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Short Communication

Adaptive capacity of co-management systems in the face of environmental change: The soft-shell clam fishery and invasive green crabs in Maine

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ABSTRACT

Co-management, or regulatory decision-making through collaboration among user-groups, government officials, and scientists, has been proposed as an effective marine management tool in the face of environmental change. One potential advantage attributed to co-management is that such systems may have greater adaptive capacity than more conventional top-down management regimes. However, it is difficult to empirically test the relative adaptability of co-managed systems in the real world. This research uses a case study of the soft-shell clam fishery in Maine to investigate the question: Are co-managed systems better able to adapt to environmental change than are conventionally managed systems? This fishery provides an ideal system with which to address this question because (1) it is differentially managed, with some municipalities engaging in co-management and some in state management and (2) it faces an imminent environmental threat in the form of invasive predatory green crabs. This research first explores the scope of the green crab invasion in Maine, showing that although there have been no detectible impacts of green crabs on clam harvests to date, geographic overlaps of highly productive clam fisheries and high crab densities suggest a high likelihood of future impact. Second, to assess relative adaptability to this threat, this study quantifies differences between state- and co-managed systems across three attributes: user group stability, resource productivity, and institutional capacity to respond to change. It finds that co-managed clam fisheries have a higher degree of stability (i.e., a well defined user group), higher and more consistent productivity (i.e., more resources and incentives for sustained management), and greater institutional capacity to respond to change in the form of "conservation hours," a flexible management tool employed in co-managed fisheries. These results indicate that co-managed clam fisheries are better prepared to adapt to environmental change than are conventionally managed fisheries.

1. Introduction

Co-management refers to a suite of resource management systems that seek to engage local communities and resource users within a nested hierarchy of governance [28]. In theory, by fostering regulatory decision-making through collaboration among user-groups, government officials, and scientists, co-management strategies can help lay the foundation for successful common pool resource management in several ways, including clearly defining resource boundaries and user groups [27], mobilizing additional capacity for monitoring and enforcement [11,28], and supporting institutional diversity allowing for flexible, multi-pronged responses to changing environmental and political contexts [21]. Interest in co-management in marine systems in particular has increased in recent decades, including efforts to create and support such systems in fisheries management [19,20,33] and marine protected area planning [31]. A growing body of research into co-managed fisheries has now empirically demonstrated that, while not a panacea, when effective, co-managed systems can indeed support improved governance outcomes by promoting increased buy-in by resource users [30] and allowing strong leaders to advocate for long-term views that promote sustainability [16].

An additional purported benefit of co-managed systems is their ability to adapt to future change, as engagement by resource users through a diversity of institutional structures can help identify local threats and more rapidly respond to such threats than can top-down systems, which have less engagement by resource users and longer processes to implement changes in management strategies [2]. Due to this perceived adaptability, systems of co-management have been designed explicitly to address threats associated with a changing environment [31]. However, evaluating

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the relative adaptability of co-managed systems is difficult, and few studies have empirically assessed the attributes of co-managed systems that allow them to address future change. This is an essential question for conservation planning, as natural systems face an unprecedented suite of changes – including climate change [29], the spread of disease [18] and invasive species [25] – whose effects may be non-linear, synergistic, and difficult to predict. The ability to design systems of resource management that can adequately respond to these changes is critical.

The Maine soft-shell clam (*Mya arenaria*) fishery provides an ideal case to explore the relative adaptability of co-managed systems in the face of future change for two reasons. First, it is differentially managed, with some municipalities engaging in co-management and some in state management. The soft-shell clam fishery is a major commercial fishery in Maine, second only to lobster in both landings and value [12]. It has a long history of co-management, with shared management between the state and local municipalities for more than 170 years [17]. Under the current policy framework, individual municipalities can apply to the Maine Department of Marine Resources to gain co-management rights to local clam fisheries, which are harvested from clam flats, or near-shore tidal areas that may extend up to a mile from the shore. In co-managed fisheries, municipalities have flexibility in setting local rules, including limits on numbers of and eligibility for harvesting licenses, requirements for maintaining a license, and area and seasonal closures. These rules are enforced at the local level through town-funded clam wardens. In total 58 towns co-manage their clam fishery in collaboration with the State of Maine, while the State of Maine is the sole authority managing the fisheries in the remaining towns (Fig. 1, Table 1).

