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Adaptive Governance of Social-Ecological Regime Shifts in Coastal Fishery Systems: A Case Study of a Potential Regime Shift in a Shrimp Fishery System in Northern Newfoundland, Canada

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Introduction

This working paper examines the governance implications of regime shifts in coastal fishery systems. Using an example from Northern Newfoundland in Atlantic Canada, we discuss the key sources of uncertainty for decision-making that attempts to enhance the anticipation and navigation of regime shifts, and situate these uncertainties in a governance context. Governance refers to the broader processes and institutions through which societies make decisions that affect the environment (Oakerson 1992). A governance lens provides us an opportunity to diagnose limitations in rules, decision-making processes, and management systems in new problem domains and identify avenues for action (Brunner et al. 2005; Folke et al. 2005). Navigating regime shifts – a substantial reorganization in system structure, function and identity that persists over time – is a challenging problem domain because regime shifts often involve a collection of intense and rapid changes to many system components at different spatial and temporal scales (Biggs et al. 2009; Crépin et al. 2012). The more intense and rapid changes are within a fishery system, and hence, likelihood of a regime shift, the greater the need for governance that is adaptive (Mahon et al. 2008). In coastal fishery systems prone to regime shifts, change and uncertainty are central themes (Adger et al. 2005; Selkoe et al. 2016). Consequently, we examine adaptive governance for regime shifts, where adaptive governance refers to a suite of processes (e.g., learning) and potential arrangements (e.g., networks) to respond to change and uncertainty in social-ecological systems (Armitage and Plummer 2010).

Coastal fisheries are linked social-ecological systems that include natural components (e.g. fish, ecosystems), human components (e.g. fishers, communities) and fisheries management components (e.g. policy, planning, research) (Charles 2001). Coastal fishery systems are dynamic, involving interactions at multiple scales, and highly vulnerable to intensifying pressures from effects of human and marine ecosystem interactions (Adger et al. 2005). Pressures related to climate change (e.g., ocean acidification and rising surface water temperatures) are exacerbating disturbances from human activities (e.g., overfishing, habitat degradation and nutrient loading) to produce dramatic social and economic consequences (Cheung et al. 2013; Möllman et al. 2015; Sumaila et al. 2016a). System-wide changes like this have been documented in many different coastal fishery systems such as fishery collapse (de Young et al. 2008), coastal hypoxia (Crépin et al. 2012), and coral bleaching (Scheffer and Carptenter 2003). For example, since the 1950s, the expansion of fishing and a ten-fold increase in fishing effort is leading to frequent crises (Sumaila et al. 2016a: 174). Job security in local fish harvesting and sea food production are becoming more precarious (Sumaila et al. 2016b). Many fishers and their families are leaving coastal communities temporarily or permanently for work, rapidly altering long-standing local economies, coastal cultures and livelihoods (Foley et al. 2015; Ommer and Team 2007).

Despite the mounting evidence for regime shifts as a social-ecological process of change, the scope of theoretical and empirical work remains limited to detecting and predicting ecosystem change and identifying its implications for policy and management (Crépin et al. 2012; Lade et al. 2013; Nayak et al. 2015). For example, regime shift literature often laments the difficulty of prediction and prevention of ecological regime shifts and makes recommendations to enhance data interpretation and modelling (e.g., Hughes et al. 2013; Groffman et al. 2006; de Young et al. 2008). Often, however, this perspective underrepresents the role for human behaviour and decision-making that trigger and exacerbate regime shifts, and hence, undermines our capacity to navigate them (Nayak et al. 2015; Crépin et al. 2012).

The involvement of people in regime shifts can be far reaching. For example, literature on the early 1990's Atlantic Cod collapse implicates overfishing and failures in governance to prevent the collapse as precipitating factors for what is considered one of the largest losses of biodiversity in history (Charles 1995; Hutchings and Rangeley 2011). Furthermore, this collapse affected 30,000 fishers and fish producers with tens of thousands more indirectly (Davis 2014; Perry et al. 2011: 433). Supporting fishers post-collapse cost over 1.9 billion dollars for the Canadian government (Davis 2015; Mooers et al. 2007). This example suggests that even with warnings of a potential collapse, fisheries managers seemed to have a limited capacity to anticipate and navigate to its full social-ecological effects (see Charles 1995; Davis 2015; Hutchings and Rangeley 2011).

If we want to learn how to better anticipate and navigate to regime shifts in fishery systems, there is value to incorporating adaptive governance in theoretical and empirical studies. By linking adaptive governance to studies of regime shifts we can better interpret how to use rules, decision-making processes, and management systems to navigate the intensifying, non-linear and rapid changes inherent to systems prone to regime shifts. Such studies, however, necessitate an understanding of how, under conditions of change, governance actors can make legitimate decisions in accountable decision-making processes, use different knowledge sources and foster social learning, determining scale and boundaries of the systems and fitting governance systems to the types of changes that occur in a regime shift. Before we turn to case where we examine these governance implications, we discuss adaptive governance and assess its use in Canadian fishery systems. Then, we synthesize elements of regime shift theory as an ecological and social-ecological concept.

Adaptive Governance and Canadian Fishery Systems

As a subset of environmental governance literature (e.g. Biermann et al. 2010, Lemos and Argawal 2006), the notion of adaptive governance is frequently recommended for governance of social-ecological systems (Brunner 2010; Chaffin et al. 2014; Folke et al. 2005; see Textbox 1 for definitions). The concept of adaptive governance is similar to that of environmental governance in that both involve institutions (i.e., informal and formal rules that constrain human behaviour, such as norms, values, policies, and regulations) and decision-making processes, with or without the government, through which societies make decisions that affect the environment (see Oakerson 1992). In addition, both adaptive governance and environmental governance are concerned with the social context of management interventions.

