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Human dimensions of climate change and fisheries in a coupled system: the Atlantic surfclam case

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Research on changes in a coupled marine system of the Mid-Atlantic Bight, focusing on Atlantic surfclams and the associated fishery and management system, is reviewed for how the human dimensions of this coupled socio-ecological system are addressed by the researchers. Our foci are on economic modelling of spatial choices, using dynamic optimization with adjustments that reflect better the natural and socio-economic realities of the fishery and on ethnographic observations of decision processes, particularly those of the regional fishery management council, with particular emphasis on cognitive frames and management communities. These are designed to be integrated with and to complement biophysical modelling of the complex coupled socio-ecological system.

Keywords: Atlantic surfclam, co-management, coupled systems analysis, individual transferable quotas, shellfish management.

Introduction: the human dimensions of climate change in a coupled system

Research on changes in a "coupled" marine system of the Mid-Atlantic Bight affords the opportunity to explore ways that "human dimensions" could be meaningfully incorporated into research on climate and fisheries. The continuing research on which this paper is based implements the mandate of the US National Science Foundation's Dynamics of Coupled Natural and Human Systems programme for "quantitative, interdisciplinary analyses of relevant human and natural system processes and complex interactions among human and natural systems at diverse scales" (www.nsf.gov). The Atlantic surfclam fishery of the Mid-Atlantic Bight is undergoing change that apparently involves environmental factors that negatively affect the survival and reproduction of clams in some areas and that are likely because of climate forcing (Weinberg *et al.*, 2002; Weinberg, 2005; Jacobson and Weinberg, 2006; Marzec *et al.*, 2010). Whether or not climate is the cause, changing patterns of stock abundance indicate that both clams and people have to make adjustments (NOAA Northeast Fisheries Science Center, 2010). The multidisciplinary research team is studying the effects of climate change on clams and hence on the fishery and how those effects are perceived, interpreted, and responded to by scientists and by public and private sector actors, who have the capacity to influence the nature of feedback in a complex ocean system.

The Atlantic surfclam case provides an opportunity to investigate coupling processes that link components of complex human and natural systems and, therefore, an opportunity to contribute to broader questions about the dynamics of ocean systems and how humans could sustainably interact with them. Coupling describes how events in one part of a system trigger events in other parts of a system. In this case, we are interested in four linkages, schematically represented in Figure 1: between regional meteorological and oceanographic scales and subregional ones; between the climate and ocean factors and clam genetics, reproduction, and growth; between clam dynamics and industry harvesting, processing, and marketing (which themselves can have multiple scales); and between all the above and organizations, such as families, business firms, industry associations, research centres, and management councils.

The case is important: surfclams (*Spisula solidissima solidissima*) are the dominant member of the marine benthos in much of this region; the fishery is a significant proportion of the commercial fishing sector; and its components are documented in sufficient detail to facilitate an ambitious multidisciplinary effort to describe changes in the related subsystems. In addition, the Atlantic surfclam fishery is distinctive, because of its long history of close interaction among managers, scientists, and industry personnel and because of its status as the first individual transferable quota (ITQ) fishery in the United States.

The project addresses two overarching research questions: (i) how climate forcing affects surfclam populations; and (ii) how the socio-economic and regulatory system responds to perceived and documented effects of environmental change. Our focus in this article is on the second question, but also on how it is linked with the first. The authors are social scientists who focus on two key points where the natural components are coupled with the human components of the system: the fisheries themselves, including harvesting, processing, and distribution, and the dominant governance institutions, which consist of laws, scientific enterprises, management councils, and activities such as data collection and enforcement. At the same time, they also are establishing methods to model coupled systems by integrating social science models with natural models developed by the Ocean Modeling Group at Rutgers University (Dale Haidvogel), in collaboration with Eric Powell (Rutgers), Roger Mann (Virginia Institute of Marine Science), and Eileen Hofmann and John Klinck (Old Dominion University). The research protocol and processes that the team develops are communicated to the broader public through outreach and education efforts led by Janice McDonnell (Rutgers University), as in a recent podcast (Shapiro, 2010).

The overall framework is the study of adaptive management of a complex and dynamic coupled system (Liu *et al.*, 2007), asking whether and how components of the socio-economic and regulatory system adapt to perceived and documented effects of climate change. Our intent in this paper is to outline some of the ways that social scientists—with backgrounds in economics and anthropology—address the human dimensions of a complex coupled socio-ecological system (Ostrom, 2009). Research is still underway, but results to date could help identify ways that "human dimensions" can be meaningfully incorporated into research on

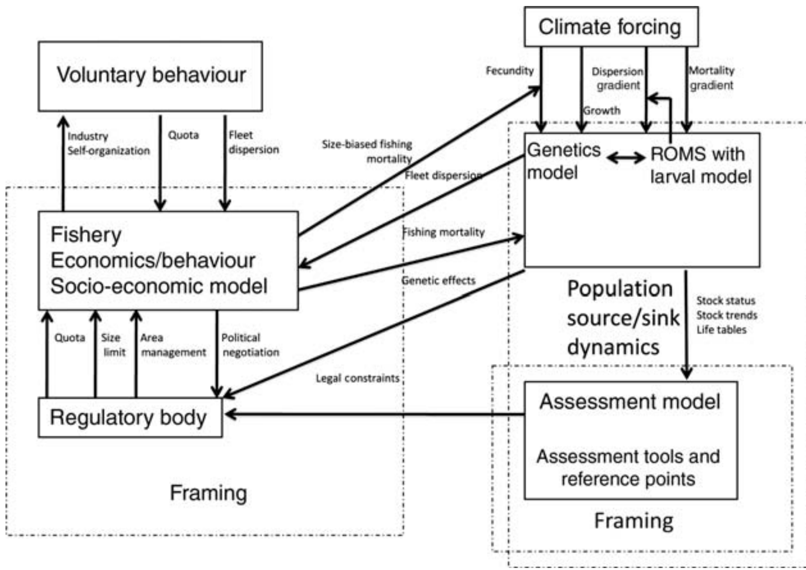

Figure 1. Coupled systems model for Atlantic surfclams and climate change.