Second, the clam fishery currently faces a substantial environmental threat in the form of invasive green crabs (*Carcinus maenas*) [8]. Green crabs were transported from Europe in ballast water and have been present in Maine for more than a century, but have been identified as a threat recently due to observed population increases and predation on soft-shell clams [32,3], as well as other ecosystem impacts [4]. In the 1950s, green crab populations rose temporarily in Maine, with observed negative impacts to clam fisheries [14]. A series of cold winters in the 1960s reduced green crab populations, and clam fisheries rebounded. The threat of resurgent green crab populations is of growing concern throughout New England, with ecological impacts already observed in Massachusetts [5,9]. Because green crab population increases have been linked to an increase in ocean temperatures [3], recent warming water trends in the Gulf of Maine [26] may stimulate the growth of crab populations along Maine's coast.

This research uses the case of the soft-shell clam fishery in Maine to investigate the question: Are co-managed systems better able to adapt to environmental change than are conventionally managed systems? It first evaluates the current and potential impacts of green crabs on soft-shell clam fisheries. Next, it compares soft shell clam fishery management institutions across a range of attributes drawn from the common pool resource management literature [27,11,33,28] in order to identify attributes that may make co-managed and state-managed systems differentially prepared to adapt to future threats from this invasive species.

2. Methods

To evaluate the current and potential impact of green crabs on Maine clam fisheries, this study used spatially specific data on green crab abundance obtained from the Maine Department of Marine Resources (DMR) green crab trapping survey, collected in August 2013 by volunteers from 28 towns along the Maine coast. Participants set baited traps in shallow water (<7 m) and recorded the numbers of crabs after 24 h [13]. In this current research, the trapping results (crabs per trap) were used to determine "low" "medium" and "high" crab towns, which were then compared to mean municipal annual clam landings (mt) and catch per unit effort (CPUE; mt per harvester) for all years with available data (2001–2012 and 2008–2012, respectively). If crab predation had begun to impact clam fisheries, declines in clam landings or CPUE would be expected in areas of high crab abundance relative to those of low and medium abundances. To evaluate potential impact, the relative abundance of green crabs and the major centers for soft-shell clam landings were mapped [15]. If crab predation is likely to have a future impact, a high degree of overlap in these regions would be expected.

Next, the relative adaptability of co-managed systems was evaluated by comparing co-managed and state managed fisheries across a suite attributes drawn from the common pool resource management literature: user group stability, resource productivity, and institutional support for adaptation (Table 2). Within the co-management framework a well-defined user group with a shared understanding of rules is regularly cited as key to successful commons management, as it may increase the ability for stakeholders to track and address problems [27,11,33]. A higher level of sustained resource productivity meanwhile provides both the financial resources and the stability needed for well-organized user groups to invest in self-governance [11,28]. Finally, institutional support for engaging resource users in actively managing new threats to a resource – measured here as the level of local conservation capacity available to combat green crabs – reflects preparedness for change, critical to the long-term survival of resource management institutions [11].

To compare the user group stability of state versus co-managed fisheries, annual changes in the number of harvesters per town were calculated for all years with available data. To evaluate productivity, landings per area, landings per harvester, and annual changes in landings were calculated and compared across the different management systems. Data on commercial landings and numbers of harvesters were obtained from the Maine DMR; clam flat data were obtained from the Maine Office of GIS. Finally, institutional support in the form of conservation hours and total conservation capacity was evaluated. Conservation hours are a management tool used by some co-managed towns; towns can require that license holders complete a set number of conservation hours to retain harvesting rights. Requirements can include attendance at town Shellfish Conservation Committee meetings, participation in clam flat reseedings, and labor contributions to green crab eradication efforts. Information on the number of conservation hours required of each individual harvester was collected from each municipal ordinance and multiplied by the mean number of harvesters (2008–2012) in each town to arrive at an estimate of total local conservation capacity. In all analyses, only municipalities that had active fisheries in at least one year since 2008 were included, which included 58 co-managed and 16 state-managed fisheries (Table 1).

3. Results

3.1. Current and potential impact of green crabs on Maine clam fisheries

There was no downward trend in landings or CPUE for high crab towns (>100 crabs/trap) relative to medium (25–100 crabs/trap) and low (<25 crabs/trap) crab towns (Fig. 2) in the past decade, suggesting that there has not been a detectable recent impact of invasive green crabs on the soft-shell clam fishery. Instead, both mean landings and CPUE have remained highest for towns with relatively high crab densities. For all three groups (high, medium, and low crab towns), total landings have been stable across time (2001–2012) while CPUE increased slightly (2008–2012).