, 1999). The challenge to the sustainable management of complex socio-ecological systems is that actors often look for belief-confirming information, interpret ambiguous information to bolster their beliefs, and have the potential to learn the wrong lesson, miscalculate the motivations of opponents, and make the same mistakes continuously over time, all of which can be self-defeating and threatening to society (Pielke, 2004; Sarewitz, 2004).

1.2. *Policy subsystem types*

Three subsystem types and three major dimensions of each are simplified and summarized in Table 1. The first is a unitary policy subsystem dominated by a single coalition. The second type is a collaborative policy subsystem, which involves cooperative coalitions where conflict is mitigated by consensus-based institutions. The third is an adversarial policy subsystem, which involves high conflict among competing coalitions. The following paragraphs define and discuss in more detail the attributes of each policy subsystem type (see Weible, 2008).

1.2.1. *Coalitions*

The ACF defines coalitions by members who hold similar policy core beliefs and show similar coordination patterns (Sabatier and Jenkins-Smith, 1993). Thus, coalition allies are expected to show a high degree of policy core belief compatibility. At the subsystem level, policy core belief compatibility refers to the degree of convergence or divergence in policy core beliefs among all subsystem actors, including those from different coalitions (Jenkins-Smith, 1990, p. 95). The three subsystem types in Table 1 vary from high belief compatibility for unitary subsystems where opponents are largely nonexistent, to low compatibility in adversarial subsystems where competing coalitions hold polarized policy core beliefs, and to intermediate levels of compatibility in collaborative subsystems where coalitions continue to disagree but develop strategies for overcoming their disagreements, perhaps by finding enough common ground to cooperate.

Coalitions are also defined by their coordination patterns. Coordination includes a range of political activities from developing and executing joint plans to modifying behavior to achieve similar or non-interfering objectives (Sabatier and Jenkins-Smith, 1999, pp. 138–141). Whereas the early versions of the ACF assumed that all coalition members interact, this assumption is unrealistic (Schlager, 1995; Nahrath, 1999). It is more realistic and still consistent with the ACF to assume that coordination among members will vary based on the centrality of a given issue to the members' belief system and to the members' access to resources. Thus, coalition members can be classified as auxiliary or principal (Hula, 1999; Zafonte and Sabatier, 2004; Silva, 2007). For principal members, subsystem issues are central to their beliefs, they have the resources to provide leadership for their coalition, and, therefore, facilitate coordination with the majority of other coalition members over extended periods of time. The expectation is that principal coalition members are either directly connected to all coalition members or separated from other coalition members by one or two other coalition members. These principal members serve as entrepreneurs for a coalition in providing leadership and in bearing much of the transaction costs in coordinating activities. In contrast, auxiliary members are peripheral to a coalition's network and coordinate with some but not all coalition members. Auxiliary members may not view the subsystem issues as salient to their beliefs, they may lack sufficient resources to participate, or both.

Table 1 – Three policy subsystem types.

	Unitary subsystems	Collaborative subsystems	Adversarial subsystems
Coalitions	Dominant coalition with high intra-coalition belief compatibility and high intra-coalition coordination	Cooperative coalitions with intermediate inter-coalition belief compatibility and high inter and intra-coalition coordination	Competitive coalitions with low inter-coalition belief compatibility and high intra-coalition and low inter-coalition coordination
Degree of Centralization and Independence	Authority is centralized and interdependence with other subsystems ignored	Authority is decentralized, fragmented across policy subsystems, or both. Coalitions share access to authority.	Authority is centralized but fragmented within the policy subsystem, fragmented across policy subsystems, or both. Coalitions compete for access to authority
Venues	Coalition influences decisions in one or two amiable venues (legislature, agencies)	Coalitions attempt to keep decisions within inclusive, consensus-based institutions	Coalitions seek to influence decisions in any amiable venue (courts, legislatures, agencies)

The three subsystems vary by the degree that coordination patterns are primarily within coalitions or between coalitions. In unitary and adversarial subsystems, coordination patterns will primarily occur within a coalition among allies. In collaborative subsystems, coordination patterns will include more cross-coalition interactions or a broker that facilitates cooperation among opposing coalitions. We also define two types of coalitions: competitive and cooperative. Competitive coalitions exist in adversarial policy subsystems and are defined by high levels of distrust, polarized beliefs, and mostly internal coordination patterns. In contrast, cooperative coalitions exist in collaborative policy subsystems and have intermediate levels of trust and belief differences and more cross-coalition interactions.

We contend that, in order for progress to be made towards sustainably managing SESs, two conditions must be present: first, an intermediate level of policy core belief conflict among coalitions; and second, some level of cross-coalition coordination among coalitions (Blackmore, 2007; Cortner, 2000; Sabatier and Jenkins-Smith, 1993). The presence of both conditions provides a hospitable setting for both trust and common understandings of subsystem affairs, possibly leading to cross-coalition learning and policy change. This is indicated by "relatively enduring alterations of thought or behavioral intentions that result from experiences and/or new information and that are concerned with the attainment or revision of policy objectives" (Sabatier and Jenkins-Smith, 1999, p. 123).

