Network Governance for Invasive Species Management

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Keywords
Cooperation; ecosystem engineers; ecosystem management; environmental policy; governance; invasive species; networks.

Abstract
Invasive species management depends not only on biological and economic issues but also on how governance institutions influence cooperation from networks of stakeholders. We use the “contingency” framework for network governance to analyze why eradication of invasive Spartina in San Francisco Bay has been more successful than many other eradication efforts. The core argument is that invasive Spartina features antecedent conditions that favor a centralized network as the best governance approach, as demonstrated by a quantitative survey of Spartina stakeholders. This centralized policy network, with a clearly defined core of actors with the expertise, authority, and resources, produces effective cooperation. The contingency framework has implications for invasive species management more generally, as well as other conservation issues featuring dynamic spatial ecological processes.

Introduction
This article argues that effective invasive species management requires understanding the role of governance as well as the biological and ecological factors driving invasion processes (Epanchin-Niell & Hastings 2010). We analyze a successful case of invasive species management in San Francisco Bay—an invasive salt marsh cordgrass, a hybrid between introduced Spartina alterniflora and native Spartina foliosa—that is governed by a local collaborative partnership, but also features a highly centralized policy network. The Spartina case may appear puzzling because most existing research either portrays the stereotype that effective collaborative partnerships require highly dense and decentralized policy networks where all stakeholders are connected to each other, or extolls the virtues of networks without recognizing how the effectiveness of different types of networks is conditional on social-ecological context (Janssen et al. 2006; Bodin & Crona 2009). We suggest that the theory of network governance developed by Provan and Kenis (2008) provides a useful approach for understanding why a centralized network is effective for Spartina management.

The Spartina case illustrates the core governance challenge facing all invasive species management: solving collective-action problems. Introduced into San Francisco Bay in 1973 through an Army Corps of Engineers marsh restoration project (Ayres et al. 2004), invasive Spartina at its peak in 2005 covered 805 acres over twelve different reporting regions, with the highest concentration in the Southeast portion of SF Bay (Figure S1). Spartina creates a collective-action problem because individual land-owners have an incentive to avoid the costs of eradication, but any location where Spartina is not completely eradicated remains a potential vector for re-invasion of treated areas (Perrings et al. 2002). In political economics terminology, the benefits of invasive species management are nonexcludable and individuals have a strategic incentive to free-ride on the eradication efforts of others; this is similar to the strategic dilemma that causes the
well-known “Tragedy of the Commons” (Hardin 1968). *Spartina* creates additional complications because it is an “ecosystem engineer” that fundamentally changes underlying ecosystem processes in ways that make it difficult to return to pre-invasion conditions (Crooks 2002; Hastings et al. 2007). Hence, effectively managing invasive species requires governance institutions and associated policy networks that encourage cooperation among policy stakeholders involved in management decisions, along with land managers or other actors who influence the ecological processes of invasion and restoration.

*Spartina* has been effectively managed by a local collaborative partnership called the Invasive Spartina Project (ISP), which was created by the California Coastal Conservancy in 2000 with a variety of California state funding. The Coastal Conservancy and an environmental consultant serve as central brokers to coordinate the activities of the involved land-owners, government agencies, researchers, and other stakeholders. ISP has successfully removed 95% of invasive *Spartina*, and is now engaged in suppressing re-invasion and ecological restoration. Especially in terms of eradication, the ISP has been very effective in comparison to other local collaborative partnerships where the impact on environmental outcomes is less clear (Koontz & Thomas 2006).

Why has the ISP’s combination of a local partnership and a centralized policy network been so effective? To answer this question, we draw on the network governance literature in public administration and policy science, which focuses on how networks enhance cooperation in the face of collective-action problems (Jones et al. 1997; Robins et al. 2011). Table 1 summarizes the network governance framework developed by Provan and Kenis (2008, p. 236), which identifies the “critical contingencies” under which different modes of network governance are expected to be effective. We adopt the term “contingency framework” for narrative ease and because it emphasizes how the effectiveness of different varieties of governance networks depends on contextual variables. The framework argues that networks range between two extreme modes of governance—completely decentralized with all participants connected, to completely centralized with all collaboration brokered by a single organization. The effectiveness of different modes of network governance depends on four critical contingencies related to the costs of cooperation: the number of participants, level of trust, goal consensus, and the need for “network competencies” or specialization among network participants.