Adaptive governance is distinct in its assumption that the tight linkages between humans and natural systems produce dynamic social-ecological systems (Folke et al. 2005). This central assumption suggests the need for flexible and multi-layered institutions to respond to intensifying, non-linear and rapid changes (Dietz et al. 2003). Similar to flexible institutions, decision-makers typically integrate deliberate experimentation into their policy processes (i.e., willingness to implement and terminate decisions based on new knowledge of change) (Brunner 2010). In these ways, adaptive

Textbox 1: Adaptive Governance and Its Definitions

The notion of adaptive governance emerged from three distinct sources (Brunner 2010; Steelman 2015). First, a version of adaptive governance originated in social-ecological systems literature that argued for a modification of governance theory to address uncertainty and complexity (Chaffin et al. 2014). Second, adaptive governance emerged from Ostrom's (1990) work on institutions that recognized the need to make rules flexible and multi-layered to be able to manage changing conditions (Dietz et al. 2003). Third, policy scientists used adaptive governance to describe patterns of novel governing practices that seemed to be successful in steering change (Brunner 2010). These multiple sources reflect inter-related, but distinct literatures. As a result, there are several definitions.

Selected Adaptive Governance Definitions

A suite of processes (e.g., learning) and potential arrangements (e.g., networks) to respond to change and uncertainty in social-ecological systems (Armitage and Plummer 2010)

A range of interactions between actors, networks, organizations, and institutions emerging in pursuit of a desired state for social-ecological systems (Chaffin et al. 2014)

An institutional theory that focuses on the evolution of formal and informal institutional relationships for the management of shared assets (Nelson et al. 2008)

A pattern of practices that emphasizes decentralized decision-making by wider participation…and by applications of local knowledge sometimes supplemented but not replaced by scientific inquiry (Brunner 2010)

Selected Environmental Governance Definitions

The interrelated and increasingly integrated system of formal and informal rules, rule-making systems, and actor networks at all levels of human society that are set up to steer societies towards preventing, mitigating, and adapting to global and local environmental change (Biermann et al. 2010: 279)

A set of regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes (Lemos and Argawal 2006: 298)

A system of institutions, including rules, laws, regulations, policies, and social norms, and organizations involved in governing environmental resource use and/or protection (Chaffin et al. 2014) governance has greater potential to fit with system-wide changes that involves interactions at multiple scales.

The Canadian Context

For most of the second half of the 20th century, governmental departments supplied management to steer change in fishery systems with less attention to the broader processes of governance (Bryant and Wilson 1998). Management refers to the "design and implementation of operational decisions to achieve specific outcomes" (Armitage et al. 2012: 246). In many natural resource problems including those related to fishery systems, a limited attention to the broader governance context of management has produced social costs relating to compliance, enforcement and conflict (Armitage et al. 2012; Fulton et al. 2011; Hilborn 2007).

Since the late 1990's, however, Canadian fisheries management has begun to transform their practices that suggest decision-makers are considering the broader governance implications of their decisions. Highlights include comprehensive legislation and policies that explicitly acknowledge the need for sustainability (Ricketts and Harrison 2007), the use of participation of resource users in decision-making about policies and rules, and the acknowledgement of ecosystem interactions in planning and stock assessments (Webster 2009). In spite of this progress, critiques highlight two limitations. First, there has been a limited use of social science and other knowledge types to implement and appraise legislation and policy (Bailey et al. 2016; Foley et al. 2015). For example, catch limits have been implemented without consideration to resource users' understanding of the system which has led to non-compliance and overfishing (Wiber and Wilson 2009). Second, there is a problem related to the limited implementing of rules and management systems (e.g., multi-species management) that consider social-ecological interactions (Ommer and Team 2007; Ommer et al. 2012). For example, policies and integrated fisheries management plans discuss ecosystem-based management but have resulted, in practice, in single species management (Ommer et al. 2012). Budrea (2007) argues that this has reduced the local knowledge of species interactions (Budrea 2007). To respond to these limitations, literature critiquing the Canadian context continues to its recommend for more adaptive approaches to address intensifying complexity and change (e.g., Ommer and Team 2007; Ommer et al. 2012; Webster 2009).

Challenges in Adaptive Governance Theory

Adaptive governance is operationalized in decision-making processes through arrangements that involve resource sharing (e.g., human, financial, political and cultural) among different actor groups (Diduck 2010). Often, the goals of these processes are to share knowledge, learn, experiment together to integrate into decisions the diverse knowledge, perspectives and interests of system-wide actors (Folke et al. 2005). Adaptive governance theory suggests that flexibility, resource-sharing, and experimentation bring to bear a host of challenges related to accountability and legitimacy, the use of knowledge and social learning, the notions of fit and interplay, and scaling and boundary-making (Armitage and Plummer 2010; Folke et al. 2005; Steelman 2015; see Table 1 for definitions). These challenges are not exclusive to adaptive governance and can relate to management. However, we refer to these in an adaptive governance context (see Panel 1 for descriptions).

Table 1: Key Terms and Definitions in the Challenges of an Adaptive Governance Context

Term	Definition
Accountability	The extent with which decision-makers report decisions to the public and are responsible for when decisions produced are undesirable (Young 2009: 32).
Legitimacy	The acceptance and justification of decision-making authority conferred through social consent (Biermann et al. 2010: 283).
Knowledge Co-Production	The collaborative process of bringing a plurality of knowledge types together to address a defined problem and build an integrated or systems-oriented understanding of that problem (Armitage et al. 2011: 996).
Social Learning	The iterative reflections and negotiations of change in a group of people that inform complexity and uncertainty in dynamic systems (Keen and Mahanty 2006)
Scale	The spatial, temporal quantitative or analytical dimensions used to measure any phenomenon (Gibson et al. 2000: 218)
Boundary Determination	The establishment of appropriate planning or analytical domain in a given system (Adams et al. 2013)
Social-Ecological Fit	The notion that institutions and governance systems are likely to succeed (or fail) in relation to how they are designed for coupled systems of people and nature (Epstein et al. 2015: 34).

Panel 1: Selected Challenges in Adaptive Governance

Accountability and Legitimacy

In governance theory, accountability and legitimacy are characteristics of functioning decision-making processes they produce socially-expected outcomes (e.g., rules, management interventions and sanctions) (Crabbé and LeRoy 2008). When decisions are made with non-government actors and different types of knowledge, ensuring accountability and legitimacy is complicated (Glasbergen 1998). The public may not consider accountable non-governmental actors and may not perceive legitimate the decision-making by non-elected local authorities (Young 2009). A lack of accountability can lead to conflict and distrust and a lack of legitimacy can lead to non-compliance and delays in management implementation (Rhodes 1997). These are heightened in an adaptive governance context because the public can experience change as undesirable and decisions that accept change as harmful to their interests (Biermann et al. 2010). Conversely, the public may consider decisions more legitimate when they arise locally because the public can see their interests more readily in decision-making (e.g., incorporating fishers' preferences into the timing and content of catch limits) (Pares et. al. 2015). In addition, these decision-makers may be more accountable because they "literally have to live the consequences" (Brunner 2010: 322). This is important when people make controversial trade-off decisions about fishery systems (Hicks et al. 2013).

