SEARCH, COMMUNICATION AND THE PRECONDITIONS FOR COLLECTIVE ACTION IN THREE FISHERIES

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INTRODUCTION

There are few fisheries in the world where collective action has led to sustainable resource management. The Maine lobster fishery is one example often cited. In the early part of the last century, the lobster fishery was thoroughly depleted (Acheson 2003; Acheson and Gardner 2010); in response, a long negotiation between the state, scientists and the industry led to effective and well-enforced rules restraining fishing and conserving the resource. But the same fishing communities that have conserved lobster with such success have also pursued and thoroughly extirpated local spawning populations of several other species, including groundfish and sea urchins. The key question is, What is it about the lobster fishery and the way it is conducted that leads to successful collective action and sustainable resource use while other fisheries exploited by the same communities are over exploited?

In this article, we compare the Maine sea urchin, lobster and groundfish fisheries with the goal of giving another viewpoint on factors causing the differential success of management efforts in these three fisheries. In 1990 Elinor Ostrom published her famous list of the preconditions conducive to successful collective action. We argue that the preconditions she lists[1], especially those that are the self-organized product of individuals' interactions with each other (not those that are principally a product of broader-scale formal governance) and with the environment, are sensitive to the costs individuals incur while learning about and adapting to complex natural and social environments. Our motivation is to address Ostrom's admonition for "further work to explain why some contextual variables enhance cooperation while others discourage it." (Ostrom, 2000b). We focus our argument on the way different environments lead to different problems of learning and adaptation, and consequently, to the emergence of different social structure and dynamics that may or may not be conducive to collective action. We then turn to a quick description of the way the problem of learning and adaption affects informal social structure and the likelihood of collective action in three fisheries. We believe this focus on learning and adaptation leads to a better understanding of the ways natural and human systems interact and, thereby, adds to the literature concerning the success and failure of collective action in the commons.

[1] Along with those listed by others building on her work (e.g., Agrawal 2002; Wade 1994; North 1990).

Learning and adaptation

In a complex world, the acquisition of useful, usually mundane, practical knowledge is a necessary and continuing part of life. By useful knowledge we mean knowledge about the order and regularity of the social and natural environment, especially knowledge about particular local circumstances. The usefulness of this knowledge lies in the guidance it offers about the likely outcome of the alternative actions the individual might take. Presumably the choices individuals make about what actions to take (the near equivalent of what to learn [or not learn]) are biased towards actions that they believe will lead to predictable, beneficial outcomes.

Practical knowledge is usually acquired through personal experience and communications; its acquisition is costly in the sense that even though each action contributes to increased knowledge, it also means the individual has incurred an important opportunity cost, i.e., the loss of the knowledge potentially gained if she had taken another action. The knowledge the individual acquires or doesn't acquire influences her subsequent decisions and focuses her knowledge about both the natural and social environment. Individuals are aware of the way this focus limits their knowledge and affects their capabilities, letting it steer their decisions about the relationships they develop with others and about where and how to compete and cooperate.

A simple, repeated decision process drives this focus. At any moment, an individual must decide whether his interests are best served through the continued reliance on already existing knowledge or through actions that might generate new, useful knowledge, i.e., through autonomous exploration or communication with others. That decision is strongly influenced by the individual's assessment of the net benefits of alternative actions and that assessment, in turn, is strongly dependent on the individual's experience, that is, his focused, tentative, and somewhat aged knowledge of his environment.

For example, in a local part of a complex environment, a search conducted by someone who is already knowledgeable about that part of the environment is likely to be more directed and more likely to produce useful knowledge than a search conducted by a person not familiar with that place. In a familiar environment, an individual better understands the context and the significance of what is observed. This experience is the source of relative advantage for the future in that familiar environment and is likely to make an individual even more strongly disposed to search that place again; but the cost of this familiarity is the loss of the knowledge that might have been acquired if other places had been searched.

Similarly, communications among individuals who are familiar with their current environment and with one another are likely to be less noisy, more nearly complete, and less ambiguous than communications among individuals who don't know one another or the local context. Consequently, communications among familiar individuals are more likely to yield more accurate and valuable information and, as a result, are likely to be favored in the future. But the knowledge acquired this way also comes at the cost of not acquiring knowledge of other circumstances from other people.

Thus, the subtle and cumulative effects of an individual's decisions tend to focus her knowledge towards areas and people with whom she is already familiar. Within those areas and among those people, the individual can make reasonably informed decisions about the likely outcome of her actions. Outside that particular environment her lack of experience creates pervasive uncertainty, making it more difficult for her to anticipate the outcome of her actions.