1.2.2. *Degree of centralization and interdependence*

Coalitions seek to influence subsystem affairs. Two of the more important factors that affect the odds of their success are the degree of centralization and interdependence of authority (legitimized power to make and enforce institutional rules) in the subsystem. In federal systems, for example, centralization is the extent that authority lies within the federal government or is decentralized (devolved) to state or even local governments. A coalition can be very influential in centralized subsystems where government officials with authority are sympathetic to the coalition's objective. Intransigent conflicts often occur in decentralized subsystems where dueling coalitions have allies among government officials from incompatible government agencies.

The degree that a subsystem is independent from other subsystems or interdependent with other subsystems partly determines the affects of a given coalition on subsystem affairs (Fenger and Klok, 2001; Jones and Jenkins-Smith, 2009; Zafonte and Sabatier, 1998). Interdependent policy subsystems provide opportunities to gain resources (e.g., coalition allies) from another policy subsystem. From a coalition's perspective, a coalition will likely maximize its influence in unitary policy subsystem, where authority is centrally located within one or more sympathetic government agencies and where externalities can largely be ignored. Adversarial policy subsystems are examples where authority is fragmented vertically within or between subsystems, providing a fertile ground for coalition competition. Collaborative policy subsystems are examples where authority among coalitions is fragmented within or between subsystems but, as will be discussed below, there exists consensus-based institutions enabling the coalitions to cooperate.

Sustainable management is potentially threatened anytime authority is wielded by one coalition without consent, and to the detriment, of another coalition or other latent actors in society (Steyaert and Jiggins, 2007). For sustainable management to occur, abuses of authority must be kept in check, through transparent and open processes as well as through engagement of rivals.

1.2.3. *Venues*

Coalitions seek to influence government decisions through decision-making venues, traditional examples including legislative committees and subcommittees, courts, executives, and administrative agencies. These traditional venues dominate adversarial and unitary subsystems with limited capacity to resolve conflicts because (i) legislatures tend to sidestep conflicts by writing vague policies, (ii) administrative agencies respond to vague legislation by making coercive top-down decisions where participation is restricted to hearings and testimonies, and (iii) courts usually resolve procedural issues not substantive disputes (Emerson et al., 2003, pp. 5–9). In contrast, collaborative subsystems include at least one venue marked by collaborative institutional arrangements, such as inclusive and open entry rules, consensus-based decision rules, and an emphasis on deliberative and face-to-face discourse. These collaborative venues or consensus-based institutions, typically include a mediator who is effective in mitigating conflict within the policy subsystem. We, therefore, expect that collaborative policy subsystems provide the best setting for sustainable management because the relevant actors will more likely be present and dialogue will more likely occur about the normative and scientific disagreements.

1.3. *Experts and the functional uses of expert-based information*

Expert-based information is content generated by professional, scientific, and technical methods of inquiry (Adams, 2004; Kerkhoff and Lebel, 2006). Expert-based information is usually based on accepted analytical approaches as defined by professional community of peers with sources including the social and natural sciences, policy analyses, government reports, and research coming from universities, think tanks, and consulting firms. Likewise, the term "expert" includes policy analysts, scientists, consultants, and researchers in government and non-government organizations. Expert-based information is distinguished from local (community or experienced-based) information that builds from trial-and-error learning in relation to a specific topic and place (Kerkhoff and Lebel, 2006; Adams, 2004). The legitimizing force of expert-based information derives from popular perceptions that science is dispassionate, rigorous, and evidence-based approach to generating information (Ozawa, 1991).

The literature on research utilization has created three functional uses of science (Caplan et al., 1975; Knorr, 1977; Peltz, 1978; Weiss, 1979; Dunn, 1994; Amara et al., 2004):

1. *Learning function.* The learning function focuses on the cognitive processes of policy participants. The learning function is derived from Weiss (1977), who argued that the accumulation of science slowly and indirectly affects policy

by altering decision makers' beliefs about causes of potential problems and solutions. Single research studies or reports rarely have significant impacts on beliefs of political actors or on policy; instead, impacts accumulate, like sedimentation, gradually altering the belief systems of the actors involved in a policy process. The learning function is the basis of policy-oriented learning, or alterations in thought or intentions, and one path for belief and policy change in the ACF (Sabatier and Jenkins-Smith, 1999). Learning comes in two types: the first is within coalitions that tend to reinforce existing beliefs; and the second is between coalitions that can challenge existing beliefs. Sustainable management of socio-ecological systems involves cross-coalition learning and not just within-coalition learning because the former compared to the later provides a stronger check on the distortion of information or politicization of science discussed earlier and a greater chance for the enduring changes in belief over time. Looking at Table 2, cross-coalition learning will most likely occur in collaborative policy subsystems and the least likely to occur in unitary or adversarial policy subsystems.