The Use of Knowledge and Learning

Different knowledge types are important for accurate and timely decisions about change and complexity (Ascher et al. 2010). The use of different types of knowledge can be operationalized in a few different ways. Governments can develop participatory mechanisms (e.g. consultation, public referral, co-management) to engage with the public (Diduck et al. 2015). Decisions-making using people's experiences, values and observations can be seen as suboptimal and conflict with well-established science (Ascher et al. 2010). Adaptive governance theory recommends social goals such as knowledge co-production and social learning (Armitage and Plummer 2010). When decision-makers work together to produce knowledge about a system, they often learn about different perspectives and can, as a group, decide about what can be known or not known about a system (Diduck 2010). This heightens the capacity for adaptation and can lead to more effective problem-solving (Berkes and Armitage 2010; Folke et al. 2005). However, problems arise when there are significant power asymmetries among actors, issues of representation, and the misrecognition of the demands, interests, and values of knowledge

co-producers (Barrett 2013; Dale and Armitage 2011).

Scaling and Boundaries-Determination

In social-ecological systems, multi-scalar interactions produce surprising effects at smaller and larger scales (Carpenter et al. 2002; Young et al. 2006). One challenge in adaptive governance theory is to mobilize knowledge and resources to adequately anticipate these interactions and effectively intervene (Steelman 2015).

However, an intervention at one scale may not work in another because the political, cultural, economic and social contexts of a problem may be scale-dependent (Brunner 2010; Steelman 2010). The interactions involved in a system is dependent on decision-makers' definition of a system and its boundaries. For example, interactions may extend beyond conventional planning regions (e.g. fishing area, coastal watershed). Boundary determination affects problem definition and the effectiveness of interventions (Pittman and Armitage 2016).

Fit and Interplay

In social-ecological systems, the notion of fit reflects the need to match governance systems with characteristics of a given social-ecological problem context (Epstein et al. 2015). Fit can refer to a spatial and temporal scaling match between institutions and the problem context or it can refer to the structural and procedural capacity of governance systems to address problems with certain qualities (e.g. non-linear change or cascading effects) (Galaz et al. 2009). With social-ecological change, scalar fit is challenging because a decision-making process may be unable to cope with disturbances because its jurisdiction is too small or large. Similarly, temporal fit is a problem when decision-making outcomes assume too short or long of a time span (Galaz et al. 2009). In addition, a governance system may not be set up to address non-linear changes or cascading effects, or may be set up in a way where too many decision-making processes, institutions and actors create an overly complicated interplay of rules and decisions which reduce, rather than enhance flexibility (Young 2008).

Regime Shifts Theory and Applications for Fishery Systems

A regime shift can be defined as a substantial reorganization in system structure, function and identity that persists over time (Biggs et al. 2009; Crépin et al. 2012). There have been other definitions that vary based on the characteristics detected in a regime shift (See Textbox 2). For example, many definitions of regime shifts include references to alternate stable states (e.g., Rothschild and Shannon 2004; Scheffer and Carpenter 2003). These definitions are problematic for coastal fishery systems research because the existence of alternate stable states in marine ecosystems is contested when regime shifts appear to be more gradual and linear, and yet result in a substantial shift in system structure, function and identity (cf. de Young et al. 2008; Scheffer and Carpenter 2003). Furthermore, there is a limited understanding of how alternate stable states relate to social-ecological systems (Lade et al. 2013). We use a less prescriptive definition because what matters to our analysis is that we distinguish a regime shift from the regular dynamism inherent in coastal fishery systems.

Social-ecological interactions in fishery systems are in a constant process of change. Disturbances can alter feedbacks, without reorganizing the whole system (Levin et al. 2013). Disturbances can include coastal development, fishing, ocean temperature change, nutrient level changes and atmospheric changes (Rothschild and Shannon 2004). Overtime, components in fishery systems adapt by reorganizing their relationships based on new information about a disturbance (Levin and Lubchecko 2008). In ecosystems, reorganization may include different predator-prey relationships to maintain similar energy transfer pathways in marine food webs (Link et al. 2011). In societies, reorganization can include fishers changing fishing technology or fishing behaviour while maintaining established relationships (Perry et al. 2011). While dynamic fishery systems often exhibit unexpected changes, these changes are typically linear, do not involve system reorganization, and hence, are easier to anticipate (Rothschild and Shannon 2004).

Textbox 2: Selected Definitions of Regime Shifts

A substantial reorganization in system structure, function and identity that persists over time (Biggs et al. 2009; Crépin et al. 2012)

Transition between alternate stable states in a system after a system crosses a critical threshold that results in hysteresis (Scheffer and Carpenter 2003: 650)

Multi-decadal fluctuations (Rothschild and Shannon 2004: 398)

A transition between one state to another that can occur suddenly and abruptly or slowly and gradually (Hughes et al. 2013)

In dynamic coast fishery systems, regime shifts are a distinct for three reasons. First, regime shifts are caused by a unique interplay of disturbances, known as mechanics (Carpenter and Brock 2006). For instance, a key fish species can decrease in abundance and the system can switch to high abundance in a different species which can alter food webs significantly (Essington et al. 2015; Rothschild and Shannon 2004). Other examples have been documented within marine ecosystems that trigger responses in other components of a fishery system (see Table 2). Second, system responses to mechanics are often non-linear (Briske et al. 2010; see Table 3 for definitions in regime shift theory). This can include an entire system shift onto a new trajectory unexpectedly or can involve a gradual process with some non-linear changes at different levels (Selkoe et al. 2016). Third, system responses include changes to many components in a system (Collie et al. 2004; Lees et al. 2006). Whether linear or non-linear, the reorganization of system components creates new relationships among components and feedbacks (Scheffer and Carptenter 2003). This produces a new identity and set of functions in a fishery system.

