Integrating Governance and Quantitative Evaluation of Resource Management Strategies to Improve Social and Ecological Outcomes

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In this article, we examine how governance can be more effectively integrated with quantitative evaluation methods in applied resource management. Governance refers to how societies organize to make decisions in ways that influence management choices (e.g., harvest allocation), such as levels of participation, the inclusion of different types of knowledge, and legitimacy of processes that lead to decisions. Using a fisheries example, we show that a failure to consider the governance context for quantitative evaluation of alternative management strategies may lead to unexpected consequences or break points in decision-making, bias estimates of risk and returns from management choices, and mask the potential for undesirable social and ecological outcomes.

Keywords: conservation, ecosystem management, fisheries, modeling, natural resources

The complexity of threats facing marine environments has led to escalating calls for ecosystem-based management (EBM; Fulton et al. 2014, Levin et al. 2016a, Marshall et al. 2017). Such appeals frequently highlight the importance of quantitative tools and simulation models (e.g., Kaplan et al. 2018), often with a focus on linking ecological, economic, and sociocultural analysis. Despite the rapid advance of scholarship on and implementation of EBM tools and approaches (see Levin and Poe 2017), the critical importance of governance is often overlooked (Bundy et al. 2017).

Governance refers to how institutions and social norms shape culture and societal behavior and decisions; inform who is authorized to make decisions about and take action on natural resources; and influence what will be conceived as politically, economically, and environmentally acceptable (see Oakerson 1992, Delmas and Young 2009). Governance is directly connected to the form and function of resource management. Therefore, undesirable outcomes of resource management may result when decisions are made without evaluating the broader governance context of the system at hand.

Governance is not commonly considered in quantitative evaluation. Applied researchers and practitioners have developed ways to incorporate social dimensions when assessing potential outcomes of management decisions and to address implementation errors in simulation models (see Fulton et al. 2011, Kaplan et al. 2012, Plaganyi et al. 2013, Grêt-Regamey et al. 2017). However, quantitative simulations typically emphasize social factors in economic terms, such as analyses of fleet dynamics or implicit indicators of economic costs of management (e.g., crop yields, harvested biomass) on different resource actors. This may limit the efficacy of quantitative decision tools for several reasons. For example, harvesters (e.g., small- or large-scale fishers) are influenced by more than profit maximization when making decisions (Poe et al. 2015). In addition, there is significant variation across contexts in the design, function, and influence of institutions (or rules) that determine how resources are used (Kooiman et al. 2005, Degnbol and McCay 2006, Chuenpagdee 2011). Finally, developing and selecting among management strategies (including what data, knowledge, or harvest rules are used to set quotas or limits on fishing duration) does not occur in isolation from the politics of decision-making (Fulton et al. 2011, Poe et al. 2015, Thornton and Kitka 2015, Essington et al. 2017, Levin et al. 2016a).

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In the present article, we examine how governance can be more effectively integrated into the quantitative evaluation and simulation modeling used in applied resource management. We use experiences with management strategy evaluation (MSE) in a fisheries context to examine this challenge. MSE is the evaluation of management strategies using simulation modeling (see supplement A). Specifically, MSE allows analysts to explore diverse trade-offs and outcomes, and the consequences of uncertainty on these outcomes, based on an analysis of a large number of alternative management strategies. As one example of a quantitative decision support tool to evaluate alternative management actions, MSE provides an important advance over a business-as-usual approach. MSE has the potential to integrate a broad set of parameters that is limited only by the vision, knowledge and objectives of those involved in its application. MSE is being applied to fisheries, as well as to other resource management fields (Mapstone et al. 2008, De Oliveira et al. 2009, Bunnefeld et al. 2011, Punt et al. 2016).

We illustrate the value of incorporating attributes of governance systems into quantitative decision support tools using a case study of a fishery in British Columbia, Canada. We use a case study as an example to explore how governance attributes could be incorporated into a quantitative tool and to encourage similar inquiries in other fields and resource management settings. We highlight broader insights offered by this example while recognizing that different settings will yield different governance and evaluation challenges.

First, we synthesize the importance of governance and governance context in resource management evaluation and summarize key governance attributes relevant to quantitative decision support tools and simulations. In doing so, we highlight two specific attributes, compliance and inertia, as useful entry points to understand how potential outcomes might vary across governance contexts, and as touchstones to consider governance in quantitative models (see also Fulton et al. 2011, Brown et al. 2012). We then illustrate how governance can be reflected in the various stages of a hypothetical fisheries management evaluation process and show how the utility and accuracy of quantitative assessment can be diminished or prone to unanticipated outcomes when the influence of the governance context is overlooked (see also Degnbol and McCay 2006). Finally, we offer insights on pathways forward and constraints on improving quantitative decision tools for applied resource management.