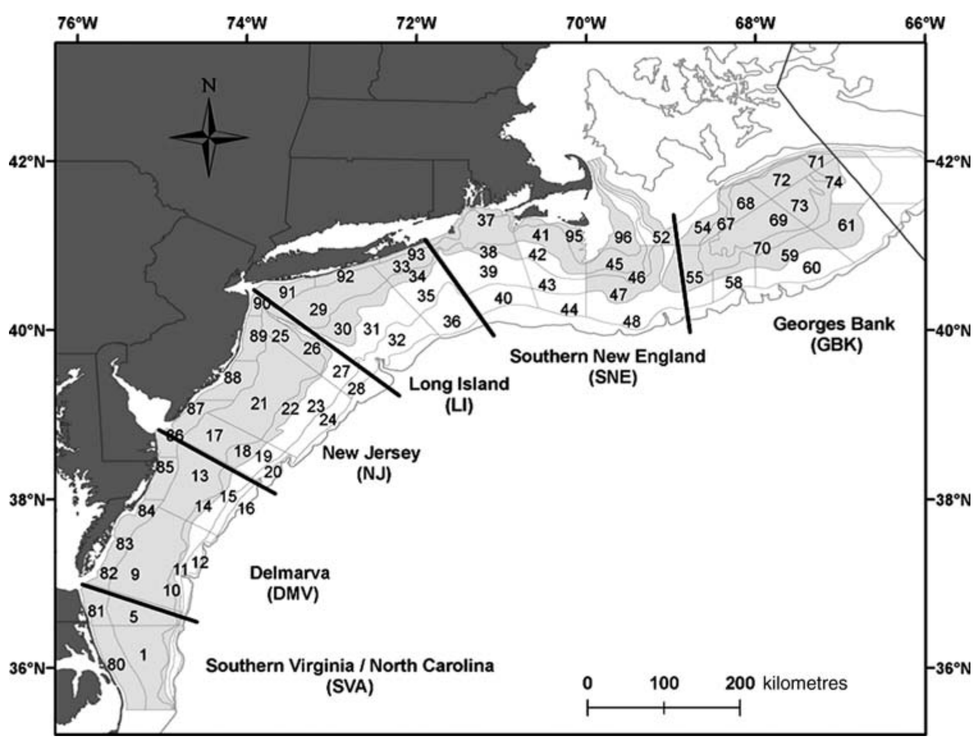

Figure 2. Atlantic surfclams in US EEZ by assessment region and sampling strata.

climate and fisheries. Furthermore, by discussing our process for collaborative interdisciplinary research, we hope to encourage similar research, which is needed to address the pressing environmental and social problems caused by climate change. Therefore, in addition to briefly reviewing the study's examination of the interplay of changing climate, hydrography, and clam genetics and population biology, we focus on research concerning actions of the fishing industry and of regional management bodies as they respond to and learn from changing signals from the environment, filtered through scientific and lay interpretations of those signals.

Background and climate change

Throughout the 1990s, Atlantic surfclams were widely distributed along the western North Atlantic Ocean from the southern Gulf of St Lawrence to Cape Hatteras. Commercial concentrations were found primarily off the states of New York and New Jersey, south to waters off the states of Delaware, Maryland, and Virginia, and north on Georges Bank, off the New England states (Figure 2). They are typically found from the intertidal zone to depths of ~60 m (Jacobson and Weinberg, 2006). They occur within both state (≤5.5 km from shore) and federal waters (5.5–370.4 km from shore). Surfclams—and ocean quahogs (*Arctica islandica*), another species that contributes to the industry—are harvested with hydraulic dredges and mostly go directly to land-based facilities, where they are processed into canned or frozen products. Since 1978, the Atlantic surfclam fishery in federal waters (5.5–370 km, the exclusive economic zone or EEZ) has been managed through the US regional fishery management council system. State-waters fisheries are managed by the individual states, mainly New Jersey, New York, and Massachusetts. Our focus is on federal management, which has involved overall landing limits or quotas, limited entry, and various other measures, including fishing time restrictions 1978–1990 and ITQs, from 1990 to the present.

The general picture for the clam population over the past decade is that of a gradual decline in biomass from the record high levels that were reached during the late 1990s (Table 1). The fishery is tightly managed by limits on allowable catches, which are set within a range that is generally far below the thresholds for overfishing. Consequently, the observed decline in the clam population is interpreted as the result of low recruitment and growth rather than the effects of fishing, although the latter cannot be discounted for specific clam beds (NOAA Northeast Fisheries Science Center, 2010). Accompanying the decline has been a shift from the south to the north in the areas of highest population abundance, as well as a shift towards deeper waters (Mid-Atlantic Fishery Management Council, 2010; NOAA Northeast Fisheries Science Center, 2010).

The idea that climate change might be involved emerged from an analysis of the southern part of the surfclam range, an area known as "Delmarva" (off the states of Delaware, Maryland, and Virginia; Figures 2 and 3). Between 1997 and 2002, mortality was unusually high, resulting in sharply decreased biomass, and this coincided with unusually warm bottom temperatures during the survey months of September (Weinberg *et al.*, 2002). High mortality was accompanied by a bathymetric shift in the population towards deeper waters (Weinberg, 2005).

An analysis of survey data from more recent years, 2002–2008, reveals even further decline in the southern and inshore parts of the range of the clams, particularly in the inshore waters off the coast of New Jersey, where a state-waters fishery virtually ended by 2008 because of a severe decline in clam populations. Surveys also revealed poorer condition of the clams in extreme inshore locations, suggesting that warmer temperatures continued to affect surfclam nutrition negatively. These results have been interpreted as lending further support to the conclusion that surfclams are negatively affected by warming in their southern and inshore range (Marzec *et al.*, 2010).

Table 1. Landings and status: Atlantic surfclam (EEZ only, 1000 mt).

Year	Quota	Landings[a,b]	Biomass[c]	Fishing mortality[b]	Recruitment
1999	19.8	19.6	1 086	0.019	98
2000	19.8	19.7	1 074	0.019	95
2001	22	22	1 059	0.022	94
2002	24.2	24	1 037	0.025	89
2003	25.1	25	1 012	0.026	87
2004	26.2	24.2	984	0.026	84
2005	26.2	21.2	955	0.023	82
2006	26.2	23.6	931	0.027	82
2007	26.2	24.9	905	0.029	81
2008	26.2	22.5	878	0.027	80
Min[d]	13.8	6.4	831	0.018	80
Max[d]	26.2	33.8	1 092	0.031	112
Mean[d]	21.4	20.1	995	0.024	99

Source: NOAA Northeast Fisheries Science Center (2010, p.12).
[a]Landings not adjusted for incidental mortality, which is assumed to be ≤12% of landings. Discards have been very low since 1992.
[b]Fishing mortality is an annual rate assuming that incidental mortality was 12% of landings.
[c]For shell lengths 120 mm+.
[d]Minimum, maximum, and mean for 1965–2008 (landings), 1978–2008 (quota), 1981–2008 (biomass and fishing mortality), or 1982–2008 (recruitment).

Biophysical modelling

The project first seeks to test the climate change hypothesis and identify processes through which climate forcing can affect clams by integrating oceanographic models with population and genetic models. We view the surfclam population as composed of source and sink subpopulations, which are affected directly by changing environmental conditions. A Mid-Atlantic Surf Clam (MASC) model is being developed by the Ocean Modeling Group at Rutgers, in collaboration with others on the project. The modelling effort includes a coupled larval–hydrodynamic model and an individual-based post-settlement model. The hydrodynamic core of the coupled larval–hydrodynamic model is the Regional Ocean Modeling System (ROMS), in use worldwide for both basic research and real-time applications (Haidvogel *et al.*, 2008).