We argue that ISP is an example of the network administrative organization (NAO) mode of governance where an outside organization (the Coastal Conservancy) coordinates a centralized policy network where a small core of actors is the main source of information, planning and implementation activities. In this case, the main actors involved with implementing the ISP are a consulting firm and set of restoration and treatment professionals, who work with individual landowners (both private and public lands) where *Spartina* occurs. The basic strategy of our analysis is to argue that the ISP exhibits the critical contingencies (last row of Table 1) that support the NAO mode of governance, and to provide empirical evidence for the following hypotheses:

**H1:** Stakeholders will perceive a moderate level of trust and cooperation within the group.

**H2:** Effective management requires coordinating a moderate number to many stakeholders across SF Bay.

**H3:** There is high level of goal consensus regarding the desirability of eliminating *Spartina*.

**H4:** The distribution of policy implementation activities involves different stakeholders with a high level of specialized capacities and knowledge.

Given these contingencies, the contingency framework predicts that a highly centralized network will evolve to encourage stakeholder cooperation, and will be perceived as effective:

**H5:** The ISP policy network is highly centralized with an identifiable core.

**H6:** Stakeholders will perceive the ISP as effective.

Our argument is structured as a “proof of concept”—the *Spartina* case demonstrates the framework’s predictions about the co-occurrence of critical contingencies and a centralized policy network. A definitive empirical test of these hypotheses would require a costly and probably unrealistic experimental design: replicated invasions with different critical contingencies, with different modes of network governance. Hence, we provide initial evidence for these hypotheses using an empirical case study and survey of invasive *Spartina* stakeholders.

There are limits to both the theory and the single case study approach that constrain our analysis to be exploratory. The contingency framework does not provide any specific empirical benchmarks for observing “moderate levels” of trust, or “high levels” of goal consensus. Therefore, our interpretation of the empirical results requires exercising best professional judgment about the levels of various variables, rather than comparing to a theoretically defined quantity. Furthermore, we do not have a set of invasive species case studies that allows us to compare policy effectiveness, governance network structure, and critical contingencies in different contexts. Future research on other case studies can be compared to our results to better calibrate quantitative empirical benchmarks for these different variables.
Our application of the contingency framework contributes to both theory and practice. From a theoretical standpoint, the contingency framework provides a starting point for analyzing the idea of “institutional fit,” where conservation management is more effective when institutional rules and networks are matched to specific social-ecological conditions (Young 2002; Brown 2003; Folke et al. 2007; Ekstrom & Young 2009; Meek 2013; Epstein et al. 2015). The idea of institutional fit has become a crucial topic in the environmental governance literature but there is a need for more specific theoretical development (Bodin & Tengö 2012; Bodin et al. 2014; Bodin et al. 2016). The contingency framework is useful because it at least specifies the social variables that may influence the fitness of different forms of network governance. Our study also offers an empirical approach that could be applied to other invasive species cases, in order to assess how specific variables might be associated with a shift from one mode of governance to another, or create the need for more or less centralized policy networks. However, as will be discussed more in the conclusion, the contingency framework needs to be expanded to include ecological variables.

From the practical viewpoint, there are many different types of invasive species problems, along with other environmental problems that feature difficult collective-action problems. The contingency framework provides policy-makers with a broader menu of governance options, and highlights the importance of analyzing contextual variables rather than expecting highly dense governance networks to provide a panacea (Ostrom et al. 2007). Empirical case studies like the ISP can help conservation managers think about how to more effectively design governance institutions and networks to solve different types of problems.

Methods: invasive Spartina project stakeholder survey

The data comes from an online survey of ISP stakeholders designed with ISP staff and interested stakeholders. The stakeholders were those organizations involved in the overall policy and management process, which includes government actors who own land and a small number of involved private homeowners. Much of the Spartina invasion occurs on public land (e.g., local open space, National Wildlife Refuges), and homeowner associations play a larger role in the policy process than individual homeowners. The general topics of the survey included the respondent’s role in Spartina management, perceptions of the problem, preferences for treatment and restoration strategies, views on endangered species conflict, views on management effectiveness including stakeholder cooperation, and a name-generator organizational network question. Prior to the survey, we conducted eight key informant interviews to understand the major issues involved. The ISP provided a contact list of 363 (reduced to 323 after removing duplicate names and ineligible respondents) stakeholders for the survey, which was fielded from February 13 to March 25, 2014. All respondents received an initial email notification with a survey link, followed up by five email reminders to nonrespondents. To encourage response, ISP staff sent out separate email reminders and respondents were entered into a lottery for ten $100 Amazon gift cards. We received a total of 133 usable surveys, for an AAPOR response rate type 2 of 42% and response rate type 4 of 47% (takes into account estimated number of ineligible respondents).

Results

This section briefly summarizes the results for the critical contingencies (hypotheses 1–4), with exact survey questions in the Supporting Information. We provide more detailed discussion of the core results for hypotheses 5 and 6 about the structure and perceived effectiveness of the governance network.