Governance, compliance, and institutional inertia

Governance refers to the arrangements and processes (e.g., top-down, collaborative) through which societies make decisions, including about natural resources (Glasbergen 1998, Lemos and Agrawal 2006). Institutions and decision-making processes are influenced by cultural values and societal preferences, and they inform who is authorized to make decisions and take actions; moreover, these values and preferences influence what will be conceived as politically, economically, and environmentally acceptable (Jentoft 1989, Acheson 2006, Delmas and Young 2009).

Box 1 summarizes a suite of governance attributes that emerged from empirical research in the social sciences and that can be used to both explain and assess human dimensions and social responses in particular contexts (see supplement B for an additional overview of selected relationships among governance attributes and arrangements). For example, the levels of participation by different groups in decision-making are often used to measure engagement with a process, beyond simple information provision or awareness (Fujitani et al. 2017). Similarly, complex resource management challenges often require the use of different types and sources of knowledge. Opportunities for knowledge integration or coproduction (Willyard et al. 2018) serve as a measure for collaboration and shared learning. The extent to which these attributes are applied ultimately influences management outcomes because they change the nature of interactions between people, institutions and natural resources.

Although governance attributes are well defined and can be measured, parameterizing individual governance attributes and their influence within quantitative models is difficult. To overcome this challenge, surrogates for governance are needed, and we draw attention to two that are relevant to resource management and evaluation: compliance and inertia. *Compliance* (e.g., by resources harvesters) is the extent to which individuals adhere to the expected or agreed on the rules of the game (Epstein 2017). *Inertia* refers to the failure of resource managers to adapt their rules—for example, harvest rules—in response to new information or conditions, the inability of the evaluation process to react to new conditions, or the choice to deviate from available evidence. Inertia could potentially also increase if decisions involve more collective action and slow the decision process down. Inertia is therefore a measure of inflexibility, such as when quota allocations are not reduced to protect short-term economic interests (see Copes 1986, Smith et al. 1999). Although compliance and inertia are not attributes of governance per se, their level or value in a system is tightly connected to and reflects that system's governance attributes. Furthermore, compliance and inertia describe behavior by actors in a natural resource management system that can be simulated in decision support tools.

Compliance and inertia are relevant to resource management and evaluation for two key reasons. The first is theoretical. Substantial literature points to a relationship among governance attributes (see box 1, supplement B) and both institutional inertia and stakeholder compliance (see Ostrom 1990, 2005). Notably, common property scholars show that compliance is affected by several elements of natural resource management systems, including participation in the design and implementation of management regulations, perceptions about the appropriateness of regulatory frameworks, and even a sense of guilt or fear about following rules of the game (e.g., harvest regulations; Hatcher et al. 2000,

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Box 1. Selected governance attributes and their definitions.

Access involves the ability of different actors (e.g., resource users) to gain and maintain resources (through time and space), as well as the decision-making processes and the resources needed to engage in deliberation and dialogue.

Efficiency refers to governance processes and arrangements that ensure the best use of existing capacity (e.g., people, resources and time) in a manner that fosters the best possible outcomes.

Equitability requires that those engaged in a governance process, including vulnerable groups, feel their interests are fully reflected in decisions considered in the decision-making process.

Flexibility or *adaptability* refers to governance arrangements that are oriented toward uncertainty and abrupt change, enhancing learning processes to deal with the complexity of social and ecological systems, promoting experimentation and innovation, and supporting cross-scale institutional links.

Knowledge coproduction is the collaborative process of bringing diverse knowledge sources and types together to address a defined problem, and to build an integrated understanding of that problem.

Legitimacy refers to a belief that a rule, leader or institution has the right to govern, and therefore an acceptance of a particular governing authority.

Participation means that all key interests and those most affected by particular decisions have a meaningful opportunity to fully engage, as they are interested and able, in decision-making in governance processes (i.e., meaningful participation is more that information provision or awareness).

Stability (rule of law) implies governance processes that are consistent with relevant provisions, policies and legislation associated with a particular problem context.

Note: The definitions are adapted from Glasbergen (1998), Kooiman and colleagues (2005), and Lockwood and colleagues (2010).