2. *Political function*. The political function occurs when decision makers use expert-based information to legitimize prior beliefs or interests, previously made policy decisions, or both (Jenkins-Smith, 1990; Knorr, 1977; Weiss, 1979; Amara et al., 2004). The political function may entail the selective use of information and distortive interpretation of information. For sustainable management of human–environmental systems the political function is detrimental because it leads primarily to within-coalition learning and exacerbates coalition conflicts. The political function will be highest in adversarial policy subsystems because of the high level of conflict and will operate at intermediate levels in collaborative policy subsystems because of the intermediate level of conflict.
3. *Instrumental function*. The instrumental function represents a more rational approach to the use of expert-based information in policy subsystem and occurs when there is a one-to-one correspondent between the implications from expert-based information to the policy decision. The instrumental function is depicted as an approach where a problem exists, research is conducted, and the decision follows the research findings (Caplan et al., 1975; Amara et al., 2004; Weiss, 1979). The instrumental function might include direct impacts of expert-based information on forecasting impacts, highlighting tradeoffs, and evaluating impacts of current policies and programs. In contrast to the political function, the instrumental function often requires a willingness to entertain outcomes that conflict with beliefs. In contrast to the learning function, the instrumental function is more observable and possibly more attributable to one or more information sources. The prospect of sustainable management of complex SESs involves the instrumental function because of its strong foundation with policy experimentation, learning, and adaptive decision making. However, sustainable management of SESs is also threatened by the instrumental function when the expert-based information is incorrect and irrelevant. One approach to mitigate threats, and increase the benefits, of the instrumental function in sustainable management is for the information to be generated by research teams with diverse analytical approaches and with iterative consultation with the policy participants. Such a process is depicted in the joint-fact finding and adaptive management literatures and most likely found in collaborative policy subsystems (NRC, 1996; Norton, 2005; Ehrmann and Stinson, 1999). We, therefore, expect that the benefits of the instrumental function will be highest in collaborative policy subsystems, compared to the other subsystem types.

These three functional uses of science do not operate independently but can reinforce each other in complementary ways (Amara et al., 2004). For example, learning from science over time can increase the incremental use of expert-based information and vice versa. With expert-based information come experts and so it is important to understand the role of experts to understand the use of science in the policy process. We identify and summarize two characteristics of experts below.

1. *Analytic compatibility*. Analytic compatibility is the extent that experts active in a policy subsystem share similar theories and methods in understanding and explaining phenomena, such as problem attributes, in a policy subsystem (Jenkins-Smith, 1990). Analytic compatibility assumes that experts with similar analytical approaches (or professional paradigms) will select similar components of a system to study, use similar methods for measuring the

Table 2 – Expert-based information and policy subsystem types.

	Unitary subsystems	Collaborative subsystems	Adversarial subsystems
Functional use of science			
Policy-oriented learning	High intra-coalition learning and no inter-coalition learning	High intra-coalition learning and high inter-coalition learning	High intra-coalition learning and low-inter-coalition learning
Political	High by dominant coalition against latent opposition	Low between coalitions	High between coalitions
Instrumental	Intermediate	High	Low
Role of scientists			
Analytical compatibility	Experts agree on theory, data, and methods	Experts reconcile differences in theory, data, and methods	Experts disagree on theory, data, and methods
Experts and coalitions	Experts serve as auxiliary allies for the dominant coalition	Experts serve as auxiliary allies or opponents	Experts serve as principal allies or opponents

chosen components, and make similar arguments of cause and effect within a system (Sabatier and Zafonte, 2001; Kuhn, 1970). Outside of policy core beliefs, analytic compatibility will provide a secondary basis for bonding experts to coalitions because a coalition will more likely listen to experts if the experts' analytical approach reinforces a coalition's belief system. Analytical compatibility will be the highest in unitary policy subsystems because the dominant coalition will work with a homogenous community of experts. The analytical compatibility of experts will be lowest in adversarial subsystems because the competitive coalitions will bring competing analytical approaches to bolster their arguments. In collaborative policy subsystems, the analytical compatibility will be low because a diverse set of experts will more likely be present just as diverse stakeholders will more likely be present; however, the experts and stakeholders will tend to cooperate through iterative, interdisciplinary research strategies. Since sustainable management of complex socio-ecological systems entails multi-disciplinary approaches to problem solving, collaborative policy subsystems provide the best setting because experts are most likely to work together rather than against each other.

2. *Experts and coalitions*. Experts will likely align themselves with a coalition based on shared beliefs (thereby possibly aligning experts and coalitions by shared interests as well) and because their information will likely buttress a coalition's arguments. Likewise, coalitions seek experts as allies because of the legitimacy of expert-based information in helping make and implement decisions. Consequently, experts may become central allies or opponents in coalition politics. Depending on the type of policy subsystem, scientific and technical experts will vary in the extent that they are perceived as central allies or opponents among coalitions. Experts will be principal members in coalitions in adversarial policy subsystems where pressure is high to legitimize policy arguments by drawing science into the argumentation. Experts will be auxiliary members in both unitary and collaborative policy subsystems because conflict will be at intermediate to very low levels. Because sustainable management of complex systems requires learning and policy adaptation, distortions to the learning must be kept at a minimum. Thus, collaborative policy subsystems provide the best setting because both coalitions provide a check others on overreacting or overlooking information sources.