In its current form, the coupled larval–hydrodynamic model combines a hydrodynamic model for the Mid-Atlantic Bight (and, ultimately, the Gulf of Maine) with an individual-based submodel for surfclam larvae. The model is formulated to encapsulate temperature- and food-dependent growth and temperature- and size-dependent vertical migration, permitting a larval transport model that integrates passive particle transport with larval behaviour. The particle-tracking capability of ROMS provides a starting point for understanding the biology of range shifts. The modelling team's initial simulations of larval transport are being used to compare the likely distribution of larvae spawned from selected

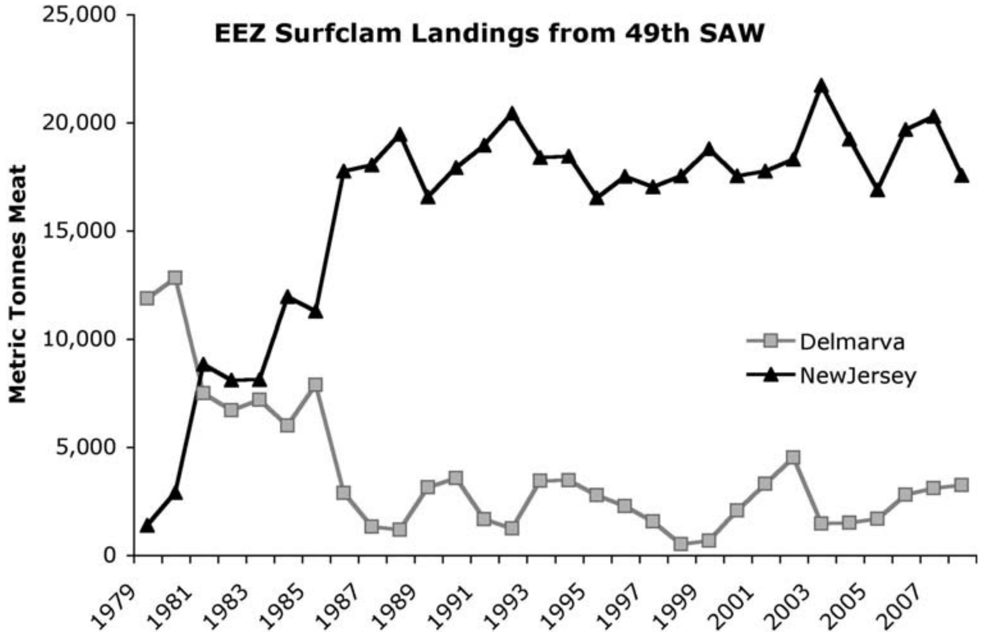

Figure 3. Trends in surfclam landings (t), Delmarva and New Jersey Regions, 1979–2009.

regions with observed surfclam distributions. This has allowed a preliminary assessment of larval transport, population connectivity, and the consequences of changes therein, resulting from altered circulation regimes that might arise from climate forcing (Figure 4). The dynamics of the sessile adult surfclam population will be simulated using an individual-based population dynamics model originally developed for hard clams (Hofmann *et al.*, 2006), but adapted for oysters and surfclams (Powell *et al.*, 2011). This model formulation includes phenotypic variability within cohorts, thus permitting inclusion of genetic variability into population dynamics.

Economic modelling

One of our tasks is to link a model representing fishing industry behaviour to the biophysical model, such that the results of environmental and biological interactions interface directly with the fishery. The human component of the coupling casts the fishery as a series of economic and sociological interconnections and response variables (Figure 1). To complement the detailed biological-physical models of the surfclam population, we are developing a spatial-choice model of behaviour in the harvesting sector that has output that is entered into the biophysical model. The model integrates improvements on the three critical components of spatial-choice modelling: the production function, the market for clam landings, and the market for ITQs. In the model, commercial harvesters decide how much to harvest, where to harvest, and when to harvest to maximize their stream of net benefits subject to constraints. The constraints include both the population of clams observed by the harvesters (the population predicted by the MASC model for the current period) and technical constraints on landings per unit effort (lpue; the production function). Net benefits, in this case profits, are defined by revenue (determined by the market price for clams multiplied by the landings) minus the sum of costs of inputs (the exogenous price of inputs, such as fuel) and the costs of individual tradable permits (determined by the market for ITQs, either leased or sold). Using dynamic optimization, this system of equations can be solved for a set of equations that describe the series of harvests over time.

The coupling between human and natural systems is completed by inserting the harvest predicted in the economic model as a shift in the initial conditions of the population model. Therefore, the harvester observes the current population and decides the optimal harvest, and this decision is reflected by a decrease in the starting population for the next iteration of the population model. In other words, the fishery generates a fishing mortality gradient across the population; this gradient is determined by fleet dispersion and its use of the agreed quota. The fishery also exerts a differential mortality on the suite of genotypes present in the population, because the fishery preferentially harvests larger and likely faster-growing individuals. Finally, the distribution of the stock influences the fishery by modifying that of effort and hence the economics of the fishery.

Such dynamic optimization models have been used to compare regulatory approaches, including ITQs (Grafton *et al.*, 2000; Weninger and Just, 2002). Our integrative approach improves upon the standard fishery bioeconomic models by linking directly with the MASC model; the latter explicitly models both the spatial variation in the resource and larval (source/sink) dynamics. Therefore, the economic model can include spatial variation in resource abundance and age-structure matters that are increasingly incorporated in fisheries economic modelling (Wilen, 2000; Hicks *et al.*, 2004; Battaile and Quinn, 2006; Mchich *et al.*, 2007; Tahvonen, 2008).

The economic model also gives due attention to the vagaries of a natural resource system, where weather and other natural forces add variability using an econometric approach allowing for stochastic variation in harvests (Brandt, 2007). The stochastic production function breaks the deviation from the theoretical production frontier into two sources, namely production inefficiency and white noise; it is written as an ordinary production function with the addition of a one-sided inefficiency term, indicating the distance from the production frontier for a given vessel

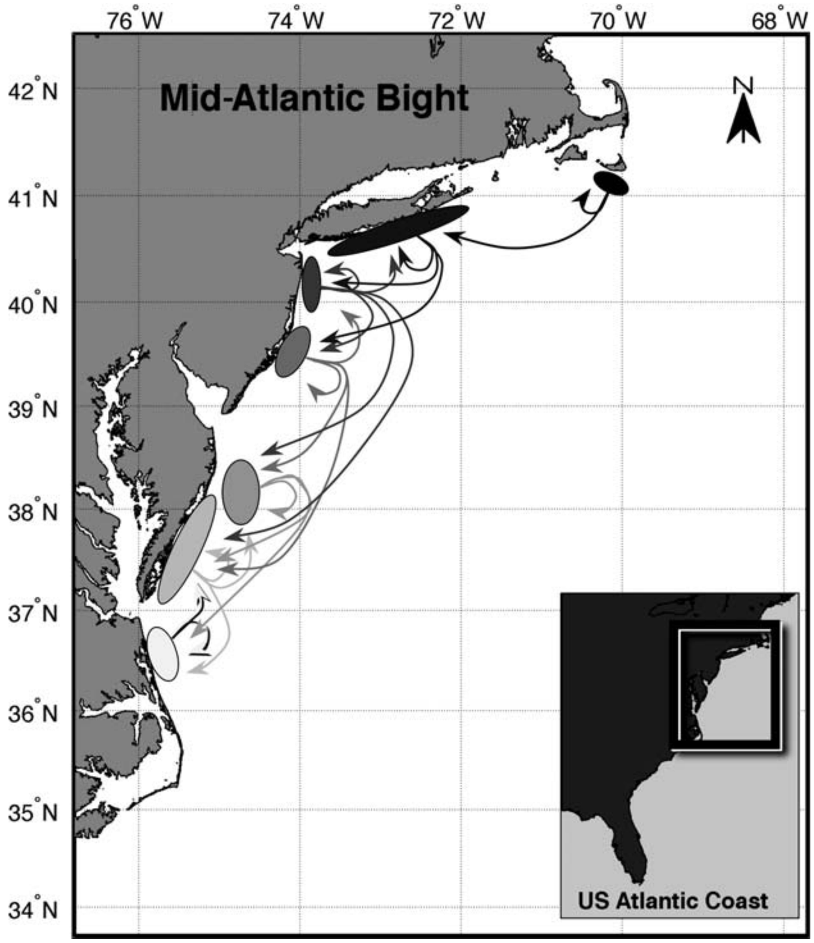

Figure 4. Simulated patterns of larval dispersal, Mid-Atlantic Bight, 2006–2009.

in each year. The outcomes of these modelled interactions will be used to represent better how the fishery influences the stock by modifying the total fishing mortality rate and the dispersion of fishing mortality geographically and by size class.