Siddiki et al. 2012). More generally, the institutional analysis and development framework (see Ostrom 2005, McGinnis 2011) points to the individual and community level drivers that determine compliance with institutional or regulatory expectations (e.g., the local action arena) that may include participation, rights, and conflict resolution opportunities (see Ostrom 2005, Siddiki et al. 2012).

Similarly, allied literatures from institutional economics and common property resources (North 1990, Ostrom 1990) offer empirical insights on questions of stability and change in institutional frameworks. In the present article, inertia is conceptualized as stickiness or the inability of institutions, as human-devised rules in use, to formulate timely responses to change (e.g., in resource stock sizes; see Rosenschöld et al. 2014). As with compliance, key mechanisms of inertia link to broader governance processes (see box 1, supplement B) and include transaction costs (including trust) of enacting change, relations of social power that enable or constrain action, and perceptions about the legitimacy of the institutional system itself (see Rosenschöld et al. 2014 for a synthesis).

The second reason for emphasizing compliance and inertia is practical. Resource managers are confronted with issues of rule compliance and challenges of decision inertia on a regular basis (see Hilborn 2007). For example, compliance can manifest in relation to monitoring and enforcement, implementation of policy decisions, or use versus protection of natural resource stocks (Epstein 2017, Alexander et al. 2018). For resource managers, compliance and the challenges of making decisions in a timely manner are tangible artifacts of the governance context.

Figure 1 provides a visual representation of the relationships among governance context and attributes, compliance, and inertia in a typical fisheries management cycle composed of assessment of stock status (use of models to estimate current abundance and trends), management decisions (e.g., control of harvest), harvest activities, and consideration of ecosystem dynamics. In the context of this management cycle, compliance with harvest rules is recognized as an outcome of a governance context that values and builds opportunities for participation, trust building, the inclusion of more knowledge and perspectives as part of the monitoring and feedback processes (see also box 1).

Complex and negative social outcomes can also be associated with governance attributes. Specifically, there are potential break points (i.e., unanticipated or undesirable outcomes; e.g., the red flag in figure 1) at different steps in the management cycle that influence quantitative evaluation of alternative management strategies. For example, more collaborative forms of governance (see supplement B) generally have higher transaction costs and may be less efficient, leading to a situation that could undermine compliance or lead to a failure to take action to solve a problem. In this regard, governance clearly influences the behavior of fishers, which, in turn, affects outcomes and future governance processes (see Degnbol and McCay 2006, Hilborn 2007). Similarly, some governance may involve low rates of participation, increased uncertainty with regard to levels of trust and overall legitimacy of the process, more rigid access rules, and, ultimately, potentially less flexibility with regard