Hypotheses 1–4: critical contingencies for network governance

The survey asked two Likert scale (1–5) questions (Norman 2010) regarding how concerned stakeholders
Figure 1  (a) Type of organization. (b) Role in Spartina management.
are about the management efforts of others (an indicator of trust), and the overall perceived level of cooperation. We interpret a maximum level of trust as a 5 on the cooperation scale (full cooperation) and a 1 on the management effort scale (no concern about management efforts of others). The average responses (standard deviation in parentheses) for current concern = 3.57 (1.02) and current cooperation = 3.54 (0.81). Although stakeholders remain concerned about the level of management effort provided by other stakeholders, they also view overall cooperation above the midpoint of the scale. In combination, these questions suggest a moderate level of trust that supports the NAO form of governance (H1).

The survey did not contain a question about whether the number of stakeholders was too high or low for effective management, and the contingency framework is vague as to the definition of a high or low number of participants. We point out that over 130 respondents answered the survey and that ISP considers over 350 individuals as potential stakeholders. Furthermore, these stakeholders are distributed throughout the SF Bay region. While this number and spatial distribution of stakeholders is low compared to some other invasive species like New Zealand mud snails or zebra mussels, we argue that is fair to say that there are enough stakeholders that the transaction costs of a shared governance mode, which requires many bilateral agreements, would be higher than transaction costs experienced by a NAO mode of governance (H2).

Stakeholders were asked what percentage of land needs to be clear of invasive Spartina at their local sites and Bay-wide. The average response for local eradication goals was 77% (mode = 100%), and for Bay-wide the average was 82% (mode = 100%). Over 40% of the respondents considered complete eradication (i.e., 100% removal) as the goal, and 64% of the respondents had the same goal Bay-wide and locally. We believe this reflects an extremely high level of consensus regarding the goals of eradication (H3), especially compared to other conservation management issues (e.g., large carnivore management) where stakeholders have extreme levels of disagreement about goals (Kellert et al. 1996).

Figure 1(a) shows the distribution of organization types and Figure 1(b) reports Spartina management roles. Federal and local government agencies represent the two largest types of government actors because Spartina is found on public lands like National Wildlife Refuges and regional parks. The U.S. Fish and Wildlife Service provides permits for endangered species like the Ridgway’s rail (formerly known as California clapper rail), and ISP includes university-based researchers to integrate science. ISP contracts with consultants to conduct most of the eradication and restoration planning and implementation. This diverse set of stakeholders contributes a variety of specialized skills and capacities to Spartina management; they are not all doing the same thing. ISP also involves a diversity of activities, especially restoration and eradication. The contingency framework uses the term “network competencies” to describe this range of organizations providing many different specialized skills to Spartina management (H4). In this case, the Coastal Conservancy serves as the NAO that coordinates and funds this diverse set of actors.

**Hypothesis 5: centralized policy networks**

A “name generator” network question asked each stakeholder to identify the other organizations with whom they communicate. A total of 80 (55%) respondents answered the network question, and named an average of 4.1 network contacts with a range between 1 and 20. The data was assembled into an undirected, binary network where nodes were individual organizations and links were communication ties. The resulting network includes 97 organizations and 368 links, with an average degree (number of links) of 3.74.

Figure 2 visualizes the network with green nodes as the core actors, blue nodes as the periphery, and node size scaled by degree. The core nodes include the ISP, the California Coastal Conservancy, and Olofson Environmental as the sponsors and primary contractor for the project. Also included are some of the major public agencies who own land where Spartina occurs, such as the two National Wildlife Refuges, East Bay Regional Parks, and the cities of San Mateo and Alameda.

We measure centralization by quantifying the variation among the centrality of individual nodes in comparison to the maximum centrality that would exist if all organizations were only connected to one central organization (a “star” network). Network centralization measures range from 0 to 1, where 0 means all nodes have the same level of centrality and 1 indicates the maximally centralized network. We use three standard measures of centrality (Freeman 1979)—degree (number of connections); betweenness (number of shortest paths between all other pairs of nodes that the given node lies on); and eigenvector (a metric where high centrality indicates that the node is tied to others that also have a high centrality).

To characterize the core-periphery structure of the network, we use a “fitness” measure that represents the correlation between the empirical network and the best possible fitting “ideal” core-periphery model (Borgatti & Everett 2000). The higher the fitness, the more the network can be described as having a dense, interconnected core and an outer, disconnected, periphery. The core-fitness algorithm also identifies the set of organizations...
Figure 2 Total and core policy networks for invasive Spartina project.
that are in the core of the network, and those in the periphery.