1.4. *Linking experts, expert-based information, and subsystem types*

From Tables 1 and 2, the following arguments emerge about the functional use of expert-based information and the role of experts in the three subsystem types.

A unitary policy subsystem exhibits a dominant coalition, one with sufficient resources (e.g., leadership, finances, supporters, scientific and technical information, and access to authority) to steer the direction of the subsystem and dampen opposition. If opposition exists, they will be unorganized and lack sufficient resources to pose any threat to the dominant coalition's position. Authority in a unitary policy subsystem will be centralized within one or two agencies or interest groups that serve as principal members of the dominant coalition. A dominant coalition will maintain the status quo by continuing to assert influence in just a few venues, by making incremental policy choices, and by dampening internal and external events that might attract the attention of actors outside of the policy subsystem. In unitary subsystems, the analytical compatibility will be high because the range of scientific and technical expertise will reflect the belief homogeneity of the dominant coalition. Scientific experts will be asked to provide positive news to people both inside and outside the policy subsystem. However, scientists will be on the periphery as important allies because coalitions will not feel the political pressure to legitimize their arguments. Learning will be constrained within the dominant coalition, largely reinforcing preexisting beliefs. One example of unitary policy subsystems is nuclear policy in the United States from the late 1940s through the early 1970s (Duffy, 1997).

The threat from unitary policy subsystems to sustainable management of complex systems is homogenous participation and distorted information flows and skewed learning. While unitary policy subsystems might provide a good setting for sustainable management if we assume that the dominant coalition will make the right decisions over extended periods of time, this possibility is unlikely given the constraints on human cognition and human susceptibility to belief-confirming observations.

Collaborative policy subsystems include cooperative coalitions who continue to disagree but who are able to find enough common ground to negotiate. Negotiations occur in venues based on open participation rules, transparent decision making, and consensus-based decision rules (Sabatier et al., 2005). Opponents regularly engage each other face-to-face; and cooperation between opponents is often aided by effective brokers or mediators. The coalitions continue to coordinate with allies but cross-coalition coordination occurs regularly. Cooperative coalitions prefer policy instruments that are flexible in means or voluntary in compliance. Collaborative subsystem actors will seek to integrate local information and expert-based information in consensus-based institutions. Cooperation across coalitions will coincide with cooperation across different analytic methods of inquiry. Policy-oriented learning will occur across coalitions. Scientists will continue to be coalition members but their centrality as actors, especially in ally and opponent networks, will decrease.

Collaborative subsystems stand the best chance for sustainable management of complex socio-ecological systems because (i) learning is occurring across coalitions and therefore across different beliefs systems, thereby serving as a check on competing conceptual filters; (ii) scientific and technical experts no longer serve as allies or opponents and instead work with both coalitions; (iii) communication among coalitions provide the best chance for trust to emerge and policies to be applied experimentally. On the other hand, collaborative policy subsystems threaten sustainable management of complex systems when (i) the participating coalition members dampen efforts for radical change through consensus-based procedures; (ii) the participating actors develop a shared set of beliefs and a shared vernacular, which ends up alienating outsiders, reducing participation and external scrutiny, and, thereby, shifting a collaborative subsystem to a unitary subsystem; (iii) the participating actors make decisions that negatively impact other policy subsystems thereby pitting two subsystems against each other and shifting the collaborative subsystem to an adversarial subsystem.

Adversarial policy subsystems will include competitive advocacy coalitions with incompatible beliefs and different patterns of coordination. Authority will be fragmented between coalitions. Competitive coalitions will usually be anchored by government agencies or a powerful interest group or two and have access to sufficient resources to challenge each other in accessing venues. Inter-coalition conflicts are compounded because coalitions prefer coercive and prescriptive policies. A competitive coalition trying to change the status quo will try to expand the scope of conflict outside of the policy subsystems by attracting attention of supportive macropolitical actors or other external subsystem actors (Pralle, 2006). A competitive coalition wanting to maintain the status quo will try to keep decisions within a subsystem and dampen conflict escalation. Because of the political value of expert-based information, experts will become central allies in their coalition. Consequently, experts will also become central opponents to a rival coalition. Learning will reinforce beliefs within coalitions and among experts with similar analytical approaches. Sustainable management of human–environmental systems will be unlikely to emerge in this subsystem because the coalitions are not learning together and success by one coalition will lead to counter attacks by the other coalition. Subsequently, adversarial policy subsystems are the least likely to provide a setting for sustainable development because the high distrust makes policy experimentation extremely unlikely and coalitions will continuously attempt to undermine any policy regime or attempt at forming lasting sustainable management of complex systems.

1.5. *Stating propositions: a summary*

Given Tables 1 and 2, a number of propositions can be derived about the role of expert-based information and experts in different types of policy subsystems. The first three propositions are about the use of expert-based information in policy subsystems and the last two propositions relate to the role of experts in policy subsystems.