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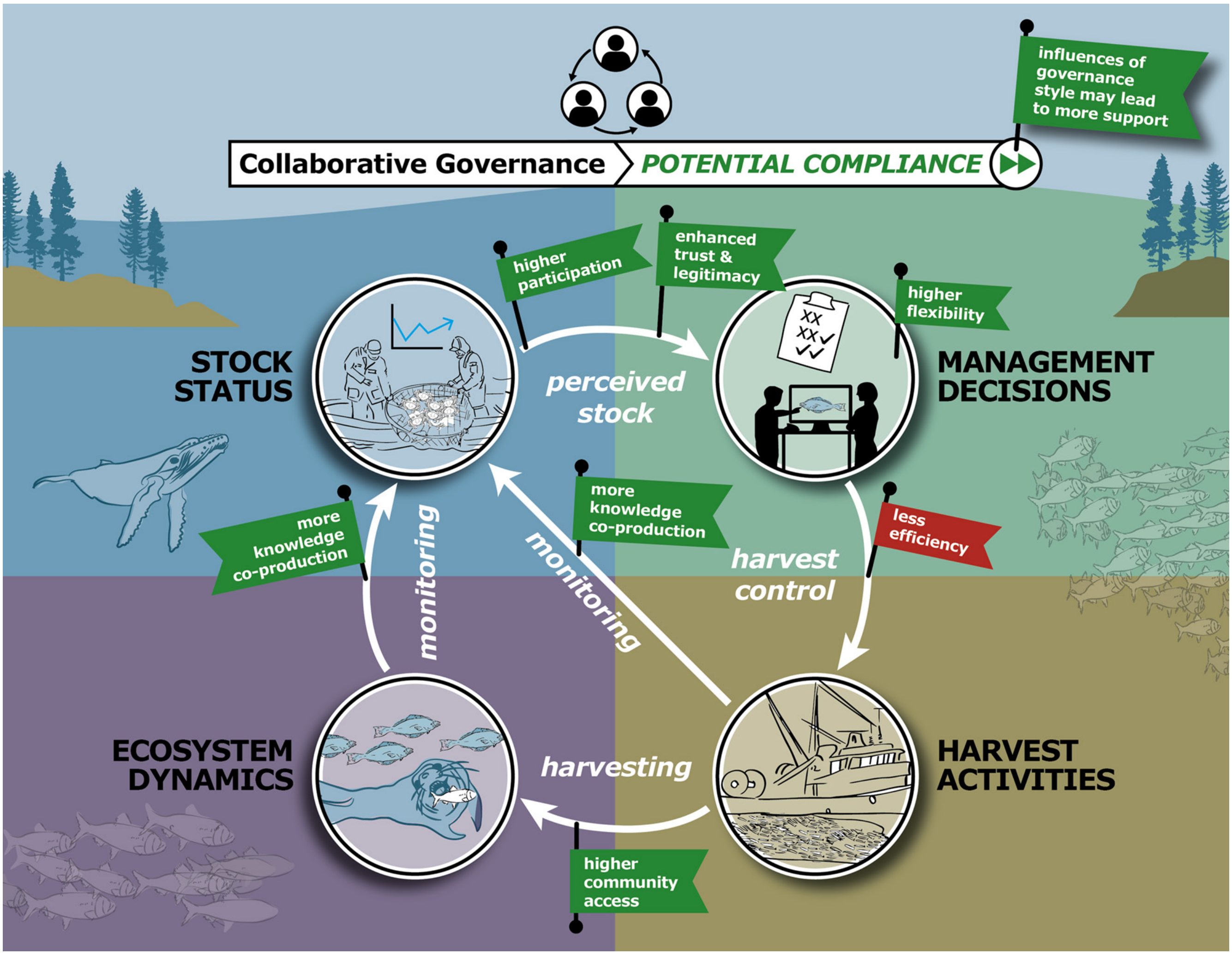

Figure 1. Governance, compliance and inertia in a typical management cycle.

to management alternatives (i.e., inertia). Notably, such approaches are not *de facto* less flexible. In some circumstances, top-down processes might enable a more rapid response to an issue because agreement among stakeholders on a response to an unexpected outcome is not necessarily required. Still, the potential for more compliance issues in this governance context can be elevated.

Operational and biological models can be used to simulate such management systems, including each stage of the cycle. As is illustrated in figure 1, the relationships among governance context and management outcomes are nonlinear, and these social conditions are difficult to isolate as variables and subsequently model (see Plagányi et al. 2013, Essington et al. 2017). For example, warnings of an impending fishery closure could lead to overfishing and exacerbate compliance problems. Our aim is not to formally test hypotheses about which set of governance attributes and processes leads to better or worse outcomes in terms of compliance and inertia. Rather, we illustrate that it is possible (and necessary) to integrate governance considerations into applied resource management. We turn now to our illustrative model of a forage fish fishery.

A heuristic model of governance, inertia and compliance in an applied fishery management evaluation

We illustrate how governance can be integrated into applied resource management by modeling compliance and inertia in quantitative management evaluation for a hypothetical forage fish fishery (see supplement A). We use a specific model to illuminate the general issues emerging from the integration of compliance and inertia into conventional quantitative evaluations such as MSE. The highly stylistic and simplified model that we use is motivated by the Pacific herring (*Clupea pallasii*) fishery in Haida Gwaii, British Columbia, Canada (Department of Fisheries and Oceans 2015, Jones et al. 2016, Levin et al. 2016b, MacCall et al. 2018, Punt et al. 2018).