Nevertheless, the benefits of familiarity are not unlimited. Familiarity feeds on itself and in the process erases some of its own benefits. That is, the more individuals know one another, the more they share a similar body of knowledge and the less new, valuable information they can acquire from one another. In a dynamic environment, this kind of closeness shuts off opportunities, creating incentives for obtaining different knowledge from other, less familiar individuals and places.

The extent to which an individual might obtain differentiated knowledge is also limited by the opportunity costs of acquiring new knowledge. Those costs depend upon the complexity of the environment. For example, in a simple, i.e., a regular or a random, environment the knowledge an individual acquires in one place is easily generalizable to other places; if the individual leaves a place, his absence is not particularly costly because when he returns the value of his previously acquired knowledge is largely intact. Thus, in the extreme instances of perfectly regular and random environments—two states almost universal in mathematical models of resource systems—both search and communication carry no opportunity cost; the individual has little to gain from relationships with any other individual, and, consequently, there is no need for social structure. In the lobster fishery, for example, the last 20 years have seen extremely high levels of abundance compared with the scarcity that existed when many of its informal institutions were formed (Acheson 2003). Compared with that era of scarcity, the current situation makes it easy for an individual to fish successfully in unfamiliar waters, lowering the opportunity costs of search and communication, reducing the advantages of social structure and making the value of restraint less apparent.

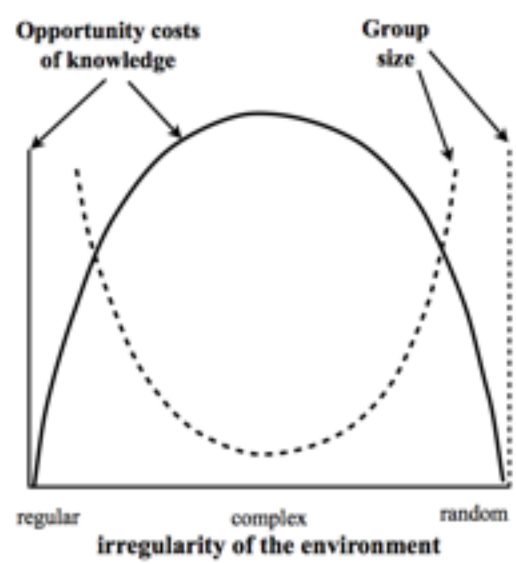

Fig. 1. The opportunity cost of knowledge varies with the irregularity of the environment leading to differing group sizes.

In a patchy, dynamic environment, on the other hand, an individual bears a higher cost by leaving a place. When she returns after an extended absence, she is likely to find that the practical value of her previously acquired knowledge is greatly diminished and that the cost of getting current again is high. This kind of environment makes it worthwhile for an individual to 'remain close to home' and to maintain persistent relationships.

Thus, an individual has to find a balance between (a) the benefits of familiarity, which tend to diminish as his knowledge becomes too much like that of the people he works with, and (b) the benefits of acquiring different knowledge. Depending on the dynamics of the environment, this balance will work out in different ways. Generally, in simple environments, the benefits of familiarity are low and individuals find little value from associations with others; if groups form, they are large with weak individual associations. In complex environments, the benefits of familiarity are high, leading individuals to favor small groups with strong internal links.

Consistent with Ostrom (1990, 2000b), we argue that when the costs of acquiring new knowledge about the resource lead fishers to

1. engage in repeated, frequent communications with one another
2. develop from those communications durable individual relationships
3. form small groups based on those relationships
4. acquire a shared and realistic mental model (or set of beliefs) about the biological dynamics leading to a sustainable resource

then the informal, self-organizing social arrangements among fishers will be consistent with collective action. Consistency with Ostrom's preconditions, of course, does not ensure successful collective action. Nevertheless, when the informal structure of the industry is congruent with Ostrom's preconditions, the likelihood of collective action is increased. Consequently, understanding why informal social structure does or does not reinforce collective action is important to the development of good resource governance.

In the following sections of the paper, we analyze the way the biophysical and technological circumstances of three different fisheries affect the opportunity costs of search and communication and how that, in turn, affects the intensity and persistence of individual relationships, the size of the groups formed by those individuals and the likelihood of collective action.

A difficult part of the analysis for each fishery concerns the co-evolution of the self-organized and the formally organized governance of each fishery. As formal rules are imposed on a fishery, the self-organizing aspects of the fishery adapt and vice versa (Ostrom, 2009) Consequently, the observation of the informal social structure in any fishery cannot be easily separated from the institutional context in which that informal structure occurs. (We try to compensate for this difficulty with a historical perspective as space permits.) The logical result of a co-evolutionary perspective is that the formal social structure of the fishery also strongly influences the evolution of the informal structure. The strong policy implication is that formal governance rules have to be devised with an eye towards the subsequent evolution of informal social structure so that it changes in a way that is congruent with conservation. Whether policies can be designed in a way that leads to this alignment, i.e., that produce the appropriate incentives, depends greatly on the realism of policymakers' mental models of coupled human and natural system. As North (1990) and Knight (1992) point out, those who are able to effectuate changes in formal rules do not always have a realistic idea of the mechanisms that might lead to their desired results and instead often reap unintended and unwelcome results. In complex multiscale systems, 'getting the model right' means bringing to the public table the fine-scale knowledge that is usually missing from management discussions.