Table 2: Selected Examples of Ecological Regime Shifts in Fishery Systems

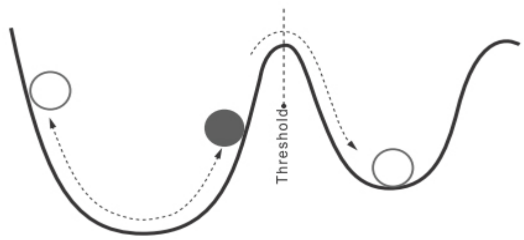
Regime Shift	Location	Description	Scope of Impacts and Examples	Sources
Species switch	Baltic Sea	Cod (Gadus Morhua) dominated to Sprat (Sprattus sprattus) dominated fishery system	Affected fisheries in nine northern European countries; Impacts to a diverse range of livelihoods	Österblom et al. 2012; Eero et al. 2012
Species switch	Northern Atlantic	Cod-dominated to shellfish-dominated fishery systems	Closed over 300-year cod fishery in Newfoundland; Created temporary job loss and changed fishing communities	Kahn and Chuenpagdee 2013; de Young et al. 2008
Eutrophication - Hypoxia	Gulf of Mexico	Creation of dead zones from agricultural run-off	Introduction of health risks to fish and humans; Reduction in seafood production and changes to agricultural practices land-use by the Mississippi Delta	Rabalais and Turner 2001; Yletyinen and Bleckner 2016.
Coral transition	Caribbean	Coral reef system to algal dominated system	Extirpated fish species and made coral more vulnerable to bleaching; Significant land-use changes for surrounding communities	de Young et al. 2008; Scheffer and Carpenter 2003

Regime Shifts as an Ecological Concept

Regime shifts originated as an ecological concept (Lade et al. 2013). In the 1970's, Holling (1973) and May (1977) argued that ecosystems with reduced resilience would experience substantial, non-linear, and discontinuous shifts due to intensifying disturbances (Groffman et al. 2006; Scheffer and Carpenter 2003; See Table 2 for Definitions). According to Holling (1973) ecosystems are dynamic because they have many components that are variable, and the introduction of disturbances, pushed and pulled relationships among system components among different basins of attraction or trajectories. Ecosystems remain within a given basin of attraction because feedbacks reinforced relationships among system components (Holling 1973; Holling 1996).

However, disturbances weaken or strengthen these feedbacks which affect the capacity of an ecosystem to absorb change and caused systems to cross a threshold onto a different trajectory (Holling 1973). This triggered a regime shift. This is commonly depicted in a ball and cup diagram where, given the scope, scale and intensity of disturbances and the resilience of a system, a system may cross a threshold and shift into a new regime (see Figure 1; see Table 3 for definitions).

Figure 1: Relationship Among Resilience, Thresholds and Regime Shifts (Adapted from Liao



In many different examples, ecosystems appeared to shift surprisingly from one state to another from apparently small changes to systems components (Groffman et al. 2006; Scheffer and Carpenter 2003). Mathematical models and field observations illustrated that regime shifts were non-linear and involved a significant reorganization of components and feedbacks along a different trajectory (Scheffer and Carpenter 2003). Several empirical applications detected regime shifts in a range of ecosystems including soil salinization, degradation of coral reefs, the eutrophication of freshwater lakes and coastal marine systems, fish species shifts in fisheries, bush encroachment on grasslands, and landscape shifts from forests to savannas (Biggs et al. 2009; Crépin et al. 2012).

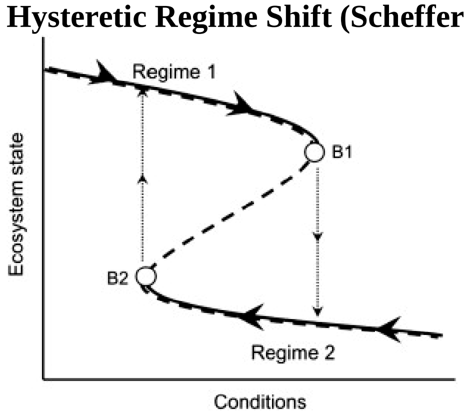
Table 3: Key Terms and Definitions in Regime Shift Theory

Term	**Definition**
Resilience	The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity (Folke et al. 2010)
Basins of Attraction	Tendency of relationships in systems to persist along a certain trajectory which is determined by the cyclical behaviour of relationships in systems and the feedbacks that reinforce these relationships (Holling 1973)
Thresholds	A threshold refers to the point at which a system can no longer absorb change and reorganize while maintaining the same identity (Groffman et al. 2006: 6)

Feedbacks	Control mechanisms that result from interactions between different components of a system (Holling and Gunderson 2002)
Non-Linearity	A system response that is disproportional to the extent and direction of a driver of change (Meadows 2008: 91)
Hysteresis	A non-linear response within a system where the return path to the original state is different from the path taken in the original state change (Groffman et al. 2006: 9)
Surprise	A qualitative disagreement between system behaviour and a priori expectations – environmental cognitive dissonance (Gunderson 2003: 36)
Mechanics	Patterns of change to the internal dynamics and feedbacks of an system that often prevent it from returning to a previous regime even when the precipitating driver of change is reduced or removed (Biggs et al. 2009)

Typically, regime shift literature uses some variation of a bifurcation diagram to illustrate regime shifts (Groffman et al. 2006). The bifurcation diagram represents a regime shifts that is highly non-linear, discontinuous and hysteretic (see Figure 2). Figure 2 illustrates how regimes close to B1 can be forced onto another trajectory from a relatively small change (Scheffer et al. 2001; Lade et al. 2013). Regime shifts are not always non-linear, discontinuous or hysteretic (de Young et al. 2004; de Young et al. 2008; Selkoe et al. 2016). Some regime shifts in coastal fishery systems can be more gradual and smooth. A system with greater adaptive capacity and resilience will have a higher potential of absorbing change and trigger a smoother shift (Selkoe et al. 2016). Conversely, people's actions can intensify environmental drivers and constrain quick action and as a result, a exacerbate the effects of shift (Biggs et al. 2009; Crépin et al. 2012).