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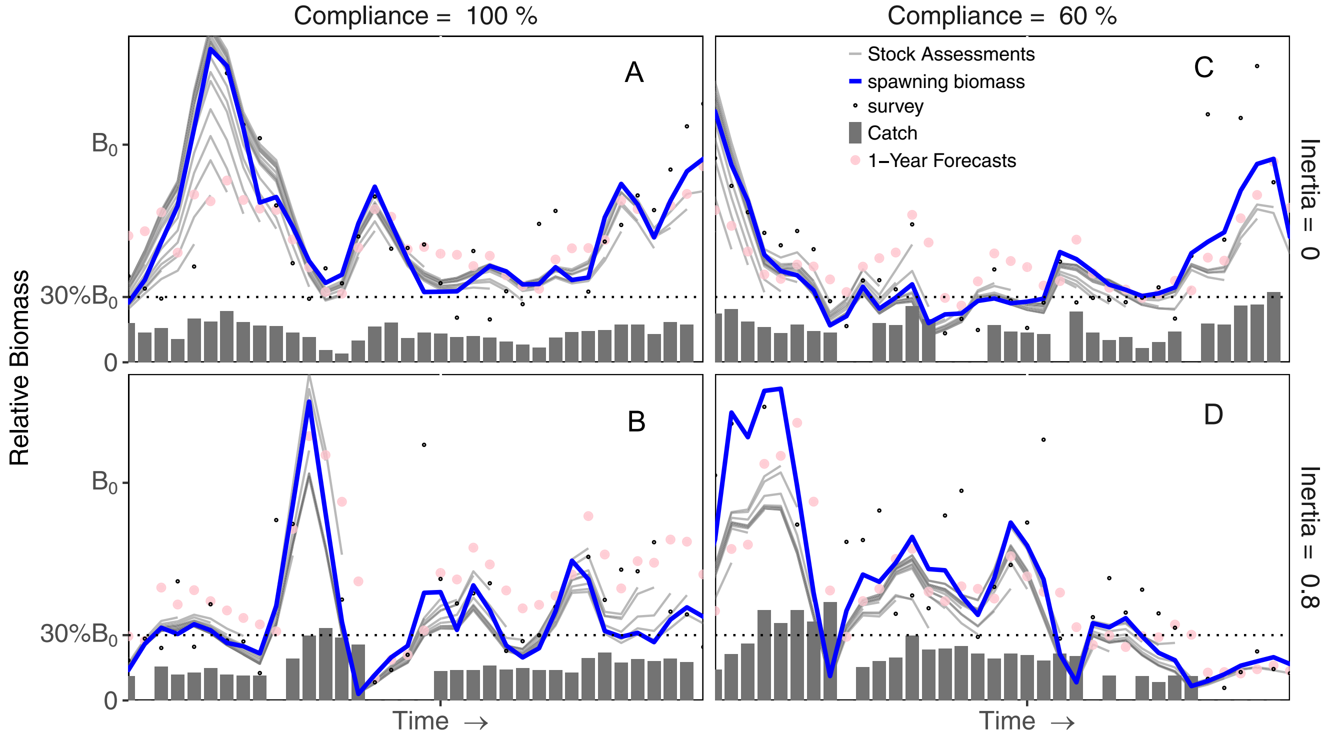

Figure 2. Examples of effects of compliance and inertia on biomass trends and harvest through time (years). Shown are single simulations after discarding the first 10 years (a burn-in period). These represent one of 300 runs for a single pixel in figure 3, which illustrates how these trends translate to average measurable quantitative performance metrics. See supplement C for model details.

This evaluation involves an age-structured operating model with stochastic recruitment, a simple stock assessment model, and harvest control rules, based on the existing rules for herring and modified to fit within the guidelines from the Lenfest Forage Fish Taskforce (Pikitch et al. 2012). In this case, we use 30% of the average unfished biomass (B_0) as the threshold for fishery closure, 25% as the maximum target harvest rate, which is applied to forecast biomass, and a tapered harvest rule such that if the fishery is expected to deplete biomass below 30% of B_0, the harvest is adjusted in an attempt to leave exactly 30% of B_0 after fishing. For simplicity, we model inertia as the degree to which managers fail to adjust harvests despite estimated stock declines resulting from a combination of overharvest, environmental effects on productivity or prior stock-assessment errors. We model compliance as the proportion of allocated harvest relative to actual harvest (i.e., how much the harvest exceeds the quota, on average). Further details on the model are provided in supplement C, and detailed descriptions of the fishery and ecosystem are found in MacCall and colleagues (2018) and Punt and colleagues (2018).

Our results (see also supplement C) reveal that compliance and inertia—used in the present article as surrogates for governance—may have dramatic effects on the outcome of MSEs (figures 2 and 3). Figure 2 illustrates the effects of compliance and inertia on biomass trends (the blue line) and harvest (the gray bars). Figure 3 illustrates the average outcomes from 300 simulated 25-year projections under various compliance-inertia scenarios. We consider these results and their implications below, and with reference to figure 1.