THREE DIFFERENT FISHERIES

Urchins

The Maine sea urchin fishery is a classic boom-bust fishery that started growing rapidly in 1987 after the decline of other suppliers to the Japanese market (Berkes et al. 2006). Maine landings peaked in 1993 when the fishery was the second most valuable fishery in the state after lobster. By 1994, nearly 3,000 licensed divers and draggers across the state were targeting the resource. The rapid increase in landings and effort led to a decline in the abundance of urchins and a significant reduction in effort. Today, the fishery remains in this depleted condition.

The biophysical domain

Sea urchins (*Strongylocentrotus droebachiensis*) are a sedentary species, moving short distances primarily to feed. They are generally omnivores, but are most commonly associated with laminarian kelp. They can detect food from a distance of several meters and aggregate around it in response (Vadas and Beal 1999). Well-fed urchins in kelp-grazing aggregations have high somatic growth rates and gonad indices (Scheibling and Hatcher 2007). Urchin roe swells in the summer and fall and spawning occurs in the spring, making the roe most valuable in the late fall and winter when it is the color, texture and taste favored by the Japanese market.

Sea urchins are prolific broadcast spawners; in Maine, there does not appear to be any shortage of urchin larval production; even in areas where shallow-water urchins appear to have been extirpated (McNaught 1999) larvae appear to drift and settle long distances from probable spawning areas. Once larvae settle to the bottom they become sedentary and are patchily distributed; they are found most often in rocky bottom areas in the subtidal and in tide pools in the low intertidal zone, but also on gravel bottoms in deep water and occasionally on sand (Scheibling and Hatcher 2007). The relevant spatial scale of these processes leads to typical patch sizes on the order of 10 to 200 m^2. In an unharvested system, the state of nearby sites can differ substantially, in part due to the differing effects of water motion, storms and ice.

Scientists have documented a strong interaction between urchins and kelp communities (McNaught 1999; Harris and Tyrrell 2001; Steneck et al. 2002, 2004). Meidel and Scheibling (2001) describe shifts in the community state due to changes in urchin abundance and feeding behavior. When urchins are in low abundance, kelp beds thrive. As urchins feed on the kelp (as drift algae or understory plants), they grow and reproduce. As their density increases, large urchins aggregate into 'grazing fronts.' As they feed extensively on the kelp along what is known as 'the feedline,' their growth and reproduction remains high. Eventually, with a reduction in feed and an increase in the local population, the nutritional state of urchins declines leading to reductions in growth and reproduction, a state called an urchin barren (Botsford et al. 2004). The urchin barrens persist until wave action, ice scouring or harvesting remove urchins. Once urchins are eliminated, diatoms and then macroalgae grow rapidly; kelp beds can become reestablished within two to three years if urchins do not repopulate the ledge. Recolonization of the kelp beds by urchins occurs via larval settlement and if they are present, migration of nearby sea urchins from slightly deeper waters.

Even though larval distribution is extensive, the repopulation of extirpated sites appears to be limited due to crab predation on new recruits (Scheibling 1996; Steneck et al. 2002). Steneck et al. (2002) describe such a local system flip in Maine that occurs as a result of urchin removal via intensive harvesting. Extirpation of urchins allows for increased growth of kelp forests providing favorable habitat for large crabs, which in turn prevents urchin recruitment. This kelp-dominated state appears to be relatively long-lived and stable.

The social domain

Sea urchin harvesters are mobile and heterogenous when compared to lobster fishermen, but less so than groundfish fishermen. Two gear groups, divers and draggers, target the resource on shallow sites that are accessed from numerous ports up and down the coast. Urchin harvesters move their operations easily from port to port and live in widely scattered coastal and inland communities.

The technology required for harvesting urchins is minimal: a small boat with a small light drag or diving equipment. The lack of technological or institutional barriers to entry (at the beginning of the fishery in 1987) resulted in a large, mobile and heterogeneous fleet of small boats characterized by skippers with diverse experience and knowledge. Practices vary among divers and draggers, with some being more selective in their harvest than others. Harvesting occurs primarily on the feedline, where urchin roe is of the highest quality, and hence, highest market value. Some harvesters practice ‘straight raking,’ where they take all urchins, while others take only the legal-sized urchins feeding at the feedline. Dragging is more important in eastern Maine, where high tides and strong currents make diving more difficult.