Figure 2: Bifurcation Diagram that Illustrates a Non-Linear, Discontinuous, and Hysteretic Regime Shift (Scheffer et al. 2001 in Crépin et al. 2012)



Regime Shift as a Social-Ecological Process

Regime shifts are social-ecological processes of change (Crépin et al. 2012; Lade et al. 2013). For example, a fishery system regime shift can result from an interplay of small, seemingly independent social and ecological disturbances. A slight increase in mean surface water temperature could affect spawning in certain fish species, coupled with the slow degradation of habitat from human activities can lead to the dominance of different species in a given ecosystem (Cheung et al. 2013; Poloszanska et al. 2013). A species redistribution can then trigger system-wide changes such as reductions in catches, shifting objectives for management, a need to design new access rules for harvesters, threats to fish processing plants, and increasing outmigration of harvesters from fishing communities (Essington et al. 2015; Kahn and Neis 2010; Perry et al. 2011).

The extent and timing of cascading effects across the human components are major sources of uncertainty (Crépin et al. 2012; Perry et al. 2011). Studies of regime shifts point to patterns of changes to the internal dynamics of a system, known as mechanics (Groffman et al. 2006; Walker and Meyers 2004). Often, mechanics include the slow, undetectable erosion of one variable coupled with a rapid shock that triggers a regime shift (Groffman et al. 2006; Walker and Meyers 2004). As a social-ecological process, studying mechanics requires an understanding of the social drivers for mechanical change.

A shift from a coral system to algal-dominated system in the Caribbean illustrates the social-ecological nature of mechanics. Research on this shift revealed a complex suite of social-ecological interactions between the removal of sea urchin, eutrophication from agricultural runoff and acidification from climate change, as well as hurricane damage, for example, in Jamaica (de Young et al. 2008; Scheffer et al. 2001). Land-use change produced agricultural run-off which set the conditions for precipitous algal growth (Scheffer and Carpenter 2003). However, an abundant sea urchin population fed on algae and as a result, masked the algae's encroachment. A combination of acidification and overharvesting of sea urchin reorganized feedbacks and algal encroachment intensified. The introduction of a pathogen finally extirpated sea urchin which triggered the algal bloom. In this example, there was an interaction between slow variables (e.g., land-use change, harvesting of sea urchin, and acidification) and fast variables (e.g. pathogen and algae) (de Young et al. 2008). The trigger was the introduction of a pathogen which led to the sea urchin's extirpation.

Prediction, Detection, and Management

The coral transition example suggests that when people are not prepared for regime shifts, they can incur high economic, social and cultural costs (Möllman et al. 2015; Nayak et al. 2015). De Young et al. (2008) argue that literature on prediction, detection, and management are needed because regime shifts are often irreversible and hard to predict. Selkoe et al. (2016) recommend management principles related to precaution and monitoring with some attention related to the social context of change. Rarely, however, do regime shift studies consider the social context as part of the regime shift process, despite clear evidence that ecological regime shifts trigger social changes (Christensen and Krogman 2012; Parlee et al. 2012; Nayak et al. 2015).

The management-only perspective includes a problematic assumption that change is undesirable and in need of prevention. Several theoretical studies acknowledge this assumption as problematic, examine the social context of managing regime shifts, and provide insights about the desirability of change its implications for management interventions (e.g., Biggs et al. 2009; Briske et al. 2010; Crépin et al. 2012). Attention to a regime shift as a social-ecological process highlights the redistribution of benefits and burdens and shifts in people's interests and demands (Christensen and Krogman 2012; Nayak et al. 2015). Insights from this literature indicates that people may or may not have an interest in prevention. For example, in two case studies, Nayak et al. (2015) finds that regime shifts alter the social relations of power which in turn change who benefits from management interventions. Consequently, a regime shift as a social-ecological process is a fundamentally different problem to be governed. In the next section, we discuss an example from a fishery system in Northern Newfoundland, Canada. We provide a social-ecological narrative for the 1990's collapse of the Atlantic Cod fishery and renewal as shrimp-dominant fishery as a potential regime shift.

A Potential Regime Shift in Northern Newfoundland, Canada

The 1990's collapse of the Atlantic Cod fishery in Northern Newfoundland and unfolding of the shellfish industry was one of the most notable examples of a regime shift in a fishery system (De Young et al. 2008; Biggs et al. 2009; Kahn and Neis 2010). In the late 1980's, Atlantic Cod abundance decreased to record lows and a multi-year moratoria on cod fishing effectively closed a fishery that had thrived for over 300 years (Apostle and Mikalsen 1995; Link et al. 2011). In the mid-1990's, shellfish-dominated fishery emerged to restructure social and economic life (Kahn and Chandra 2006; Sinclair et al. 2015). As of 2016, shrimp abundance has decreased and cod abundance has increased, although not to historical levels (DFO 2016).

The Collapse of the Atlantic Cod Fishery

In North America, the establishment of International Convention for Northwest Atlantic Fisheries in 1950 and the 200-mile Exclusive Economic Zone (EEZ) and Northwest Atlantic Fisheries Organization (NAFO) ushered in a new era of Canadian and American fisheries management (Gough 2007; Hanna 1997). In both countries, legislation established federal departments to manage domestic fisheries within the EEZ with an expansion of rules relating to catch limits and limited-entry licensing (Link et al. 2011; Steelman and Wallace 2001).

Post-World War II financial loan and transfer payment programs stimulated the groundfish industry in Canada which led to worldwide increases in fleet and vessel size, investments in fishing technology, and fish production (Gough 2007). In the early 1980's, the Atlantic groundfish industry experienced a major economic downturn due to increases in large scale, vertically-integrated fishing fleets operating off Nova Scotia and Newfoundland's coasts (Apostle and Mikalsen 1995). The expansion of fleets outgrew stock sizes (Apostle and Mikalsen 1995). This led to major policy and financial restructuring of the groundfish industry. In the early 1990's, Atlantic Cod populations dropped precipitously (Apostle and Mikalsen 1995; Link et al. 2011).