The default assumption of most MSEs is that compliance is high and inertia is low (although some work does challenge these assumptions; see Dichmont et al. 2003, Fulton et al. 2011). Under this conventional assumption, the fishery in our model would be closed about 10% of the time (figure 2a, upper left corner of figure 3a). However, such assumptions do not reflect the uncertainty in stock assessments, and managers may have to make in-season adjustments while fisheries are taking place. Harvesters can perceive this as managers getting it wrong, increasing the likelihood of conflict (e.g., among harvesters, or between groups of harvesters and management agencies). Indeed, increasing inertia and decreasing compliance in the model leads to dramatic increases in the frequency of fishery closures (figures 2b–d and 3a) and modest increases in the annual variability of catch (figures 2b–d, 3a, and 3c). Over time, reduced compliance and resistance in the system will manifest in governance breakpoints (see figure 1), and subsequently in the reduced efficacy of stakeholder boards and other processes meant to increase participation.

Our results also show that excluding governance from MSE has the potential to lead to biased estimates of risk

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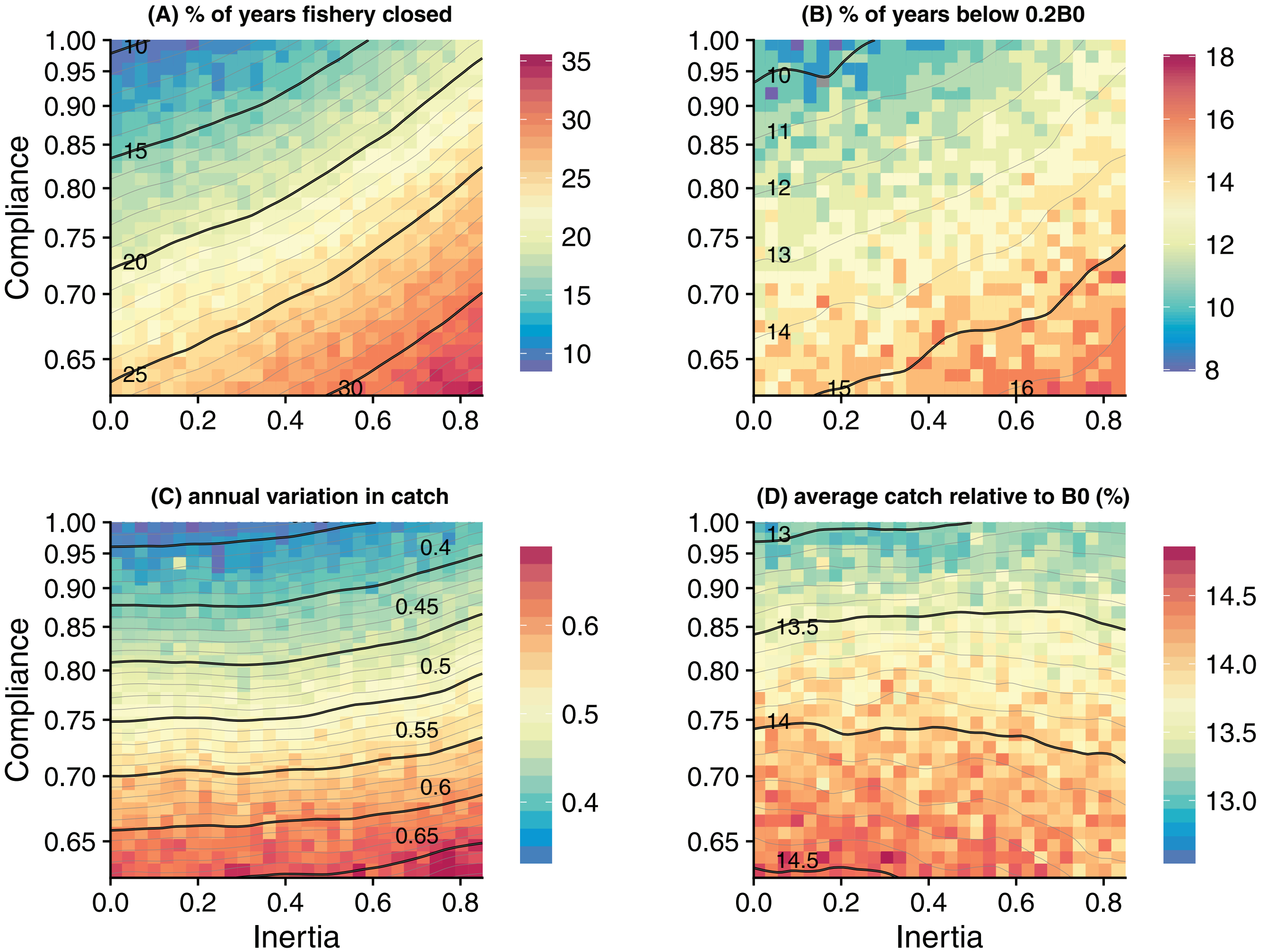

Figure 3. Average outcomes for performance metrics from 300 simulated 25-year projections under various compliance-inertia scenarios. See supplement C for model details.

and returns. For example, a decrease in compliance from the default assumption of 100% to about 72% leads to a doubling in the years the fishery is closed (figure 3a). If we model less compliance, outcomes may be more realistic, encouraging managers to focus more on the issues that drive compliance. This might include more collaborative sharing of knowledge about stock assessments and building more trust in the process so compliance can increase through time (see figure 1).