The sedentary nature of adult urchins would appear to indicate a simple search problem. However, the complex interactions of urchins and kelp and harvesters mean that the location of economically viable patches can change rapidly, creating a peculiar search problem with definite antisocial implications. At the time the fishery began, urchins were so abundant that little knowledge or experience was needed for success. This meant that there were few or no incentives for either sharing or withholding information about the location of urchins (Johnson et al. 2012). A completely autonomous diver could leave an area and return the next month, or year, with only a small learning cost. As a result, harvesters appear to have formed few associations that they depended upon for search information.

The depletion of the fishery has led to different biological circumstances but little apparent change in individual and social relationships among harvesters. Depletion is not a simple reduction in the average density of urchins. Rather it leads to increasing patchiness of economically viable urchin aggregations. In the current fishery, a large number of previously productive sites have 'flipped' to a kelp-dominated/urchin-extirpated state. All indications are that few, if any, of these sites have seen a regrowth of urchins. The remaining productive sites are in various states between the flipped state and an urchin barren. The quality and age distribution of urchins and the density of fishable aggregations vary widely on these sites and, as one might suspect, create a different search problem for harvesters. A harvester might visit a site one day, leaving it in a nicely fishable state, only to return a week later and find it stripped by another harvester. As a result in today's depleted fishery, the sedentary nature of urchins, combined with the lack of exclusionary rights at the scale of individual urchin sites, makes it irrational for harvesters to share information. As a result, there are generally few interactions among urchin harvesters and no basis for cooperation (Johnson et al. 2012). Further, the large spatial extent of available fishing (and management) areas means they rarely encounter other urchin harvesters, let alone the same individuals repeatedly during the fishing season. Monitoring other urchin harvesters' behavior is difficult if not impossible. The heterogeneous and mobile nature of the fleet, combined with the scale of management and infrequent contact among harvesters, has not led to the emergence of individual and group relationships. Therefore, the kind of longer term personal and group relationships that characterize the lobster fishery are absent in the urchin fishery, leaving little organizational basis for the growth of informal and formal institutions.

Formal institutions for managing this fishery have not been effective at preventing further resource decline or rebuilding. Management did not begin until 1992, when an urchin license was required. Soon after, in 1994, the state created a co-management system, including an advisory council of industry members and independent scientists charged with providing management advice to state managers, limited entry, seasons, and a minimum size limit. The state also was divided into two large management zones, and, eventually, fishermen were permitted to fish in only one zone. The Sea Urchin Zone Council is an advisory panel; decisions are not made locally in the same way they are in the lobster fishery. The fishery has been managed primarily through effort controls, specifically reductions in numbers of days fished through the establishment of fishing seasons, as well as minimum and maximum sizes limits. However, the scale of these management restrictions leaves individual fishing sites in an open-access condition, and therefore, susceptible to overharvesting in the form of local system flips from urchin-kelp-dominated to kelp-dominated systems (Johnson et al. 2012).

Lobster

The American lobster (*Homarus americanus*) is found in the inshore waters off the Atlantic Coast of North America from Newfoundland to Virginia. The lobster fishery is an inshore day fishery conducted from small boats, using traps as the catch method. The majority of boats are 35 to 40 feet long and are operated by one- or two-person crews who fish an average of 575 wire traps. They use hydraulic haulers to retrieve traps. The electronic gear for communications and locating traps is quite standard. Currently there are about 6,000 lobster boats in Maine (Acheson 2003).

Biophysical domain

Although lobsters can be found at depths ranging up to 1,200 feet, the vast majority live in waters within three miles of shore at depths less than 150 feet (25 fathoms). Lobsters are relatively sedentary. Early work on migration in the 1950s found that the majority of lobsters were caught within two miles of where they were released. Other studies show that more extensive local movements occur (Krouse 1977). Under some circumstances lobster will move long distances (Cooper and Uzmann 1971; Pezzack and Duggan 1986). Movement over the annual round is quite restricted, however. Lobsters move into shallow water to molt in late spring and summer. At this time of year, fishermen place most of their traps in shallow water. Since there is relatively little of this 'shedder bottom,' traps are crowded and placement is highly competitive. Fall is the most productive time of year. Catches are high, and fishermen put all of their traps in the water, concentrating their traps in areas between 20 to 30 fathoms, which can be a few miles from shore. As fall turns to winter and the water turns colder, lobsters are best caught in deep water on muddy bottom. Fishermen respond by moving traps into these areas. Since there is a good deal of this mud bottom and fishing is less productive, traps are further apart and less competitive. The location of concentrations of lobsters plays a major role in determining where fishermen place traps. They are also constrained by territorial rules and zone boundary lines.