The Cod collapse resulted from a complex interplay of drivers. Atmospheric pressures caused cooling which relocated capelin spawning areas and pushed cod southward to follow capelin (Perry et al. 2011). In addition, the cumulative biological effects of overfishing (e.g., increased harvesting efficiency and temporal and spatial changes in fishing effort) reduced remaining cod populations (Hutchings and Rangeley 2011; Underwood 1995). Several assessments argued that the collapse was precipitated by failures in fisheries management. Managers ignored information from scientists about anticipated cod stock declines (Officer of the Auditor General, Canada 1997). Charles (1995) described three other failures. First, fisheries management goals were unfocused. Second, quotas were set with little precaution. Third, decision-making involved very little input from resource users. Burke and Brander (1995) argued that the most critical management failure was to actively support single species harvesting by subsidizing fishers which allowed them to stay in one fishery. In 1992, in response to an undeniable drop in cod abundance, the Department of Fisheries and Oceans (DFO) implemented a multi-year moratoria.

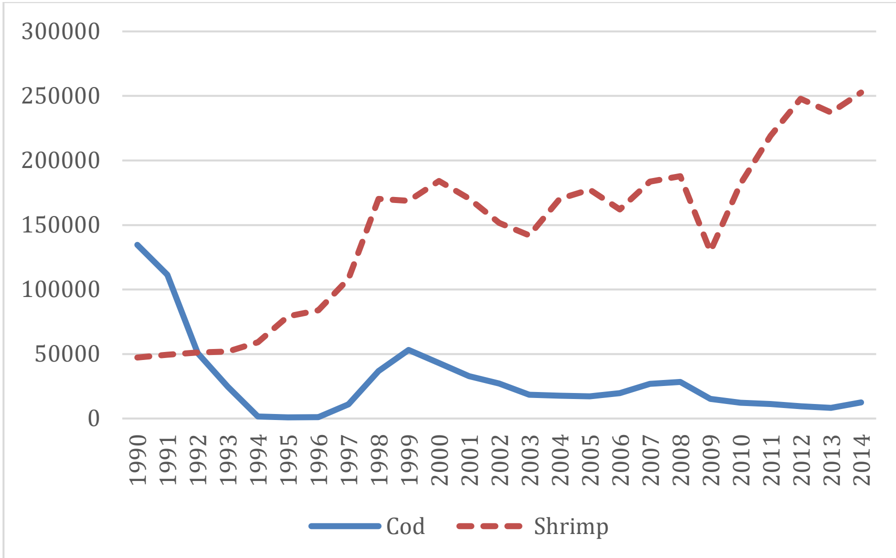
The social-ecological effects of the collapse were far reaching. Hutchings and Rangeley (2011) argued that near extirpation of cod represented an unprecedented change in marine ecosystem biodiversity. In addition, the collapse involved a 40% decline in employment (Davis 2014). This led to fish plant closures, outmigration of fishers and their families, and community closures (Foley et al. 2015; Ommer and Team 2007). The cod fishers that remained were spending more time ashore which altered patterns of family life. While many fishers enjoyed more time with their families and communities, many experienced increased tension at home and psychological stress due to lost wages and the inability to cope with stress through fishing (Binkley 1995).

Massive political and economic restructuring programs followed the moratorium. The federal government implemented two short-term programs that provided income to cod fishers: the Northern Cod Adjustment and Recovery Program (1992) and the Atlantic Groundfish Adjustment Program (1993). After political pressure, in 1994, Human Resources Development Canada and DFO developed and implement the Atlantic Groundfish Strategy to provide longer term income support. The cost of these programs was over 1.9 billion dollars (Davis 2015).

The New Shrimp Fishery

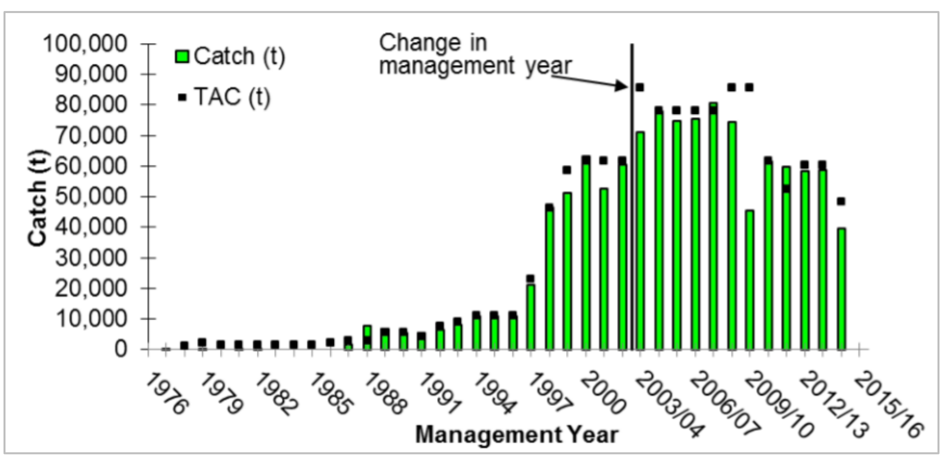
During the cod collapse, Northern Shrimp (Pandalus borealis) abundance peaked unexpectedly (Hutchings and Myers 1994). The changes to climate that pushed capelin and cod southward, reduced predation pressures on shrimp (Kahn and Chandra 2006). When the remaining cod populations dropped to record lows, further reduced predation pressures released shrimp populations and created a boom in abundance (Kahn and Chandra 2006). Offshore trawlers and inshore fishers that invested in shrimp reaped the benefits and shrimp-dominated fishing industry emerged (Perry and Ommer 2003). Consequently, the landed values for shrimp steadily rose (see Figure 4).

Figure 4: Landed Values ($) for Cod and Shrimp in Newfoundland from 1990-2014



Shrimp fishing predated the boom. In the 1960's, a small Atlantic offshore and inshore shrimp fishery emerged (Sinclair 1983). In 1980, DFO implemented Shrimp Fishing Areas that fell within the EEZ boundaries (Foley, P., et al. 2013). In 1997, catch rates and quotas begun to rise (see Figure 5). In the same year, DFO implemented rationalization programs and redrew inshore boundaries which involved a redistribution of quotas that encouraged the inshore shrimp fishery. Ultimately, this phased out younger fishers (Davis 2014). By the 2006/2007 management year, the Newfoundland shrimp catch peaked to over 80,000 tonnes (Figure 5).

Figure 5: Historical Northern Shrimp Catches from Shrimp Fishing Areas 4 to 6 and Total Allowable Catches from 1976 to 2014/2015. 2014/2015 data not fully reported (Retrieved from DFO 2016).