1. *The political function will be highest in adversarial subsystems*. The high value conflicts in adversarial subsystems, makes expert-based information appealing as a political weapon to argue against opponents.
2. *The instrumental use of science will vary from the highest in collaborative, to an intermediate level in unitary, and to the lowest in adversarial policy subsystems*. Expert-based information will least likely be used instrumentally in adversarial policy subsystems because actors will primarily be set on defeating opponents and reinforcing their policy positions and not on following the suggestions from expert-based information. The instrumental function will most likely be found in collaborative policy subsystems because of the potential for iterative and joint-fact finding to get the right science and to get the science right for decision-making actors (NRC, 1996; Ehrmann and Stinson, 1999). The instrumental function will be found in unitary, as long as the science reinforces the status quo, but will be ignored otherwise because of the homogeneity of beliefs among members of the dominant coalition.
3. *The learning function will occur within coalitions in all subsystems and across coalitions in collaborative subsystems*. In adversarial and unitary subsystems, learning will mostly reinforce existing beliefs or analytical methods. Low conflict and presence of consensus-based institutions make collaborative policy subsystems the best for learning across coalitions.
4. *Scientists will more likely be perceived as allies and opponents in adversarial policy subsystems than in collaborative policy subsystems*. Because expert-based information is most likely used politically in adversarial policy subsystems, scientists too will most likely be viewed as allies or opponents in these systems. We expect to find high citations to scientists as allies and opponents in adversarial systems compared to collaborative or unitary policy subsystems.
5. *Coalition members will more likely coordinate with scientists when the scientists' analytical approach corroborates the coalitions' policy core beliefs*. We expect a symbiotic coupling between analytical approaches of scientists and coalition belief systems and to find correlations between certain degrees or specializations with a coalition's policy positions, especially in unitary and adversarial policy subsystems.

2. Part 2: Empirical application

Sustainable management is impossible to measure directly. Therefore we often rely on proxy measures that indicate, for example, the presence of learning or adaptive decision capacity. We investigate one proxy: the degree that scientific and technical experts are perceived as coalition allies and opponents in two adversarial and two collaborative policy subsystems. While not presenting direct evidence of learning or sustainable management, we consider the centrality of scientists and consultants as a viable litmus test for gauging the sustainability of the policy subsystem and the extent that learning is occurring within or between coalitions. The hypothesis is that scientists will more likely serve as central allies and opponents in adversarial compared to collaborative policy subsystems. Our two adversarial policy subsystems are 2002 California marine protected area policy and 1993 San Francisco Bay-Delta water policy. The two collaborative policy subsystems are the 1997 San Francisco Bay-Delta water policy after the emergence of CALFED and 76 collaborative watershed partnerships, measured between 1999 and 2002. This empirical application includes a brief background of each policy subsystem, the results, and a discussion of the findings. We place the variable measurement in the supplemental material published online.

2.1. *Case study background*

2.1.1. *California marine protected areas policy*

Marine protected areas (MPAs) are a spatially based management strategy that restricts the use of areas of ocean waters. In

1999, the California Marine Life Protection Act charged the Department of Fish and Game with developing a plan for establishing MPAs along the coast. Between, 2000 and 2001, a team of scientists developed a preliminary MPA plan that was then made public in open meetings where fishing interests and local government officials mobilized a strong protest. Several months later, this first attempt to implement MPAs in California ended. The data from the California MPA policy subsystem included a mail-in questionnaire and in-person interviews that were administered in the late summer of 2002 seven months after the first attempt ended and 1 year after the public meetings. The mail-in questionnaire was administered to a sample of 310 people with the intent to generalize to policy participants who were directly involved with the California Marine Life Protection Act process.[1] A total of 194 people responded (62% response rate). The MPA questionnaire data are used as an example of an adversarial policy subsystem.[2]

2.1.2. 1999–2002 California and Washington watershed partnerships

Watersheds are topographic areas where surface water runoff drains into a specific water point, such as a stream or lake. To help facilitate watershed management, watershed partnerships have emerged (Leach and Pelkey, 2001). Watershed partnerships engage diverse stakeholders, including landowners, businesses, environmental groups, and government agency representatives, in consensus-based decision making. The collection for the watershed partnership data occurred between 1999 and 2002 and included 76 watershed partnerships in California ($n = 46$) and Washington States ($n = 30$). A watershed partnership was included in the population if it met at least four times per year, focused on managing one or more streams, rivers, or watersheds, and had at least one state or federal official, one local government official, and at least two opposing interests. This paper is based primarily on data from the mail-in questionnaire that was administered to all participants in a watershed partnership (response rate = 65%, $n = 1625$).[3] The data from the watershed partnerships are used in the current paper as examples of a collaborative policy subsystem.