Recent oceanographic modeling work suggests recruitment of postlarvae lobsters to the benthos may be strongly localized. "Self recruitment ranged from a few percent to >90% of competent postlarvae. Although it was common for postlarvae to come from many, often distant, sources, most of the competent postlarvae in a zone originated within one to two zones in the prevailing 'up-stream' direction, forming shorter connections along the coast than the energetic currents [away from the immediate coast] might otherwise suggest." (Incze et al. 2010)

The social domain

The Maine lobster industry is one of the most successful fisheries in the world today. From 1947 to 1989, catches averaged about 20 million pounds per year (Maine Department of Marine Resources, Historical Lobster Landings). Since the late 1990s, catches have been more 50 million pounds, record high levels never achieved in any other period. Although there is no consensus on the reasons for these record high catches, two factors are almost certainly involved: (1) environmental factors (e.g., favorable water temperature, low predation by large finfish) and (2) effective conservation laws (see Acheson and Steneck 1997), stemming from a strong conservation ethic which developed over the course of decades (Acheson and Gardner 2010).

Yet, it was not always this way. In the late 1920s and early 1930s, catches dropped to between five and seven million pounds. During this 'bust,' low catches were matched by low prices (Acheson and Steneck 1997). Incomes were so low that 40% of lobster fishermen went out of business between 1928 and 1930 (Correspondence of the Commissioner 1933). The bust was a searing experience for the industry—one that caused a major change in attitudes towards conservation (Acheson 2003; Acheson and Gardner 2010).

The lobster industry is highly territorial. To lobster, a person must gain acceptance by a group of people fishing from one harbor, called by Acheson (1988) a "harbor gang." Once admission is gained, the fisherman can fish only in this group's territory, with territories averaging about 100 square miles. This means that lobster fishermen spend their lives crisscrossing a small body of water, which they come to know intimately. This territory is jointly held by a group of people they also know well, and it is defended by keeping intruders at bay, in some cases by the surreptitious destruction of gear (Acheson 1988, 2003)**.** (It needs to be stressed that offshore, where skippers exploit far larger areas, it is common for lobster fishermen to operate as roving bandits, taking concentrations of lobsters wherever they occur.)

The people who fish from the same harbor are some of the most important people in a fisherman's life. Most live in the same town as the harbor. Many are members of long-established families, which have commonly intermarried (Acheson 1988). They have long-term multistranded links to each other. Those who fish from a harbor have a good deal of intense interaction with others fishing from the same harbor. Clusters of fishermen will gather on docks. At sea many fishermen from a harbor keep their radios turned to the same channel and talk to their friends for hours. In the winter, cliques from the same harbor often get together to build or repair traps and gear. If they do not interact together by radio or personally on a daily basis, they know each other by reputation

These gangs are also reference groups. One is a good or bad fisherman in comparison to others in the same harbor or from nearby harbors. In such harbor groups, a good deal of social capital has been built up. As a result, they are able to organize to defend certain fishing territories, they cooperate in getting bait, and many have organized cooperatives. None of this is to suggest that fishermen in the same harbor gang are always friendly. If they are useful to each other, they are also competitors. Within any gang there is intense competition to become a "highliner," a person who earns a lot and catches a lot of lobsters Acheson 1988). An important aspect of territoriality is that it restricts the movement of fishermen. Fishing outside one's territory can be very costly because of the defenses raised in other territories and even if a fisherman does move successfully to another area the cost of 'coming home' can be very high.

Fishing skills are important for success. Those who have learned where to place traps catch far more lobsters than others fishing in the same place using the same amount of skill and effort. Learning trap placement skills is not easy. Lobsters move across the bottom and are rarely in the same place for more than a few weeks. The very local places where they are found will almost certainly change from year to year. Learning how to find these concentrations of lobsters is a never-ending process and is a lesson that highly skilled fishermen have mastered, but that remains a mystery to the 'dub' fishermen.

A large number of factors influence where traps should be placed and how they should be fished: season, type of bottom, bait type, number of traps in the area, depth, and working time of the bait (Acheson 1988: 2003). To complicate matters, other fishermen will try to obscure their degree of success. Nevertheless, it is far easier to learn about lobster concentrations than it is to learn about locations of other types of fish. One source of knowledge is communications among fishermen. Older kinsmen will often instruct novices about lobster movements. Moreover, fishermen will often exchange accurate information on their lobster operations and degree of success with others at the same level of skill. There is no reason to be secretive about lobster locations after concentrations of lobsters have moved out of the immediate area. Fishermen make little effort to conceal their activities in many circumstances. In addition, GPS and sonar have made it much easier to learn about depths, locations and types of bottom than it was before such devices were readily available. And most important, one can see where others have traps and how they are moving them.