Observations on feedback from the economic to the biophysical system

Judging from reported data on landings and interviews with industry representatives, such modelling approaches should aid interpretation of events that are apparently unfolding. They are purposely intended to generate insight into the conditions for and against major adjustments in the coupled system, particularly through surfclam management. Of principal interest is the distinction between behavioural changes that are decoupled from the marine ecosystem and others that potentially affect the resilience of the coupled marine ecosystem and, therefore, might call for management interventions.

Changes in the surfclam populations are modifying economic conditions in the fishery. Commensurate with the decline in clam populations to the south and inshore, productivity has declined: "The most worrisome trend in the surfclam fishery continues to be the relentless decline in the productivity of effort. . . . A fleet-wide calculation of surfclam . . . lpue has declined by an average of almost 10% each year between 2000 and 2008, from 129 to 57 bushels per hour" (Mid-Atlantic Fishery Management Council, 2009). Moreover, this decline is accompanied by a spatial shift. The data thus far reveal the movement of fishing effort northwards, focusing more on the relatively abundant clam beds. Consequently, the industry has come to depend heavily on just a few 10′ rectangles off the state of New Jersey in recent years (Mid-Atlantic Fishery Management Council, 2009, 2010), as demonstrated in a comparison of lpue data from 2002 to 2007 (Figure 5).

The spatial shift is apparently a logical response to spatial changes in productivity; however, there is evidence that concentrating on few small areas is resulting in further declines in productivity. Using outputs from the spatial-choice model to link to the biophysical models should allow us to explore the extent to which localized depletion is taking place and the significance of localized depletion for the larger population. A major hypothesis tested in the biophysical modelling is that areas such as the heavily fished grounds off the northern New Jersey coast are functional sources of recruitment, whereas areas where clams are stressed by climate change, to the south and inshore, function as net sinks, where climate-induced conditions might be poor for larval setting, survival, and growth; recruitment then tends to come from other subpopulations. Initial modelling results suggest that there might be additional sinks to the north, resulting from various oceanographic factors. In other words, the fishing industry could be adjusting to environmental change by focusing

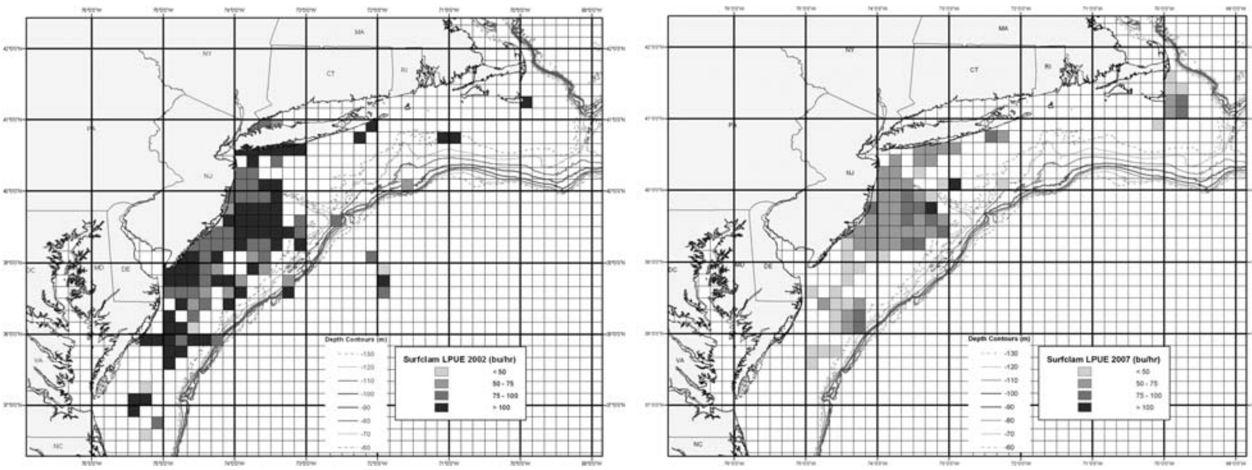

Figure 5. Atlantic surfclam lpue, 2002 and 2007.

on "abundance highs", which are key sources of future recruitment, hence threatening the resilience of the surfclam population and consequently the coupled system.

To some observers, the localized depletion of clam beds is a mounting problem calling for management action, such as temporary or rotating closures to protect "source" populations, a spatial management approach used to good effect in the region's sea scallop commercial fishery and considered appropriate where there are strong source–sink relationships (Fogarty and Botsford, 2007). However, as of the 2009 stock assessment, data on such localized subpopulations make little difference to the status of surfclams overall, because of three factors: (i) the broad distribution of the clams, (ii) a legislative mandate to manage fish and shellfish stocks throughout their range, and (iii) potential access to a substantial population on an area of Georges Bank closed to harvest since 1990, because of the risk of infestation with agents of paralytic shellfish poisoning (PSP). Economic modelling, combined with information from interviews and observations (see below), should allow us to determine the likelihood that those areas will continue to be targeted and/or whether a threshold in yields, profits, or other variables will precipitate changes that require concerted action, such as the creation of voluntary measures or regulations that reduce such localized fishing effort. Modelling could be helpful in suggesting the thresholds that result in major changes in the system, such as creation of area-based management measures.

Following the logic of the "economics of flexibility" developed for ecological systems (Slobodkin and Rapoport, 1974) and applied to marine fisheries (McCay, 1978) and other human-environmental interactions, agents are expected to make fairly conservative, minimal responses at first, which may be viewed as lower-level or coping responses. Only when those responses no longer suffice or when they become too costly will agents make more costly responses that could have implications for the coupled socio-ecological system, including responses that change significantly the ways and intensities with which humans interact with the marine environment. The latter could include responses that warrant the term "adaptations", higher-level responses that, when successful, restore the capacity of the system, or the actors within it, to carry on with minimal adjustments. This systems framework, distinguishing coping from adaptation, but recognizing links between them through the processes of response to environmental stressors like climate change, is a key component of the study of vulnerability and resilience (Davidson-Hunt and Berkes, 2003) in human–environment interactions.

Many of the observed behavioural responses to climate change and those expected in the near term in this fishery are lower-level coping responses, adjustments within the framework of "business as usual". The immediate economic implication of the previously described concentration of harvesting effort is additional pressure on costs of harvesting through crowding externalities and through travel costs. Some boat owners (or quota-holders) might make little, if any, change, absorbing the costs of additional time taken to fill their boats and orders or greater distances to get to the fishing grounds or new ports; they might also be able to offset costs by reducing crew share, putting off maintenance, and other measures. In some cases, the costs are essentially passed onto the processors because of long-term contracts. Diversification, an important coping strategy in many fisheries (McCay, 1978), is not likely in this case, except by switching to ocean quahogs, a choice constrained by lower demand and the requirement to fish in deeper waters.