2.1.3. 1992 and 1997 San Francisco Bay-Delta environmental policy

The San Francisco Bay-Delta environmental policy has a long, conflict-ridden history. In the late 1960s and into the 1970s, the major issue was pollution from surface runoff and from municipal and industrial dischargers. The State Water Resources Control Board tried to establish water quality standards starting in the late 1970s and into the 1990s but were challenged by a Federal appellate decision in 1985, by outraged stakeholders in 1988, and by the U.S. Environmental Protection Agency in 1991 and in 1993 (Zafonte and Sabatier, 1998; Hundley, 2001). In the early 1990s, the winter run salmon and the Delta smelt were listed as threatened species under the Federal Endangered Species Act. To help remedy fish declines and in the context of a severe drought, the U.S. Congress passed the 1992 Central Valley Project Improvement Act, which reserved large quantities of water for the environment and encouraged water marketing with southern California. The State Water Quality Control Board responded to the Central Valley Project Improvement Act with limits to water exports, which panicked water users (Jacobs et al., 2003). In 1993, the U.S. Environmental Protection Agency was ordered by a Federal District Court to issue water quality standards or violate the Clean Water Act.

In 1994, the major policy participants, including water agencies, agricultural interests, and environmental and fishery organizations, negotiated and reached consensus with the Bay-Delta Accord. The Bay-Delta Accord set new water quality standards to protect fisheries while minimizing costs to water users. Part of the solution was CALFED, which engaged a large number of federal and state government agencies and interest groups in managing Bay-Delta environmental policy.

This article uses data from 1992 and 1997 mail-in questionnaires of Bay-Delta policy participants. The sample of policy participants targeted individuals who either directly or indirectly attempted to affect Bay-Delta water policy.[4] The 1992 mail-in questionnaire was administered 2 years before

[1] Three formal methods of data collection were used in the California marine protected area project. The first method included 47 semi-structured, in-person interviews of policy participants representing of a cross-section of the sample. These interviews were recorded, transcribed, returned for comment, and than coded. The interviewed stakeholders included federal agency officials ($n = 3$), state agency officials ($n = 8$), local government officials or harbormasters ($n = 3$), commercial fishing interests ($n = 7$), recreational fishing interests ($n = 8$), environmental groups ($n = 8$), and scientists ($n = 8$). Two of the 47 people interviewed fall in an "other" category. Approximately half of the 47 interviewees completed and returned the mail-in questionnaire. The second method was an analysis of documents/reports. The third included was a mail-in questionnaire. The mail-in questionnaire sample was collected from three sources: (1) Starting with suggestions from nearly 50 preliminary interviews, a modified snowball-sampling technique generated a list of stakeholders ($n = 178$) and a list of California Department of Fish and Game officials ($n = 13$). Also collected were names of people in leadership positions from interest groups and related government agencies. (2) A publicly available list provided the initial active members on the Stakeholder Working Groups ($n = 105$). (3) A publicly available list provided the initial members on the Master Plan Team ($n = 14$).

[2] The Department of Fish and Game tried a second time to develop a MPA plan using a multistakeholder collaborative process in the fall of 2002. The questionnaire used in the current paper was administered before the start of this second attempt. In 2003, the second attempt ended because of cuts to funding during the California budget crisis. A third attempt was successful with a collaborative-based process reaching and implementing an agreement on the California central coast. For more information on the third attempt please see http://www.dfg.ca.gov/mrd/mlpa/).

[3] There were three methods of data collection for creating the watershed partnerships dataset. First, a member of the research team visited the watershed and conducted semi-structured, in-person interviews with three to seven partnership participants. Second, a member of the research team analyzed documents and reports for each partnership to obtain information regarding partnership rules and activities. Third, a mail-in questionnaire was administered to participants and knowledgeable nonparticipants.

[4] The list of policy participants came from testimonies at Bay/Delta hearings and members of various Bay/Delta-related organizations.

the Bay-Delta Accord, a period of intense political conflict. It was mailed to 845 policy participants with 465 responding (55% response rate). The second mail-in questionnaire was administered in 1997, roughly 3 years after consensus was reached in the Bay-Delta Accord. The 1997 mail-in questionnaire was administered to 1527 policy participants of whom 671 responded (44% response rate). The current paper uses the 1992 questionnaire data as an example of an adversarial policy subsystem and the 1997 questionnaire data as an example of a collaborative policy subsystem.

2.2. *Results*

Table 3 splits the four policy subsystems into two columns. On the left are two adversarial policy subsystems: California marine protected area policy and San Francisco Bay-Delta environmental policy in 1992. On right are two collaborative policy subsystems: California and Washington watershed partnerships and San Francisco Bay-Delta environmental policy in 1997. Table 3 further subdivides the subsystems into environmental and resource user coalitions. Table 3 provides two quantitative summary statistics to describe coalition membership: coalition ally density and mean (standard deviations) pro-environmental beliefs.