For each of these descriptive centralization measures, a conditional uniform graph (CUG) test analyzes whether the empirically observed network is more centralized than the average centralization expected from a sample of 5,000 graphs randomly generated with the same number of edges as found in the empirical network (Butts 2008). Crucially, the random graph simulations forbid ties between two actors who did not respond to the survey, which eliminates the possibility that our networks appear more centralized because we were unable to observe relationships among pairs of peripheral actors. All of the CUG tests show that the empirically observed network is outside the 95% confidence interval of the sample of random graphs, which means that the ISP network is far more centralized than would be expected from the random null model (see Supplementary Material for methods details).

**Hypothesis 6: perceived effectiveness**

The survey measured perceived effectiveness with the following question: How effective has the Invasive Spartina Project been for achieving the following goals? (1 = Not effective at all; 5 = Very effective). Respondents rated 12 goals: coordinating treatment, monitoring *Spartina* levels, providing personnel, providing treatment information, coordinating restoration, providing restoration information, funding, scientific research, managing permitting, integrating broader ecosystem goals, analyzing environmental effects, and species management. Since the answers to these questions are highly correlated, we averaged their responses to create a highly reliable overall "ISP effectiveness" scale (Cronbach’s $\alpha = 0.92$). Given the reduction in *Spartina* levels accomplished by ISP, it is no surprise that the mean of the effectiveness scale $= 4.0$. Although there are not significant differences between the individual goals (Figure S3), the eradication aspects of the program receive the highest evaluations, followed by the more recent restoration activities. Species and ecosystem goals receive the lowest effectiveness rating, reflecting a conflict between *Spartina* management and the fact that *Spartina* provides habitat for the endangered Ridgway’s rail and thus constrains eradication efforts (Lampert et al. 2014).

**Discussion**

The ISP case study provides insights into the role of network governance in invasive species management. In the *Spartina* case, the ISP represents a NAO mode of network governance centered on a core set of organizations coordinated by the California Coastal Conservancy. The effectiveness of the ISP is supported by four critical contingencies that exist in the *Spartina* case. The analysis makes a contribution by integrating a theoretical framework from public administration to help analyze the “institutional fitness” of different modes of network governance relative to key social parameters. We provide a substantive proof of concept that under the right conditions, a local collaborative partnership coexists with a centralized governance network.

The contingency framework also offers the basis for practical recommendations. NAO governance could be effective for other conservation problems with similar critical contingencies. For example, *Spartina* management in Willapa Bay, WA did not begin to make headway until the Washington State Department of Agriculture was designated as a NAO to coordinate other actors and serve as an information clearing house (Hedge et al. 2003), and conflict continued until there was agreement on herbicides as the most effective control method. Another lesson is that managers can facilitate the effectiveness of a particular governance mode by creating the right conditions. For example, coordinated scientific research in partnership with stakeholders can be used to develop consensus on the extent, causes, costs, and appropriate control methods.

The theoretical and empirical limitations of this analysis suggest important steps for future research. Comparative case studies across different invasive species management contexts are needed to calibrate the critical contingencies, and link them to network structure and effectiveness. Reflecting its social science roots, the contingency framework does not explicitly consider how ecological variables might influence critical contingencies. The NAO form of governance may not be effective for conservation issues with fundamentally different ecological parameters. Epstein et al. (2015) identify the spatial, temporal, and functional characteristics of social–ecological systems as key biophysical variables that should be integrated into a broader theory. *Spartina* spreads fairly slowly over a relatively small geographic range, with the spread of seeds governed by tidal flows; hence the number of actors remains manageable for the NAO mode of network governance. An extreme contrast is the New Zealand mud snail, which is spread quickly and globally through many and diverse transport mechanisms (Alonso & Castro-Diez 2008). Managing such a species requires cooperation from myriad organizations and individuals, for example anglers using different gear in infected waters or freezing infected equipment to kill the tiny snails.

Linking ecological dynamics to governance and policy network dynamics is an important theoretical frontier...
going forward, in order to develop a social–ecological approach that will help diagnose appropriate network governance for different types of conservation problems. Such theoretical development would be applicable not only to invasive species, but other conservation management problems where dynamic spatial processes create interdependence among stakeholders, and thus require coordinated management decisions. Examples include plant pests and diseases, species that migrate over different spatial and temporal scales, and fire management, among others. Spartina demonstrates the importance of analyzing the intersection between ecology, economics, and governance for understanding management effectiveness for spatial ecological problems that require cooperation.

**Supporting Information**

Additional Supporting Information may be found in the online version of this article at the publisher’s web site:

- **Figure S1** Spatial distribution of Spartina in 2012 (from Invasive Spartina Project).
- **Figure S2** Distribution of centralization scores from conditional uniform random graph tests.
- **Figure S3** Perceived effectiveness of invasive Spartina project.
- **Table S1** Results of conditional uniform random graph tests for centralization measures.

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