We can identify many coping responses to climate change in the fishery for the intermediate term. Primarily, if the spatial distribution of the harvest is not in line with processing capacity, some processing might be redistributed to plants that are closer to the new source. When costs reach a critical level compared with revenues, some participants will exit the industry altogether. At some point, a basic change might happen in the socio-economic relationships between harvesters and processors and between processors and wholesalers/distributors, as well as change in the bargaining power between agents. These changes could be expressed in changes in contracting, in the ownership and value of ITQs, and other factors. Eventually, some firms and people could go broke and leave the fishery; delayed maintenance and changes in labour management could increase risks at sea, worsening losses; the process could result in structural change within the industry, but also to serious consideration of making changes in how the fishery is prosecuted and managed.

Both structural and managerial changes can be seen as higher-level responses, with potentials for adaptation in the coupled socio-ecological marine system. In sum, we expect to find coping or "business as usual" responses to predominate as important components of the adaptive capacity of the industry in the early period of climate-change-induced decline in surfclams. As time goes by, if the climate-induced stressors continue or worsen, will the industry, and the larger government–industry–science management system, have the capacity to make more transformative and corrective responses?

Knowledge, frames, and community

Coupling in the socio-ecological system is not only at the point of fishing. It also happens indirectly through the statutorily mandated fishery management process that focuses on quota-setting and other management measures. The complex decision-process involved in surfclam management is a focus of our ethnographic research, which in turn feeds back into construction and interpretation of the economic and biophysical models. This is an iterative process, because quantitative and qualitative models, scientific and lay, play important roles in communicating about and interpreting the nature of the system and changes that might be called for, including the possibility of spatial management to protect local clam beds from heavy harvesting pressure and/or adjustments downwards of the overall limit on allowable landings.

Understanding whether and how the surfclam management community and its adjuncts within the industry adjust the fishery management plan or come up with alternative, voluntary measures to mitigate the effects of climate forcing on the surfclam population calls for analysis of the socio-cultural, political, and cognitive dimensions of the decision process. The ethnographic approach can extend and enrich the economics model, thereby contributing to the larger modelling project. In our ethnographic extension, we assume that culture, history, and institutions affect people's choices for their own responses to climate change, as well as their abilities to influence a collective choice. Members of different social groups might share a good deal of history and yet see things differently, based on their access to information, their type of expertise, and their own interests. The aim of ethnography is to map out these social groups and identify how they see things. Which facts do they consider? Which facts do they consider irrelevant? What options do they see as realistic to consider? What are the tipping points that would make them take more drastic measures to protect this fishery from the impacts of climate change? What else would make them take individual or collective action?

Therefore, in this project we also document and analyse interactions and discursive processes within the stock assessment and quota-setting processes. Human dimensions research includes study of the social and cognitive processes involved in making management decisions as key coupling mechanisms between natural and human elements of the system. In the Atlantic surfclam management system, which is located within the regional fishery management regime for federal waters, information from scientific stock assessment goes to the Mid-Atlantic Fishery Management Council (the Council), after being vetted by its Scientific and Statistical Committee (SSC). As of 2007, the SSC has the mandate to determine the biologically acceptable upper limits of allowable catches, factoring in scientific uncertainty. The Council's Surfclam Committee and its Industry Advisory Panel make further recommendations. Through the SSC, the stock assessment will affect management decisions, but the nature of that process and options available are informed by legislatively determined constraints and political negotiations within those constraints, as well as the cognitive models or frames by which people make sense of and persuade others about what is happening and what should be done: the crux of adaptation to environmental change.

Knowledge coming from and represented by models, as well as observations and narratives, plays a role in constructing cultural "frames" for understanding and action (Snow and Benford, 1992; Kahneman and Tversky, 2000). In the social sciences, frames are interconnected sets of ideas or categories that "... provide a basis for forging shared meanings and coordinating social action" (McLaughlin, 2001). They are similar to what some anthropologists describe as cultural models (Paolisso, 2002, 2007), but they could include scientifically developed models. The scientific models produced for surfclam management are critical components of the institutional frameworks that help the management community agree on the situation, as well as on strategies and actions appropriate to it.

Models do not stand alone; they are accompanied by metaphors and narratives used in discussing circumstances and presenting the models, as well as both explicit and tacit assumptions about scale, goals, acceptable levels of risks, the workings of nature, core values, the "social situatedness" of those involved in creating and using them (Taylor, 2005), and the ways that even global ideas and events are channelled via media, experience, and politics (Broad and Orlove, 2007). In fisheries management, certain frames—complexes of scientific understandings or models, discourses, legal requirements, norms and values, and management strategies—might be dominant, but also differ among participants and settings and change over time, influencing the outcome of decision-making.

A key question for this type of analysis is what determines the outcomes of Council deliberations on surfclam management, particularly in relation to changes in the fisheries that relate to climate change. The analysis examines how interpretive frames, including those related to scientific models, affect decision-making, which voices and models become persuasive (Creed, 1991), and by what means (Dryzek, 1990; Hajer, 1995). For example, observing and reviewing reports of meetings reveal competing views and how they are framed; they also identify which views became dominant enough to shape fishery management decisions, as revealed by votes and management decisions. Our observations in scientific meetings also suggest that fisheries stock assessment itself is a powerful cognitive framework with boundaries, and thus far, climate change is outside those boundaries.

For surfclam management, the dominant frames or interpretive paradigms pertinent to management also apparently changed since the 1970s. Our preliminary research indicates that in the early period, when it seemed that there were very few year classes in the fishery and no signs of new recruitment, the frame used in management was similar to that of "mining"; the quotas were established according to the rate at which the industry agreed to take what had to be seen as a non-renewable resource, though with the hope that another commercial-size set might occur. In later times, with signs of recruitment and more successful year classes and with changes in legislation and science, the classic surplus production and "maximum sustainable yield" models of fisheries management science were applied to Atlantic surfclams. Our research takes place at a time when policy shifts towards ecosystem-based fisheries management (EBFM; Pikitch *et al.*, 2004) and when the effects of climate change are challenging the earlier models, shifting the frames used for analysis and opening up possibilities for change in policy and practice. In particular, we are watching for signs that evidence of climate change will promote more ecological or "ecosystem-based" visions of the surfclam fishery, which has so far been viewed in a single-species and production-orientated framework.

We use ethnographic methods to document both resistance to frame shifts (which can also be considered paradigm shifts), as well as the emergence of new cognitive models or frames in the science and decision-making processes. Ethnography supplements the modelling done in this project to document the ways that people and the organizations they interact with interpret and respond to signals of change, including participant observation (DeWalt and DeWalt, 2001) at advisory and Council meetings, formal and informal interviewing (Bernard, 2005), and textual analysis of discourse (Dietz, 1994; Hajer, 1995; Wilson and McCay, 1998; Campbell, 2002; Gelcich *et al.*, 2005). This work is continuing; an example of the kinds of observation that we make comes from a science-management meeting held in early December 2010. In a two-day meeting on issues of uncertainty and variability in fisheries stock assessment for the northeast region, climate change was not mentioned, and when a National Oceanic and Atmospheric Administration (NOAA) scientist at the meeting was asked by one of us why, we were told that now there are functional divisions between those who are doing stock assessments and those studying the effects of climate change on fisheries. We will pursue further reasons why research on climate change in fisheries apparently proceeds separately from population dynamics work for stock assessment. We will continue to explore why there is little place yet in stock assessment and hence in developing recommendations for management, for incorporating climate change, even in discussions of sources of variability and uncertainty and despite discussion of spatial variation in key parameters, such as natural mortality.