Looking first at coalition membership, the environmental coalitions usually included environmental groups, most federal, state and regional agencies, and university researchers. Typical federal government agencies in the environmental coalition were the Environmental Protection Agency, the National Park Service, and the National Marine and Fisheries Service. Typical state and regional governments in the environmental coalition were fish and game agencies, water quality control boards, and CALFED. The resource use coalitions consisted of resource users and local governments. Resource users were farmers, most fishers, forest industries, businesses, and developers. Among local governments were city and county governments, local water districts, and harbormasters. Exceptions to this pattern of coalition membership included the federal National Resource Conservation Service and state Resource Conservation Districts, which provided support to resource users in watershed partnerships and were members of the resource use coalition.

Some organizational affiliations were members of the environmental coalition in one subsystem but members of the resource use coalition in a different policy subsystem. Commercial and recreational fishers anchor the resource use coalition in California marine protected area policy. In San Francisco Bay-Delta environmental policy, on the other hand, fishing groups aligned with the environmental coalition to conserve water quality and supply for fisheries.

For the quantitative summary statistics, coalition ally density equals the number of within-in coalition citations to the total number of coalition citations for ally networks. For example, 87% of ally citations (154 out of 178) by the environmental coalition were to the environmental coalition in California marine protected area policy, whereas only 13% (24 out of 178) of ally citations went to the resource use coalition. Across all networks and subsystems a majority of citations were within coalitions and not across coalitions. The environmental coalitions' citations within their coalition ranged from 70% for watershed partnerships to 94% in 1992 San Francisco Bay-Delta policy. The resource use coalitions' citations within the resource use coalition ranged from 61% to 81%.

Table 3 lists the mean (and standard deviation in parentheses) for pro-environmental beliefs by the two coalitions. The environmental coalitions' pro-environmental beliefs fall near the top end of the seven-point scale with means ranging from 5.8 to 6.1. The resource use coalitions' pro-environmental beliefs fall near the middle of the seven-point scale with means ranging from 4.3 to 4.9. The means between coalitions differ significantly in all policy subsystems ($p < 0.000$).

Table 4 compares the environmental and the resource use coalitions' citations to scientists for ally and opponent networks. Our hypothesis is that citations to scientists as allies and opponents will be lower in collaborative compared to adversarial policy subsystems.

Table 4 is split with adversarial policy subsystems on the left and collaborative policy subsystems on the right. The percents equal the proportion of coalition members citing scientists. For example, 44 out of 100 environmental coalition members in the California marine protected area policy subsystem cited scientists as allies; but only 13% of the members of the resource use coalition mentioned scientists as allies. The Welch's test was used to generate the *p*-values, which indicate that the resource use coalitions and the environmental coalitions differ in citations to scientists within each policy subsystem.

Table 4 provides support for our hypothesis. We find higher proportion of coalition members citing scientists as allies and opponents in the two adversarial policy subsystems compared to the two collaborative policy subsystems. Out of the environmental coalition members, 44% cited scientists as allies in California marine protected area policy and 37% cited scientists as allies in 1992 San Francisco Bay-Delta environmental policy. Only 3% of environmental coalition members cited scientists as opponents in the two adversarial policy subsystems. In contrast, members of the resource use coalition were more likely to mention scientists as opponents and less likely to mention scientists as allies. The difference between coalitions in their ally and opponent ties to scientists in the adversarial policy subsystems is statistically significant ($p < 0.003$).

The results are different in the two collaborative policy subsystems where environmental and resource use coalitions cited scientists at lower frequencies for both ally and opponent networks. Of the members of both coalitions, 11–18% cited scientists as allies and only 3–5% as opponents.

Interestingly, the discrepancy between coalition members' perceptions of scientists as allies and opponents mostly disappears in collaborative policy subsystems. Almost the same proportion of members from both coalitions mentions scientists at the same frequency as allies and opponents.

2.3. *Discussions of empirical findings*

In the empirical application, we test and find support for our hypothesis that scientists will play a more central role as coalition allies and opponents in adversarial compared to collaborative policy subsystems.

Table 3 – Coalitions membership, densities, and environmental beliefs.

	Adversarial policy subsystems			Collaborative policy subsystems	
	Environmental coalition	Resource use coalition		Environmental coalition	Resource use coalition
California marine protected area policy			California and Washington watershed partnerships		
Coalition members	Environmental groups, federal and state agencies, scientists, non-consumptive divers	Commercial and recreational fishers, local governments, harbormasters, consumptive divers	Coalition members	Environmental groups, federal agencies, state agencies, water quality control boards, CALFED, university researchers	Resource users, local governments, resource conservation districts, National Resource Conservation Service
# of respondents	100	85	# of respondents	1024	557
Coalition ally density	87%	81%	Coalition ally density	70%	66%
Mean Pro-Env beliefs[a]	6.1 (0.78)	4.3 (1.2)	Mean Pro-Env beliefs[a]	6.0 (0.98)	4.8 (1.4)
1992 San Francisco Bay-Delta environmental policy			1997 San Francisco Bay-Delta environmental policy		
Coalition members	Environmental groups, state & federal agencies, water quality control boards, scientists	Agricultural interests, water users, private and public dischargers	Coalition members	Environmental groups, state & federal agencies, water quality control boards, scientists, CALFED	Agricultural interests, water users, consultants
# of respondents	335	112	# of respondents	430	157
Coalition ally density	94%	63%	Coalition ally density	87%	61%
Mean Pro-Env beliefs[a]	5.8 (1.1)	4.4 (1.2)	Mean Pro-Env beliefs	5.9 (0.88)	4.9 (1.1)

[a] Standard deviations are given in parentheses next to the mean pro-environmental beliefs with 1 = strong disagreement and 7 = strong agreement.