The Maine lobster industry is unusual in that it has had great success in solving the collective action problems it has faced by promulgating rules to constrain individual action. Over the course of the past 120 years, five important laws have been passed:

1. Lobsters may only be caught by traps.
2. Lobsters must be 3.25 inches on the carapace to be legal, which protects juvenile lobsters, and less than 5 inches on the carapace, which creates a protected pool of large, long lived, reproductive-sized lobsters.
3. Traps must be equipped with escape panels to allow small lobsters to escape.
4. A lobster with eggs attached to her belly may not be taken, and must be marked with a notch cut in her tail (lobsters with a 'V-notch' may not be taken as long as the notch is visible [Acheson 2003]).
5. In 1995 the legislature passed the so-called zone management law, which changed many aspects of lobster management (e.g., apprenticeship program, statewide trap limit). It also established a co-management system making it possible for lobstermen in any one of seven zones to change several management practices in that zone by a two-thirds majority vote. In recent years, many of the most important lobster management rules have been passed within the framework of the new co-management system.

Lobster fishermen have successfully lobbied for conservation laws, and virtually all of these laws were passed with strong support by the industry. These laws were passed after long negotiations (sometimes lasting decades) between the industry and the state government (i.e., the marine resources commissioners, with strong support from members of the legislature). The high rate of compliance with these rules is due to the conservation ethic of the industry, the long familiarity that members of harbor gangs have with each other, and their ability to monitor each other.

Groundfish

The Gulf of Maine groundfishery pursues demersal fish such as cod, white hake, pollock, haddock, flounders and miscellaneous other finfish, 17 species in all. Since the beginning of management in 1977, these species have been managed as if each was comprised of a single broad-ranging stock that inhabited the whole of the Gulf of Maine (and for some species all of Georges Bank and southern New England waters also (Apollonio and Dykstra, 2008). For nearly 20 years, almost all the species in the fishery have been severely depleted with abundance today near or below the levels in 1977.

Since 1977 there has been strong disagreement between fishermen and scientists about the abundance of fish and a failure to devise successful collective action (Acheson 2011). Fishermen, extrapolating from their fishing experience, often claimed that there were more fish than estimated from scientific surveys. There was some dissembling in those claims, but they were generally accurate reports that came from mobile fishermen who were able to find fish and from small 'day' boat fishermen who happened to be located in places, e.g., the western Gulf of Maine, where fish were, in fact, abundant. Other small-boat fishermen located in areas where stocks had been extirpated, such as Downeast Maine and the Massachusetts islands south of Cape Cod, argued that scientists were overstating the abundance of fish. Scientists, while not denying fishermen's observations, but arguing from their broad-scale randomly stratified surveys, claimed that 'on average' the species in question were not nearly as abundant or were more abundant than fishermen claimed (depending on which fisherman they were talking to). The point is that over the span of the groundfish-management regime, the heterogeneous nature of the biological regime and the differing scale and location of the observation of the groups engaged with the fishery have never led to a shared sense of the current abundance of groundfish nor to a common mental model about the effects of fishing. Scientists and managers (and ENGOs) have one view based on the broad scale at which they observe the system; fishermen have several views that differ according to the location and scale of their experience. When scientists/managers/ENGOs and different groups of fishermen have such different mental models of the natural system and how it has reacted to fishing, the likelihood of collective action is low; the more likely result is collective rules that are the result of political capture by one or a coalition of the interested parties (Acheson and Knight 2000). Whether conservation or depletion results, it is the incidental outcome of a distribution fight.

Compared with the usual management practice, recent scientific evidence points to much finer-scale population structure among the groundfish species (the evidence is most developed in the case of cod), i.e., multiple demographically distinct stocks of the same species occupying the same area currently managed as if there was only a single stock. The evidence from New England (Ames, 1997 and 2004; Wirgin et al. 2007; Howell et al., 2008; Kovach et al., 2010) from Atlantic Canada (Ruzzante et al., 2000; Green & Wroblewski, 2000; Robichaud & Rose, 2001; Bradbury et al.; 2008) and from elsewhere around the world (Fevolden & Pogson, 1997; Hutchinson et al., 2001; Karlson & Mork, 2003; Pampoulie et al., 2006; Hauser, 2008; Cardinale et al., 2011; Svedäng et al. 2010; Knutsen et al., 2011; Poulsen et al., 2011; Thorrold 2001; Robichaud & Rose 2004; Svedäng, et al. 2007) generates a picture of an ocean that is much more consistent with what we know about ecological systems than our current, single species theories and models. In the paragraphs that follow, we describe the fisherman's search problem in terms of these finer-scale behavioral and population processes and the recent scientific work with which it is consistent.