Frame analysis in the fisheries cases is also a way to understand the outcome of particular decision-making interactions. The frame of "science" could be contrasted to discourses of fairness, efficiency, or community welfare; which frame dominates or is deemed acceptable in a meeting could drive the outcome. In some committees, particularly the SSC, efforts are made by the chair to ensure that the frame of science predominates, and in those and other meetings, situations can be observed where efforts of some members of the industry to bring social equity questions into the discussion come into conflict with those who claim science-based assessment of clam biology to be the only legitimate framework for discussions about setting quotas.

Cognitive frames are also important in what is known as "boundary work", particularly in organizations that bring together science and policy, so-called boundary organizations (Guston, 2001). In a highly participatory situation, such as fisheries management in the United States, boundaries between science and non-science, always problematic (Gieryn, 1995), can become very blurred and may be contested. Science itself is based on openness and transparency, but one of its paradoxes (Wilson, 2009) is that when scientists reach out to others, as increasingly is the case, those features can result in a perceived reduction in the legitimacy of the knowledge produced, requiring renewed efforts to construct boundaries, which could in turn jeopardize cooperation and communication (Johnson, 2007). We are documenting this process as it manifests itself in stock assessment and management council deliberations for the surfclam fishery.

Knowledge is not enough. Community is also critical to system change, particularly in common pool resource situations (Ostrom, 1992; Singleton and Taylor, 1992; McCay and Jentoft, 1998; McCay, 2002). Local communities are of less political importance in the Atlantic surfclam case than in many other fisheries, because the surfclam ports tend to be highly diversified; captains, crews, and boats move about; and the fishery is heavily industrialized. However, social groupings are important, as both networks of affiliation or factions within the industry and as networks that have formed around management issues. For surfclam management, these networks have considerable historical continuity, depth, and significance to those involved, warranting their conceptualization as communities and study of them as they influence management decisions.

Hence, we find that industry members, scientists, managers, and others engaged in surfclam management form a "management community", an enduring, although changing social network through which fishery management plans and their amendments are devised, deliberated, and implemented within legal and administrative structures. This is similar to an "epistemic community" (Haas, 1992), a network of professional experts formed around an issue. Over time, those involved have developed mutual understandings, if not full consensus, on causal beliefs and notions of validity and relevant norms. However, the surfclam management community includes the non-professional or experience-based expertise of industry members who participate in various capacities. Consequently, it is closer to an "extended peer community" (Funtowicz and Ravetz, 1992, 1993) that helps assure quality control in the production of knowledge for policy, which is deemed particularly important in situations of high uncertainty, considerable risk, and decision-making urgency.

Consequently, our approach to the human dimensions of fisheries and climate change calls for an ethnographic analysis of how scientific models, including scenarios that are generated from this project, are understood by and receive input from important stakeholders (such as harvesters, processors, and environmentalists), how they are represented in discourse within relevant communities, and how and whether they influence management decisions, whether public (state and regional fisheries management) or private (individual fisher and company decisions, collective industry decisions).

ITQs and decision-making

An important factor in the mix of collective decision-making about climate change and surfclams is that the fishery is managed with ITQs, a system where the tradable and private assets involved change incentives, so that asset-holders make choices that foster more efficient uses of a common-pool resource (Grafton *et al.*, 2006). In this case, perhaps the industry could devise and agree upon voluntary or self-regulated temporary closures to protect resources and reduce congestion. Could it overcome "free rider" disincentives for collective action (Olson, 1965; Ostrom *et al.*, 1994), or will it have to rely on the mandated authority of the Council, and in that case, can the Council be the venue for that kind of response to climate-forced changes in surfclams? Changes in the quota or closures would represent significant disruptions to the industry, which has been resistant to changes in the *status quo*, especially since ITQs were implemented in 1990, involving major capital investments and rearrangements of the distribution of power and wealth. Enforcing area closures would represent major costs to government as well as industry.

ITQs offer certain aspects of private property to participants in a fishery (Squires *et al.*, 1995; Anderson and Sutinen, 2005) and are promoted for their contributions to reducing the incentives to overcapitalization that often accompany common property fisheries, as well as to providing incentives for improved stewardship (Grafton *et al.*, 2006). Large and heterogeneous groups have particular difficulty overcoming problems that forestall collective action for public goods and common pool resources, like fisheries. ITQs have reduced the size of the industry and changed the pattern, if not the degree, of heterogeneity.

The Atlantic surfclam fishery was the first in US federal waters to be managed with ITQs. In this fishery, the ITQs are percentages of the annual total allowable landings (TAL) and are annually represented by a certain number of tags to be put on the wire cages that hold 30 bushels of surfclams each. The initial allocation of ITQs, in 1990, went to vessel owners according to a formula whereby 80% came from historical performance and 20% from the size of their vessels (Creed, 1991; McCay and Brandt, 2001).

The implementation of ITQs in 1990 resulted in rapid consolidation of fishing power and ITQs. As of 1990, 128 vessels participated in the limited licence federal fishery for surfclams; in 1991, after ITQs were implemented, the number declined to 75. Once ITQs went into place, the owners divested themselves of the excess capacity that had built up because of the "race for the clams" incentive structure of the previous management system, which had time restrictions, fixed quotas, and limits on vessel and gear dimensions (Figure 6). With ITQs, an industry already marked by the dominance of a few large vertically integrated firms became even more so, as small-holders either sold out or chose to lease out their allocations rather than continue to fish and as some firms bought out others (Brandt, 2005). The net effect today is a very small harvesting sector: in 2010 only approximately 38 vessels in the surfclam and related ocean quahog fishery, though a much larger number of ITQ holders (67 for surfclam ITQs and 55 for ocean quahog ITQs) reflecting historical participation and a much smaller number of firms that control much of the ITQ either directly, as owners, or indirectly, through their leasing power. Over this period, processors decreased the number of harvesters they needed to contract, but their total volumes and trucking distances were not affected substantially by the transition to ITQs.

The surfclam fishery is now a relatively efficient, lean system, the kind that economists and administrators envision for other fisheries and are trying to encourage through various policies and actions, including current policy emphasis on "catch shares" and "sector management" (NOAA Office of Sustainable Fisheries, 2009). Pertinent to our analysis, the ITQ feature of Atlantic surfclam governance, in combination with other features of the system, might affect its capacity to respond adaptively to signals of climate change. Whether and why that might be so are among questions we address. One hypothesis, for example, is that with reduced numbers of participants the transaction costs and conflicts likely to make collective agreements difficult in a fishery are reduced and there might be greater opportunities for voluntary ("self-governing") initiatives on the part of the industry, as suggested by the economist Anthony Scott (Scott, 1993, 1996). More generally, fisheries where overcapacity has been reduced through changes in incentives, as with ITQs (Grafton *et al.*, 2006), might be more resilient in the face of climate-induced and other environmental changes (Grafton, 2009).

Our research, therefore, asks how ITQs influence behavioural choices and collective action in response to the effects of climate change. The economics literature on property rights and natural resources has focused on two extremes: fully assigned exclusive property rights, resulting in efficiency through market trading (Coase, 1960; Townsend, 1998), and no property rights, resulting in overuse (Hardin, 1994). From this perspective, ITQs have emerged as tools for both increased efficiency and improved stewardship in marine fisheries (Squires *et al.*, 1995).