In addition, our results show that as compliance declines or inertia increases, catches can increase (see figure 3d) but this results in an increase in the frequency of stock collapses (biomass dropping below 20% B_0; figures 2 and 3b). Therefore, although inertia may exist in an effort to buffer against significant short-term changes in catch (e.g., large annual variability), in the long term, it actually has the opposite effect by accelerating or exacerbating population declines (see figures 2 and 3c). The resulting higher frequency of collapses more than offsets the short-term benefits of inertia, leading to modest increases in long-term variability in catch. In a similar manner, noncompliance may result from perceptions that a stock is underused but can result in frequent fishery closures. Governance processes that assume but do not seek to actively foster group compliance (see figure 1) are likely to be overwhelmed by individual behaviors of resistance or that seek to maximize short-term gain. Therefore, accurately estimating compliance and inertia (as surrogates of the broader governance context) can help to avoid an overly optimistic view of management strategies and the potential for negative social and ecological outcomes.

As is reflected in figures 2 and 3, the quantitative modeling of relationships among governance surrogates (compliance and inertia) and outcomes is complex. Social conditions and individual behaviors are difficult to isolate as variables and subsequently model. However, our results do highlight the potential for unanticipated or undesirable outcomes (i.e., breakpoints) that are embedded in different stages of

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quantitative assessment, including the MSE we use in the present article to consider a hypothetical forage fishery.

Models, governance, and outcomes

In natural resource management, uncertainty is inherent even in the most careful evidence-based decisions. No single governance process will yield consistent outcomes (see supplement B). Different governance contexts reflect different social trade-offs with ecological, cultural, and economic implications. We have used a hypothetical fishery and associated quantitative evaluation to illuminate governance issues, specifically using inertia and compliance. Other fisheries and natural resources will vary from the example we examine in the present article, but the general insights from our analysis are broadly applicable.

We show that a lack of consideration of governance can lead to a break down in the utility and accuracy of quantitative evaluation and modeling in the applied resource management cycle (figure 1). For example, beneficial outcomes over the long term are expected when people are legitimately involved in the decision processes (see box 1) that affect them (Kooiman et al. 2005). However, there are trade-offs between implementation effectiveness and efficiency of management strategies with increased collaboration (e.g., inertia). Conceivably, bad governance as perceived by various actors in a system (e.g., lack of opportunity to participate) could yield a reasonable outcome, such as when there is an urgent need for higher-level authorities to take quick action to address an unexpected and severe stock decline. Therefore, as our hypothetical model shows, efficiency (e.g., economic outcomes) is not necessarily the best indicator in management evaluation because it can mask the benefits of other key governance attributes that have higher transaction costs (e.g., trust building, equity across actor groups, building capacity for adaptiveness). There are also instances in which the management system may not comply with the evidence-based assessment, resulting in inertia with regard to achieving social or ecological objectives. The reasons for this are not likely to be found using a lens of individual rational economic behavior but, rather, in the messy world of governance in which values, norms, institutions, and competing visions are at play.

Hard and fast rules do not exist for how governance attributes such as knowledge, legitimacy, or flexibility (see figure 1) influence compliance and inertia. Governance attributes will manifest differently depending on the social and ecological context (e.g., number and type of fishers, complexity of fleet arrangements, stock characteristics). Context is always crucial (see Honadle 1999) and trade-offs often exist among attributes. For example, a governance process that appears relatively efficient and characterized by a degree of stability (rules generally clear and applied as intended) may come at the cost of legitimacy if it is implemented primarily by a central authority. A governance process that emphasizes participation and access to decision-making will likely have high transaction costs and will, therefore, be perceived by some as inefficient. Moreover, flexibility may be desirable, but trade-offs among options are difficult to identify unless flexibility can be modeled (i.e., no management strategy if there is infinite flexibility). Tracing the pathway from governance attributes to specific social and ecological outcomes is therefore very difficult (see Plummer et al. 2017a, 2017b).