No matter what technological scale fishermen employ, they still have to search for patches or schools of fish. Where they fish and what kinds of aggregations they can or prefer to target depends upon the scale and kind of gear they employ; nevertheless, the behavior of the fish does not reflect the kind of gear that might catch them and for this reason groundfishermen working at all scales face a similar search problem (except that draggers/trawlers have the luxury of fishing much less dense aggregations). This problem determines what kinds of knowledge fishermen hold close and what kinds they tend to share. As we discuss, the social result of these competitive forces is another major reason why the basis for collective action in the fishery is so weak.

Adults of each of the groundfish species show variations on a common behavioral pattern over the course of the year. Spawning times for local stocks occur in either spring (most common) or fall. Before spawning, stocks tend to form fairly dense aggregations usually on the shoulder of the coastal shelf. These aggregations then move towards a spawning site on the shelf, spawn and afterwards disperse to follow a seasonal pattern of feeding opportunities. Generally, the broad direction of migratory movements is fairly reliable, but the timing and local deviations from the general route vary, often significantly, from year to year depending on water temperatures, storms, currents, the movements of prey species such as herring and alewives and, sometimes, competing species such as dogfish (which fish like cod tend to avoid).

The distances typically moved by each species differ, with haddock having a reputation for being the least likely to cover large distances and pollock the most. The population patterns of cod appear to be flexible; stocks appear to adapt to local residency and even to highly migratory life styles ; this flexibility may extend even to fish within a single local stock (Robichaud and Rose 2004; Rose et al. 2007). The finer-scale movements of flounders appear to be less well known; generally, the opinion among fishermen is that flounders are influenced less by mobile prey and more by relatively sedentary benthic food sources. As a result, there seems to be a belief that flat fish move from deep to shallow water as the shallow waters become warm (relative to the deep waters) staying on preferred bottom types – mud or sand – in the process. As shallow waters cool, the movement tends to reverse.

All fishermen know the broad seasonal patterns of the species they fish and readily discuss them in public. This open discussion attests to the low competitive value of knowledge of broad-scale fish movements; the industry allows data about broad-scale fishing to be public, but only at the scale of a 10 minutes of latitude, 10 nautical miles or about 18 km. What is not discussed but is much more important for successful fishing is knowledge of the current location and direction of movement of fish aggregations. The scale of this knowledge occurs at much greater resolution than 10 minutes of latitude. Because fish move, this value of this knowledge is short lived, but also valuable. Fish can stay in roughly the same place for days or weeks, but currents, storms, changes in water temperature and the movement of prey can cause the location of targeted aggregations to change quickly. Understanding how these changes affect the movement of the fish is the key to efficient search and catching. By efficient search we mean the ability to consistently search in places to which aggregations of fish have moved. Fishermen call it ‘staying on the fish.’ When efficient search takes place in the usual regulatory environment that assumes very broad scale, panmictic, populations it creates strong incentives that lead to the serial depletion of finer scale subpopulations (Wilson, et al. 1999; Wilson, et al. 2012)

In environmentally complex areas with rough topography, strong currents and a large tidal range, experience in a particular locality is important; knowledge about why fish might be in one rather than another place and why they might move this way rather than that is specialized, that is, tailored to that particular environment. Such specific knowledge does not travel well to other locations because of the complexity of the local physical environment in which it was acquired. Nevertheless, a good fisherman from a place like this might do well in a different physically complex environment because he knows what he has to learn, but still would take a while to acquire the necessary local experience. In the more commonly fished, deeper and less complex environments, knowledge of fish behavior is more easily generalized from place to place. Thus, in these deeper areas a good groundfisherman, i.e., one who understands the way fish respond to changes in local conditions, can rapidly learn where the fish are even in an unfamiliar environment. Fish finders are helpful, but their range is local, and they do not replace the fisherman’s understanding of the right places to look. This understanding is what leads a good fisherman to the fish; it generates specific knowledge of the immediate location of fish and when consistently repeated defines a highliner. As might be expected, knowledge at this temporal and spatial scale is the source of competitive advantage and is held very tightly (Wilson, 1990).

The result of these search circumstances is that groundfishermen have little reason to share valuable fine-scale information with one another; but it appears to be common for them to share broader-scale information (Holland 2010). Groundfishermen tend to range rather widely; even small boats cross local stock boundaries (Acheson 2011). They often come from many different ports and go for long times without seeing one another. Although they do develop personal relationships, these relationships do not seem to be related to on-the-water activity – more alliances in the regulatory arena – and, depending on the scale at which they work, they develop similar, if not identical, mental models of the broad-scale movement of the fish. However, they do not get reasonable feedback about the effect of their actions on the fishery. Consequently, there is little basis for self-organizing social structure supportive of the kind of restraint necessary for successful collective action.