ITQs involve assigning to individuals or firms exclusive rights to shares of a quota, allowing them to be traded, promoting greater efficiency, but also, insofar as rights are secure over some period, promoting incentives for stewardship. However, as is true for many other natural resources, such privatization happens within a system of public ownership (Cole, 2002). Consequently, the right to determine the overall level of exploitation and other regulatory controls—a key "management right" (Schlager and Ostrom, 1992)— is reserved by a public body, the fishery management councils, where ITQ holders have only general public rights of participation, although they are far more likely than others to exercise those rights. Therefore, although ITQs are more "perfect" than most other fisheries allocation systems (Scott, 1996), they are incomplete. This raises the question of whether and under what conditions they might result in both efficient outcomes and incentives for stewardship and how they intersect with other institutions.

In a study of Mexican fisheries concessions that assign exclusive use rights to cooperatives rather than individuals (Ponce-Diáz *et al.*, 2009), uncertainty about the security of rights (the renewal of concessions) intersected with the extent to which the duration of a concession was appropriate to the life cycle of the shellfish involved (abalone vs. lobster) to influence whether a concession holder will take a short-term, mining approach to managing the fishery, or a longer term, sustainable harvest approach (Costello and Kaffine, 2008). In the surfclam case, the agreement to switch to ITQs and subsequent experience with them could also affect the strategies and interpretive frameworks used for resource management in the context of climate change. The first 20 years of ITQs were notable for relatively stable overall quota limits, but increased uncertainty about population size could create volatility in future value of ITQ holdings. These changes in future values and variability could affect the Council's decisions, as well as those of the industry, giving greater weight to short-term vs. long-term payoffs. Table 2 indicates both the stability and

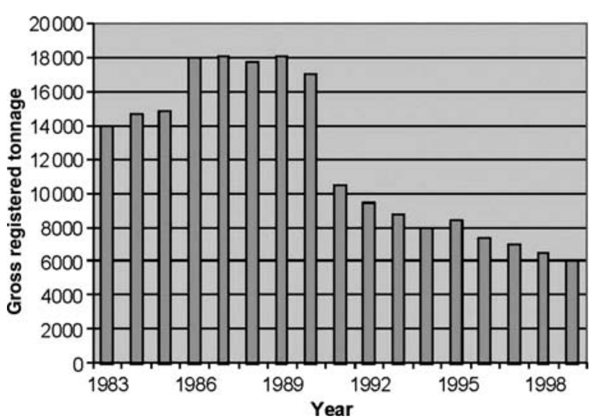

Figure 6. Atlantic surfclam fleet tonnage 1983 – 1999.

Table 2. Atlantic surfclam landings, quotas, and vessels, EEZ only, 1996–2010.

Year	Landings (bushels h^{-1} × 1 000)	Quota (bushels h^{-1} × 1 000)	% Quota	Number of vessels
1996	2 569	2 565	100	34
1997	2 414	2 565	94	33
1998	2 365	2 565	92	31
1999	2 538	2 565	99	33
2000	2 561	2 565	100	31
2001	2 855	2 850	100	35
2002	3 113	3 135	99	39
2003	3 244	3 250	100	34
2004	3 138	3 400	92	35
2005	2 744	3 400	81	36
2006	3 057	3 400	90	29
2007	3 231	3 400	95	33
2008	2 920	3 400	86	32
2009	2 594	3 400	76	36
2010	n.a.	3 400	est. 60	n.a.

Source: adapted from MAFMC (2010), based on NMFS Clam Vessel Logbook Reports; some of the vessels were also used to harvest ocean quahogs; in 1996, 14 were used for both species; in 2009, 8 were.

instability of the industry. The overall quota stayed the same for much of the 1990s; it began to increase in 2001 and reached the current level in 2004. The fleet had declined to the low 30s by 1996 and stayed small even with increased quotas. It caught more than 90% of the quota until 2005, and another downward trend began in 2008, the result of market problems, such that in 2010, as much as half the quota might not be caught.

Of particular interest in this study is how these and other factors influence whether and how members of the industry coordinate their efforts in response to shifts in the density of harvestable surfclams, or in the terms we used earlier, whether they will shift from "business as usual" coping responses, mostly at the level of individuals and firms, to responses that call for coordinated and collective action. Economic modelling of an ITQ fishery (Costello and Deacon, 2007) has suggested that when a stock is heterogeneous in density or location, the potential "rent" that could be gained from the resource might be dissipated through competition for the more accessible or denser resources, reproducing collective action problems, as evident in the surfclam case. However, either more precise delineations of the ITQs or agreements among harvesters to coordinate their effort might eliminate the inefficiencies generated (Costello and Deacon, 2007). In the surfclam fishery, ITQs are already precisely delineated, suggesting that the latter is the better solution as firms struggle to deal with the increasing volatility of the system. Our coupled model of the marine ecosystem and harvesting sector allows us to use simulations to describe likely outcomes under various climate scenarios or management options. For example, the problems created by concentration of harvesting pressure might result in creation of area-specific ITQs or area closures. These changes can be reflected in constraints of the economic model. Alternatively, we could compare predicted harvests where perception of the effects of climate change on economics is consistent with the biological model to predicted harvests where the agents' perception differs. Last, we can add to this system a constraint to reflect how legislation and administrative rules define overfishing to illustrate effects of changing such a key definition.

Precautionary approaches to climate change

Thus far, coordination for addressing climate-related issues in surfclam fishing has taken place mainly through industry meetings in 2008 and 2009 to discuss the potential for spatial management, building upon the social capital created over the previous decade for industry cooperation in supporting cooperative research with academic and government scientists (Bochenek *et al.*, 2005; Johnson, 2007). However, little follow-up happened and our ethnographic and economic research is trying to explain why. On the surface, it appears that climate-change issues have intersected with others, such as the reopening of Georges Bank's clam beds, far to the north, and whether an "excessive shares" regulation would be imposed, as well as serious market problems for the industry. In other words, even climate-change issues have contexts and competition.

One of the scientists involved in the stock assessment process for surfclams asked at an assessment meeting in 2010, "Is it time to raise the red flag?"—apparently not. In spring 2010, the Council once again voted to maintain the *status quo* for surfclam management, despite concerns about depletion of some clam beds and the die-offs to the south. This decision came about partly because of the legislative constraints, but also likely because of strong pressures from the more powerful members of the industry to avoid change and reluctance to act given uncertainties.

Conditions in the industry and the management system appear to support continuation of low-level coping tactics and to delay or mitigate adaptations to climate change. Our preliminary research has, for instance, observed how the legislative requirement to manage a stock throughout its range, which affects the determination of whether "overfishing" is taking place, can work against the adoption of early measures to protect shellfish stocks in the face of climate change. Moreover, for market, regulatory, and other reasons, some of the major companies in the industry apparently adopted a cautionary "wait and see" approach.