Table 4 – Citations to scientists by coalition.

	Adversarial policy subsystems				Collaborative policy subsystems			
	Environmental coalition ($n = 100$)	Resource use coalition ($n = 85$)	Total ($n = 185$)	p-Value	Environmental coalition ($n = 1024$)	Resource use coalition ($n = 557$)	Total ($n = 1581$)	p-Value
	California marine protected area policy				California and Washington watershed partnerships			
Ally	44%	13%	30%	0.000	15%	18%	16%	0.14
Opponent	3%	28%	15%	0.003	3%	3%	1%	0.87
	Adversarial policy subsystems				**Collaborative policy subsystems**			
	Environmental coalition ($n = 335$)	Resource use coalition ($n = 112$)	Total ($n = 447$)	p-Value	Environmental coalition ($n = 430$)	Resource use coalition ($n = 157$)	Total ($n = 587$)	p-Value
	1992 San Francisco Bay-Delta environmental policy				1997 San Francisco Bay-Delta environmental policy			
Ally	37%	17%	32%	0.000	17%	11%	16%	0.06
Opponent	3%	15%	6%	0.000	4%	3%	3%	0.74

Notes: The percents indicate the proportion of coalition members citing scientists for a particular network. For example, for ally networks in CA MPA policy, 44 out of 100 (44%) of the environmental coalition members cited scientists as allies.

Our findings indicate first, that scientists are more involved as important members of coalitions in adversarial than in collaborative subsystems. This is probably because many scientists like getting involved in contentious policy debates. In addition, one can assume that more money is present for advice in adversarial systems. On the other hand, scientists get mentioned relatively infrequently in collaborative systems and are roughly equally perceived as allies and opponents by the coalitions. This suggests that scientists are more likely to fill their traditional role of neutral experts in collaborative systems.

There are obvious threats to the validity of this empirical application. For example, since we are using a quasi-experimental design our sample is threatened by non-random assignment and omitted variables. Thus, we must temper any arguments of causality and recommend a degree of caution while interpreting our results. Yet despite the limitations of our analysis, we know of no other publication that has compared the network role of scientists across policy subsystems using questionnaire data of policy elite.

3. Conclusions

Measuring progress in the sustainable management of SESs is a nontrivial task. The best we can hope for are indirect indicators based on explicit theories and empirical and systematic measures. Based on the ACF, we hypothesize that the sustainability of SESs will most likely occur in collaborative policy subsystems when these indicators are present:

- Cooperative coalitions,
- Scientists, who are not principal coalition allies or opponents,
- Diverse analytical approaches,
- Cross-coalition policy-oriented learning,
- Low political use of expert-based information,
- High instrumental use of expert-based information.

We tested and found support for one of our indicators that scientists were less likely to be cited as allies or opponents in adversarial compared to collaborative policy subsystems.

Our findings support the arguments made by proponents of consensus-based institutions that such arrangements provide the best approach for integrating science into policy (Lee, 1993; Norton, 2005). While consensus-based institutions provide the best approach for sustainable management of complex SESs, we continue and encourage a healthy skepticism of collaborative policy subsystems. Collaborative subsystems, for instance, can threaten sustainable management by dampening conflict between coalitions. Consequently, a shift to adversarial policy subsystems might very well be the best remedy for collaborative subsystem when decisions become more detrimental than sustainable. As a result, sustainable management might require conflict to escalate thereby recasting the relations between coalitions from cooperative to competitive. In turn, adversarial policy subsystems again become a vital subsystem type in a path toward sustainable management of complex SESs.

While generalizations of our propositions are best framed as a topic of future inquiry, we expect our propositions to provide a good foundation for studying many complex SESs. Other hypotheses in the ACF, for instance, have been robust in their application across diverse policy subsystems, including ones in Africa, South America, Asia, and Europe.

Our theoretical and empirical analysis also highlights two viable strategies for studying the potential for sustainable management of complex SESs in the future. First, it requires explicit and clear theories. Sustainable management involves complex, dynamic interactions within and between systems that require explicit attempts at simplification and clear conceptual definitions. What researchers choose to ignore or emphasize in their analysis will have impacts on whether policy decisions aid in the creation of sustainable management or not. Since no single research enterprise can provide a complete understanding of a system, the research assumptions must be communicated during the interactions between researchers and policy participants. Second, studying sustainable management of complex systems from a social science perspective requires longitudinal datasets and multiple methods of data collection with careful attention toward systematic documentation of observations. We know of no other way of learning from our own mistakes and proceeding adaptively as researchers.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.envsci.2010.05.005.

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