Explicit consideration of governance highlights opportunities to add to existing best practices in quantitative evaluation (see Punt et al. 2016, Essington et al. 2017). In the present article, we add the need to consider governance more generally in applied resource management and, more specifically, to conceive of quantitative simulations and models as a potential focal point for engaging with stakeholders. This form of knowledge coproduction reflects a collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and to build an integrated or systems-oriented understanding of that problem (Armitage et al. 2011, Willyard et al. 2018). There may be other specific and tractable ways to enable knowledge coproduction in quantitative assessments. Empowering harvesters and community members to participate in the design of simulation models or define appropriate points in evaluation processes to reflect on objectives are ways to do so. Identifying alternative hypotheses to be included in operating models is another way, as is considering the range of uncertainties with those most affected by management decisions. Indeed, these objectives, hypotheses, and operating models need to be place based to truly account for critical aspects of the social–ecological system (Sterling et al. 2017, MacCall et al. 2018, Van Putten et al. 2018).

As our analysis illustrates, we need to model applied resource management decisions as linked social–ecological systems with unique and influential institutions, cultural expectations, and prone to politics and power imbalances (Berkes and Folke 1998, Österblom et al. 2013, Thornton and Herbert 2015, Levin et al. 2016a). As such, our work highlights the value of interdisciplinary teams for quantitative evaluation and greater engagement with communities and user groups affected by decisions derived through those decision processes (see Girondot and Rizzo 2015, Woodhouse et al. 2015). The Ocean Modeling Forum (oceanmodelingforum.org), the catalyst for this collaborative article, is one example of an interdisciplinary team whose membership and perspectives are diverse (see Francis et al. 2018, see also MacCall et al. 2018). In such contexts, outcomes are more likely to be perceived as legitimate and can build trust among harvesters, Indigenous peoples, coastal communities, scientists and decision-makers. Such contexts are far less likely to limit opportunities to identify desired outcomes (i.e., increased compliance and decreased inertia, decreased conflict, increased fish stock health).

Ultimately, the core of any quantitative evaluation should be as much a learning process as it is a technical exercise. The broader goal should be to feed into adaptive governance processes (Folke et al. 2005, Armitage et al. 2009, Fujitani et al. 2017) and to engage a full range of stakeholders (see

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also Smith et al. 1999, Stephenson et al. 2018). However, we caution that even if attentive to governance, quantitative evaluation may still struggle to reflect the interests of all key actors in or affected by management decisions (e.g., vulnerable or marginalized groups) or to identify surrogates for all relevant attributes of governance. Complexity and uncertainty mean that even the most careful evidence-based decisions cannot be fully robust to the fact that institutions well outside of the management system can significantly or unexpectedly influence outcomes. These might include, for example, international market dynamics, new legislation, higher court decisions, or in the cases of North America and Australia, for example, the resolution of Indigenous treaty or resource or land claims.

Conclusions

In extractive resource sectors (e.g., fisheries, forestry), alternative management strategies are frequently evaluated using quantitative decision support tools, simulation models, and scenario evaluation (Phillips et al. 2004, De Oliveira et al. 2009, Bunnefeld et al. 2011, Kaplan et al. 2013). By simulating and quantitatively evaluating management strategies (Punt et al. 2016), scientists can provide useful information for decision-makers seeking to support EBM and address trade-offs among ecological, economic, and sociocultural objectives (Stephenson et al. 2018). The present article is a first step in examining how to better integrate governance into quantitative assessments for applied resource management. We used compliance and inertia to explicitly consider the role of governance in decision-making about a fishery and to explore the opportunities and challenges in doing so.

There are no governance panaceas or blueprints that ensure ideal social and ecological outcomes in resource management (Ostrom 2007). This makes the importance of reflecting the influence of governance in decision-making all that more crucial, but it remains a largely unaddressed dimension of most quantitative and simulation efforts. People and their motivations to participate in decision-making are largely considered a black box, and their willingness to comply with a given set of management decisions is often reduced to a rational economic choice (Fulton et al. 2011).

Just as there are no governance panaceas, there is no single pathway to reflect governance context in quantitative evaluations for applied resource management. Governance, whether integrated into quantitative evaluation or not, is implicit in any management regime. However, a failure to consider the consequences of governance (good and bad) and its potential to create breakpoints in decision processes, will undermine the utility and predictive ability of quantitative evaluation and simulations of alternative management strategies.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

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