Our preliminary analysis reveals very little proactive or reactive adaptation to climate change beyond the movement of harvesting effort to more abundant clam beds and despite strong evidence of serious depletion of those beds. The dominant industry strategy, on the level of major companies, is "wait and see", trying to keep businesses going, while making minor adjustments in how business is done and exploring alternatives. The situation is marked by economic uncertainty and distress, because of declining demand for surfclam meat, resulting in "underfishing" as it were, catching far fewer clams than allowed by the annual quota—which itself is far lower than the level judged to be biologically safe for the population throughout its range. This throws a wrench into the ITQ system, threatening the value of ITQ investments, because some holders find themselves without contracts. The effects of climate change remain evident in the northward shift of harvesting and crowding and intensified pressure on the "hotspots" or dense clam beds, resulting in sharply declining catches per unit of effort (cpue), which raises the costs of harvest and interacts with declining market demand to reduce profitability at the harvest end of the chain. As of 2010, it has become an industry under severe pressure.

One expected response to economic pressure, including decline in the value and hence price of ITQs, is further consolidation. However, this is stalled, at least, by uncertainty about the regulatory climate. In 2009, the overseeing agency, NOAA, raised the issue of defining "excessive shares" in the ITQ system; the fisheries legislation requires that such a system involving the allocation of fishing privileges be "carried out in such manner that no particular individual, corporation, or other entity acquires an excessive share of such privileges." When this ITQ system was implemented in 1990, a decision was made by the Council and approved at higher levels of NOAA not to define what "excessive" would be in the Atlantic surfclam fishery, with the understanding that the Department of Justice could be counted upon to act if there were signs of monopsony, but in 2002 a recommendation emerged to require all regional management councils to set excessive share limits for such programmes (General Accounting Office, 2002). By 2009, it was clear that the surfclam industry was not exempt, but as of the end of 2010, no decision had emerged. Because of uncertainty about the outcome, some industry representatives indicated that the option of further consolidation in response to economic and resource issues was not realistic soon.

There are other "wait and see" factors. One that differs in having required major investments in technology and experimentation is uncertainty about the reopening of clam beds in the northern part of the range, on Georges Bank. As noted above, harvesting the Georges Bank surfclam population has been discontinued since 1990, because of PSP risks, and members of the clam industry have invested in collaborative work with the government to develop monitoring and testing facilities, permitting the reopening of an area called Cultivator Shoals. Reopening would allow the northern processors and large, offshore-capable vessels to shift and reduce dependence on southern clam populations—as well as smaller-scale harvesters and the ports that depend on them. Given hope about reopening Georges Bank, it makes little sense to work on climate-related issues, such as overcrowding, and overworking of the clam beds off the coast of New Jersey, at least for the better-situated and endowed processors and vessel owners prepared to exploit those clam beds.

Conclusion: Adaptation to climate change and dramas of the commons

Research on climate change and the Atlantic surfclam fishery system is yet in its early stage, but planning allied with early implementation are useful in identifying ways that human dimensions can be meaningfully incorporated into multidisciplinary research on climate and fisheries. We have outlined the economic spatial-choice modelling that directly links to and will provide feedback to a biophysical model and ethnographic research on the roles of knowledge, community, and property rights in the process of making decisions about the fishery, which is critical to adaptation to climate-induced environmental change and which can be used for refinement of the economic model.

Some well-known approaches to the human dimensions of fisheries are not emphasized in this paper. The topic of human influences on the marine system is implicitly addressed regarding fishing mortality, but it is otherwise neglected, despite evidence of cumulative impacts of human activities on marine ecosystems (Halpern *et al.*, 2008), including anthropogenic climate change. The topic of social impacts (Pollnac *et al.*, 2006) is equally important, but it is already very well represented in fisheries science. We therefore have disregarded it, except to point to the competition between cognitive frames that allow for discussion of social equity and community issues and those that focus on biological science and stock assessment in fisheries management decision-making. Climate-change fisheries research will require far more emphasis on social impacts to address questions about differential vulnerability (Adger, 1999), which is central to understanding the potential of adaptation to climate change.

In our focus on management decision-making, we adopt a perspective about "human dimensions" methodology that differs from certain traditions in fisheries and climate-change research. The standard ways of thinking about humans in relation to marine ecosystems presuppose human activities and by-products as threats, whether discrete or cumulative (the "anthropogenesis" factor); humans as consumers of "ecosystem services" (including "valuation" and "trade-off" analyses); and, from the social scientists, humans as those affected by environmental or regulatory change (the "social impact" approach). In addition, there is the larger view of humans as "tragedians of the commons", reflecting the inadequacies and failures of our institutions for managing marine systems, where property rights are complex and fluid and jurisdictional boundaries rarely coincident with ecosystem properties (McCay, 2009).

The situation with surfclams today—their die-offs in the south and inshore and the possibility that their resilience will be threatened by intensified fishing on the "abundance highs" off New Jersey and other places—adds some urgency to a human dimensions approach that casts people as thoughtful, interested, creative, and differentially situated actors in "dramas of the commons" (Dietz *et al.*, 2002), not just as sources of problems for natural systems and not just as recipients of social and economic impacts from how those systems behave and are managed. The actors are not just fishers and vessel owners, not just buyers and processors, but also managers and scientists trying to make sense of the situation and find workable and acceptable solutions. One encyclopaedia definition of comedy is: "The drama of humans as social rather than private beings, a drama of social actions having a frankly corrective purpose" (McCay and Acheson, 1987). In that sense, the efforts of members of the management community to interpret and respond to signs of environmental change may be considered a comedy of the commons. We are left wondering what the industry, the scientists who carry out stock assessments, and the management councils would do if, and when, the effects of climate change on surfclams and other benthic creatures worsen and are integrated into fisheries science.

This begs the question, what about the larger institutions of science and management? Significant changes are already taking place in US fisheries science and management, including policies favouring both "catch share" and market-based management, of which the surfclam fishery is a prime example, and EBFM. EBFM could benefit from the more focused, incremental approach represented by this case, where traditional single-species management is enhanced by addressing a major environmental factor, climate forcing, and the fishing industry has a strong presence in decision-making. EBFM efforts are often hampered by the immensity of the tasks involved, if the effort is to encompass all aspects of a large-scale and complex ecosystem, or even if differences in appropriate scale are acknowledged (McLeod *et al.*, 2005; Crowder *et al.*, 2006; Leslie and McLeod, 2007). Even more daunting is the claim that climate-change-related ecological issues are "wicked" problems (Rittel and Webber, 1973), calling into question the very enterprise of "management" (Roe, 1998; Ludwig, 2001; Taylor, 2005; Bavington, 2010). Moreover, although there is a strong public contingency for ecosystem-based approaches to the ocean, thus far it has been difficult to get fishing industry acceptance. A more focused, incremental approach could contribute to the development of the scientific basis for ecological management when warming waters and other manifestations of climate change are eventually incorporated into management.

This particular drama is still unfolding and we cannot tell yet whether it will result in a comedy or a tragedy. Free rider and other common property issues continue to shape events and their outcomes, even in this case, where access rights to a fishery commons have been privatized. Indeed, in this modern, industrialized fishery, those with access rights are competing among themselves and with others for access to the resource to compete successfully in the marketplace. Therefore, they both cooperate and compete; they co-manage and they make their own business plans. To that extent, the people involved could be acting out a tragedy of failure to correct the consequences of decisions that seemed right at the time, but that over time, and in the aggregate, can prove costly. However, the ocean and the clams are not privatized and, hence, the venue of decision-making is public, open to open to the possibility that people will work together to interpret the situation and actions that meet larger and longer term goals in adapting to the effects of climate change.

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