CONCLUSIONS

We suggest the principal force leading to informal relationships among individuals and the organization of groups is the opportunity costs individuals bear while acquiring valuable knowledge about the resources they use. Depending on the attributes of the environment, the cost of knowledge and, therefore, these informal relationships will vary in ways that affect the likelihood of successful collective action.

In simple environments, such as might occur in situations in which the spatial and temporal distribution of the resource is either regular and predictable or, at the other extreme, predictably random, the cost of useful knowledge about the resource is low, and there is little or nothing that individuals gain by associating with one another. Consequently, there is likely to be no informal social context supportive of collective action.

In complex environments, on the other hand, the opportunity cost of useful knowledge is positive and individuals can gain by associating with one another. The extent of the gain and the resulting social context depends upon the particular learning problem individuals face in various environments. In some environments, such as the lobster fishery, the speed and patterns of movements of the resource and the harvesting technology (especially, the way it affects the rate of extraction the resource) may bring fishermen together on a near daily basis. In these circumstances, repeated interactions allow fishermen to form relatively secure expectations about one another's behavior, to develop a continuing beneficial relationship and an understanding of the value of restraint. This is the basis for the formation of persistent relationships and for the growth of those relationships into groups, or harbor gangs. This social context increases the likelihood of successful collective action.

In the urchin fishery, on the other hand, even though the resource is sedentary and patchy, its method of extraction leaves little room for cooperative activity; fishermen do not interact frequently, do not develop close working relationships and have only weak personal incentives encouraging restraint, rendering the prospects for collective action rather bleak. In the groundfishery, even though the resource is mobile, the fine-scale patterns of fishing also lead to infrequent encounters and weak incentives for restraint and, as in the urchin fishery, do not lay down the social conditions supportive of collective action.

The scale at which these individual relationships arise is also important. If they do not arise at the scale or scales congruent with the demographic scale of the resource and do not result in a collective mental model that is consistent with resource sustainability, the likelihood of successful collective action is diminished. For example, resource predictability (or randomness) from the perspective of the individual fisherman depends on both the resource and the behavior of other fishermen. In the urchin fishery the sedentary behavior of urchins would seem to indicate a high level of predictability at a demographically appropriate scale; however, the unpredictable activities of other fishermen tend to convert a regular resource into one that is almost random from the fisherman's perspective. Thus a social context appropriate to collective action does not emerge.

Although fishermen also disturb the natural patterns of the resource in the lobster fishery, the rate of change in the local abundance of lobster is much slower. Additionally, buoys mark fishing activity making it easy to observe other fishermen's activity; consequently, simple observation is a fairly accurate, but not infallible, signal of local abundance. This sets the stage for repeated interactions that are the basis for persistent relationships at a scale that is demographically relevant and supportive of collective action. An important aspect of these individual/group scale social arrangements is that they become the forum in which the fine-scale ecological aspects of the fishery are vetted and brought to the public table. As the work of Incze et al. (2010) suggests, localized recruitment may provide the kind of biological feedback, or evidence, that reinforces and is perhaps necessary for fishermen to believe that restraint and conservation is really in their interest.

The idea that formal and informal norms co-evolve suggests that policies for fisheries such as urchin and groundfish need to be designed with the knowledge that the informal aspects of the fishery will evolve in response to any formal rules. This idea is not new; economists have long argued that the alignment of private incentives with the social goal of conservation was an important part of any policy. Nevertheless, the perspective we seek to bring to this discussion is the idea that the fine-scale social-ecological dynamics that might create that alignment depend upon the fisherman's problem of acquiring useful knowledge about the system. In some circumstances that problem may lead to secretive, nonsocial behavior that is not supportive of collective action; in others, the circumstances of the problem make cooperation attractive and lead to long-term individual and social relationships. These relationships inculcate restraint and lay a good foundation for collective action. It is especially important that they bring into the public forum the knowledge of fine-scale aspects of the natural system that are often missed by management science. This makes the chances of the governance process arriving at the 'right model,' i.e., a workable understanding of the likely social-ecological outcome of policies, much greater.

We suggest the evidence supports the idea that the right model and a multiscale system of informal and formal governance emerged from the co-evolutionary process in the lobster fishery. The history of the long 'negotiations' between the state, scientists and the lobster industry illustrates the ways in which that co-evolution was channeled by the biophysical conditions of the fishery, by fishermen's knowledge of those conditions and by the thoughtful political process conducted by the state commissioner when the principal formal institutions were formulated (Acheson, 1983). In the urchin and groundfish fisheries, managers applied restraint at a broad scale using traditional management models that were irrelevant to the demographic fortunes of local stocks/aggregations; at the same time, the search problem in each fishery did not lead to informal social arrangements conducive to collective restraint. The result was strong and perverse economic incentives, so-called roving bandit incentives (Berkes et al. 2006; Wilson 2006), that led to the serial depletion of both resources.

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