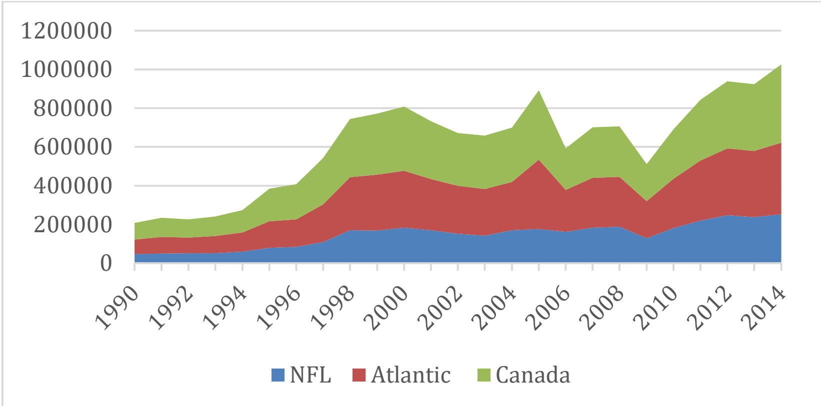
A New Regime Shift from Shellfish to Cod?

There is evidence that cod stocks are slowly recovering (DFO 2016). Kahn and Chandra (2006) documented decreases in cod parasites which could release pressure on cod and increase predation on shrimp. While there has been increased predation on capelin, shrimp remain important prey for cod, although not the same extent as capelin. Coupled with recent shrimp stock declines (DFO 2015), the uncertain influence of both climate and international market value of shrimp, a new regime shift could be on the horizon (Davis 2014). However, the timing and extent of social changes in a future regime shift remain unknown.

Several actions at different governance levels may soften the effects of a shift. For example, DFO has adopted the use of integrated management planning and improved the stock assessment process (Link et al. 2011). In addition, DFO has begun to inject capital and build capacity in unions, offshore fishing companies, and local government authorities by providing them with offshore licenses and special allocations (Foley, P., et al. 2013; Foley and Mathur 2016). However, criticisms remain that DFO rarely considers the role of social science and local knowledge in stock assessments for the Newfoundland region (Link et al. 2011; Smith et al. 2014), has limited use of management strategy evaluation in the region, and does not align management objectives with community objectives (Link et al. 2014).

In the Newfoundland region, there is a significant social, cultural, economic dependence on shrimp which make tens of thousands vulnerable if cod stocks recover and shrimp stocks continue to decline (Davis 2014). Shellfish are extremely important to the Canadian economy. The landed values of Newfoundland shrimp represent 62% of total Canadian landed values for shrimp (see Figure 5). However, uncertainty abounds related to the influence of multi-scalar interactions within human components on the timing, the extent and desire for reversibility of cod stocks, and the extent to which a shift would restructure livelihoods of fishers and in fishing communities. With the processes of social-ecological change are unknown in this case, Davis (2014: 698) questions whether a cod recovery is good or bad for Newfoundland, “While the biological recovery of cod populations was once taken for granted by most people as an inherent good and as essential to the future well-being of coastal inhabitants, the prospect of cod rebounding now is raising some troubling questions that would have been unimaginable just a short time ago.” However, we argue that a regime shift is neither good nor bad, but a problem to be governed.

Figure 5: Landed Values ($) for Northern Shrimp in Newfoundland, in Atlantic Canada, and in Canada from 1990-2014



Discussion for Governing Regime Shifts in Fishery Systems

In this section, we discuss the regime shift literature in an adaptive governance context, related the influence of multi-scalar interactions on timing of a potential shift, the reversibility of the cod stocks, and redistribution of benefits and burdens.

Timing of Regime Shifts and *Multi-Scalar Interactions*

A key principle in regime shift literature is that time-scale between regimes is shorter than during a regime (de Young et al. 2004). Regimes can be multi-year, -decadal, or -centurial (de Young et al. 2004; Rothschild and Shannon 2004). The rapidity of a shift, then, is relative to the length in a given regime (Hughes et al. 2013). In a social-ecological process of change, this timing is determined by the intensity of drivers, societal responses to change, and effectiveness of interventions (Biggs et al. 2009). Consequently, it is difficult to know when a regime shift will happen, the duration of the shift and duration of a new regime. Multi-scalar interactions can trigger regime shifts unexpectedly (de Young et al. 2008). Large-scale regime shifts can result from many smaller-scale events, and large scale events can trigger small-scale shifts (Barnosky et al. 2012). Events at larger scales can link seemingly independent social or ecological processes to create unexpectedly synergistic drivers of change (Barnosky et al. 2012). In the Newfoundland case, the shift to shrimp (approximately 10 years) was significantly shorter than the cod regime (over 300 years). This occurred as a result of many unexpectedly linked drivers. The potential for another shift suggests the time in a shrimp dominated regime (potentially 30 to 40 years) is substantially shorter.

A lack of coordination between decision-makers and scientists can intensify the changes within a regime shift process (see Pittman and Armitage 2016). This relates to the use of knowledge and the notion of fit and cascading effects. Anticipation can involve linking integrating co-produced scenarios into fisheries management plans and evaluating management decisions for the various risks to the public interests involved in a given scenario. In addition, this involves reflection on the ways that different institutions and decision-making processes to engage system-wide actors should a given scenario seem likely. Should cod recover and shrimp continue to decline, who will decide how fisheries licenses are redistributed? Will fish plants be saved and if so, how? How will communities be supported? Anticipation, then, involves the evaluation of the capacity of institutions and decision-making processes to mitigate and navigate unexpected system change. The notions of fit and interplay suggest that there is a need for complex, and multi-layered institutions (fit), but that too complex of an institutional arrangement can stall progress as rules conflict (interplay).

Irreversibility is a Normative Problem

Often regime shifts are characterized by their irreversibility (Biggs et al. 2009). In a slowly unfolding regime, it may be years or decades while feedbacks reorganize and begin to reinforce a new regime (Hughes et al. 2013). Once a shift is completed, a new set of thresholds exist (Biggs et al. 2009; Briske et al. 2010). Hughes (2013) argues that during the unfolding of a regime shift, there exists an opportunity for policy intervention that triggers a reversal back across the same threshold (Hughes et al. 2013). Biggs (2009) argues that a policy window is unlikely given that an opportunity for reversal is predicated on the timely ability of decision-makers to act and the intensity of drivers. Our case illustrates the normative dimensions of reversibility.

In Newfoundland, a regime shift back to a cod-dominated fishery system may not be completely desirable. A shift back to cod will have high transaction costs for fishers who invested heavily in shrimp. At the same time, communities in Northern Newfoundland may have significant cultural ties to cod. Anticipating a shift, in this case, require trade-offs decisions. In order to effectively and legitimately navigate these trade-offs, decision-makers need understand the desires of resource users and fishing community residents and the interventions that mitigate the impacts for those likely to bear the greatest burdens (e.g., resource users, families and communities only invested in shrimp harvesting). Consequently, navigating the normative aspects of regime shifts requires deliberate negotiation of system-wide interests, values and preferences (see Andrachuk and Armitage 2015; Blythe 2015). As result, rules and mechanisms are needed that effectively engage people and promote social learning about the cascading effects in regime shifts. Adaptive governance theory suggests this is achieved ideally through knowledge co-production (Diduck 2010). In the Newfoundland case, the capacity may be limited to engage directly with resources users about stock change should cod return and shrimp continue to decline.

Regime Shifts Results in Winners and Losers

Relating to the normativity of change, regime shifts include an uneven redistribution of benefits and burdens to people (Christensen and Krogman 2012; Nayak et al. 2015). In coastal fishery systems, decisions about the distribution of burdens and benefits are notoriously contentious (Ommer and Team 2007). In the Newfoundland case, this involved politically contentious income support and rationalization programs. This in turn aged the system, as young fishers phased out, and reduced its continuity (Davis 2014). Our case emphasizes that decisions about regime shifts must involve attention to power and equity in decision-making about coastal fishery system.

In the anticipation of regime shifts, attention to power and equity suggests the need for strategizing about who might be involved in planning and decisions and how to build capacity in the system (Nayak et al. 2015). For example, rules are needed about who gets to define a system's boundaries. The system definition can determine who is considered in planning which has power and equity implications. Furthermore, flexible institutions are needed to build capacity in the system. Examples of this are the licenses provided to unions, offshore fishing companies, and local government authorities. However, by taking limited catch away from local resources harvesters, DFO make a trade-off. Trade-offs like this need institutions mitigate undesirable outcomes.

Conclusions

Regime shifts are a unique governance problem because they involve abrupt, cascading, system-wide changes (Collie et al. 2004; Lees et al. 2006). When a regime shift is a social-ecological process, there are more changes, more complexity and greater uncertainty related to societal responses and their influence on management (Biggs et al. 2009; Briske et al. 2010). As part of the process of change, regime shifts can reorganize how people relate to one another and alter their interests, values, and demands. In other words, regime shifts shape people's experiences and in doing so, shape the social context within which management interventions are designed and implemented (Christensen and Krogman 2012; Nayak et al. 2015). A management-only perspective is limited likely in its capacity to account for the social context of regime shifts

We argued that anticipation and navigation are desirable goals in the governance of regime shifts. Furthermore, we proposed adaptive governance as an appropriate theory to inform the broader processes and institutions that decision-making use to respond to regime shifts in fishery systems. Our case indicated that anticipation requires engaging system wide actors to understand how a regime shift process might affect them, use these insights to design interventions that mitigate the undesirable changes, and steer people towards the adaptation to changes that are inevitable. Engaging people about the effects of change requires attention to normativity, equity and power. The goal of adaptation, then, is to coordinate science and local knowledge in decision-making processes with to design institutions that are flexible and appraisable. Our case illustrates that this is complicated because uncertainties abound in a system prone to regime shifts.

In the Newfoundland case, we do not know for certain if or when a substantial reorganization may take place, who will win or lose as part of the process, and how interactions at different scales will affect the system (see Davis 2014). Anticipating, then, will necessitate reflections on decision-makers' assumptions about the dynamics in a system. If decision-makers assume a system is prone to regime shifts, they should leverage social science, establish and nurture participatory mechanisms, and evaluate and modify institutions for their flexibility. These actions take time and resources. Often in governing regime shifts, there is too little of either to respond effectively (Biggs et al. 2009). However, the Newfoundland case illustrates the costliness of unrecognized regime shifts. This means political discussions are necessary about how to share resources and govern explicitly for regime shifts. While DFO has made progress towards adaptation, its leaders and scientists must consider how to continue to build capacity in the system and involve system-wide actors in planning (e.g., management strategy evaluation and integrated fishery plans).

We examined this Newfoundland case a pathway to discuss the governance implications of regime shifts. In doing so, we provided a brief scan of some implications for adaptive governance related to accountability and legitimacy, the use of knowledge and learning, scaling and boundary determination, and fit and interplay. This discussion revealed that regime shifts have interacting governance implications. However, we merely scratched the surface about these implications and only briefly mentioned other implications such as trade-offs and coordinating science and policy. Theoretical and empirical studies of regime shifts require deeper reflection about governance.

Given the need for social-ecological regime shift studies that integrate governance, one pathway for future research is to examine how governance can better incorporate human behaviour into the anticipation of regime shifts. Human behaviour can exacerbate or mitigate the effects of environmental change when drivers of change are anthropogenic, responses to change are social, and when people enable or constrain effective governance interventions (Clark 2012; Fabricius et al. 2007). However, human behaviour and decisions are not well understood in the environmental change literature, particularly related to fisheries, and this limitation constrains ongoing efforts to anticipate and navigate regime shifts when they do occur (Biggs et al. 2011; Blythe 2015; Fulton et al. 2011). Research suggests when people experience change, their behaviour may not seem rational (Cohen 2005; Wolfe 2012), may be delayed or oriented toward different objectives (i.e., at the family or community level) (Clark 2012; Fulton et al. 2011), and may support governance interventions that appear to be against their own interests (e.g., supporting subsidies that encourage harvesting of declining fish stocks) (Lowenstein 2006; Norton and Steinemann 2001). Consequently, more effort is needed to take stock of the motivations for human behaviour in the context of regime shifts, build scenarios that account connect these motivations to system change, and to identify a vision for adaptive fisheries governance that can better account for the motivations of human behaviour.

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