Competition, cooperation, and learning in the marine commons: Implications for collective action

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Abstract: Success or failure of governance of the marine commons can be traced to the complex interactions of the natural and the human systems. The coupled human and natural system dynamics that generate the preconditions for collective action, especially the adaptive dynamics that lead to the emergence of informal social and economic structure, are not well known. We hypothesize that competitive interactions among fishers seeking knowledge about resource conditions lead to the emergence of dynamic social patterns and informal structures that reflect the particular circumstances of the natural and social system; the scale and mechanisms of those patterns and structures in turn affect the feasibility and effectiveness of collective action and, through that, the sustainability of the natural system. We examine this hypothesis in the context of the Maine sea urchin fishery. Although currently very small, it was a classic gold rush fishery during the late 1980s and the 1990s until the population became depleted and fishable aggregations became sparse. We conducted semi-structured interviews with key informants from the Maine sea urchin fishery to understand the biophysical circumstances in which cooperation might be feasible and that might form the basis for collective action. We find that the biophysical conditions relevant to sustainable processes in the fishery occur at the scale of individual ledges, a much finer scale than current management. In spite of co-management, limited entry, and a number of input control mechanisms the relevant unit in the fishery, the ledge, is still an open access fishery.

Key words: collective action, fisheries, learning, sea urchins, scale, and overfishing

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INTRODUCTION

Ocean fisheries are a notorious example of the failure to govern human activity in a way that sustains major natural resources (e.g., Hutchings and Reynolds 2004; Worm et al. 2006; Myers and Worm 2003; Pauly et al. 2002). Yet, among the world's fisheries there are interesting examples of successful governance, such as through self-governance and co-management (Hilborn 2007; McCay and Acheson 1987; Wilson, Nielsen, and Degnbol 2003). Well-designed property rights systems or co-management regimes are expected to counter the tragedy of the commons. However, what works well in one fishery may fail completely in another; there are no panaceas (Ostrom 2007). If there is a problem extrapolating lessons learned in one fishery to another, it lies in understanding how the particular biophysical and social attributes of a given situation affect the alignment of private and social interests and, through that, the feasibility of collective action and the sustainability of the resource.

Coupled human and natural systems are dynamic, and characterized by thresholds, feedback loops, time lags, resilience, heterogeneity, surprise, and path dependency (Liu et al. 2007) and they operate at multiple scales. A large number of preconditions that are consistent with the sustainable use of common-pool resources have been identified (Ostrom 1990; Agrawal 2003), but the dynamics that generate those preconditions, especially the conditions that lead to the emergence of informal social and economic structures, continue to be a significant area of research and debate. It is critical that institutions are matched appropriately with the social and ecological scales in ways that allow adaptation and learning (Wilson 2006). For example, even in limited access and individual quota fisheries mismatches can create fishing rights and strategies that erode the underlying population structure and the system itself (Wilson 2006). Avoiding mismatches requires understanding how the particular social and natural circumstances of coupled human and natural systems influence adaptation and learning, and how this relates to the alignment of private and social interests.

We hypothesize that the competitive interactions among individual fishermen seeking knowledge about resource conditions (i.e., learning when and where to fish) lead to the emergence of dynamic social patterns and informal structures, which in turn affect the feasibility and effectiveness of collective action and, through that, the sustainability of the natural system. This hypothesis has been examined in the Maine lobster fishery (Wilson, Yan, and Wilson 2007), where the physical and social characteristics of this resource lead to patterns of information sharing that ultimately result in the emergence of social structures and patterns that are considered the precursors for collective action. In this fishery, the co-management system is reasonably well-designed; management operates at several different scales and at each scale management authority tends to match up with the scale of biophysical conditions and emergent social structures (e.g., lobster gangs) (Wilson, Yan, and Wilson 2007; Acheson 2003).

Here we examine the case of the Maine sea urchin fishery, a classic boom-bust fishery, where, unlike the lobster fishery, efforts to sustain the resource failed despite the creation of a co-management system. The collapse of the sea urchin fishery in Maine was part of a global sequential depletion of this resource (Berkes et al. 2006). This global depletion began with the collapse of the Japanese resource in the mid-1970s. With the loss of domestic supplies, imports to the Japanese market began to arrive from increasingly distant locations. By 1987, the market arrived in Maine and instigated an explosive boom. Before that time, the resource in Maine was marginally exploited and, at the time the market began, extremely abundant. Extensive areas of shallow near-shore ocean bottom were covered almost exclusively by urchins. Steneck et al. (2002) attributes this abundance to the near extirpation of the groundfish predators along the Maine coast beginning as early as 1930. This incredible abundance made harvesting very easy and facilitated rapid growth in the fishery. Initial harvests concentrated near Portland, the location of the first buyers, but rapidly spread eastward as the economic opportunities became apparent. When viewed at the scale of counties within the state, the pattern of depletion was almost a social fractal of the pattern observed at the global scale (Figures 1a, 1b; Berkes et al. 2006), but as would be expected at a finer scale the spatial pace of the pattern was much more rapid (Figure 1a). This occurred because the spatial extent of the State is much less than the global and (perhaps) because previously formed business relationships led to rapid distribution of knowledge about the market opportunity and meant minimal requirements for the construction of new infrastructure locally. Although we do not have the data at this time, the descriptions from informants suggest the same pattern occurred at the scale of individual ledges, at a still more rapid pace. State landings averaged over all locations show a typical boom and bust fishery, but the same pattern played out for each ledge and for each bay. State-wide landings peaked in 1993 and subsequently declined due to stock depletion (Figure 2; Chen and Hunter 2003). In response to concerns about the condition of this fishery, the State of Maine started managing the fishery in 1992 and implemented a co-management system in 1996. This co-management divided the Maine coast into two zones and created an advisory council of industry members and independent scientists charged with providing advice to State managers. Unfortunately, this co-management system has not been able to halt the depletion, much less manage a rebuilding of the resource.

Co-management, of course, is not a panacea. In the urchin fishery it clearly failed to align private and social interests. We suggest this is due to its application at a scale that was not congruent with the biophysical scale at which cooperation and collective action might lead to sustainability. In our analysis of the collapse of this fishery, we identify the key biophysical characteristics of the fishery and the conditions under which collective action might be possible.

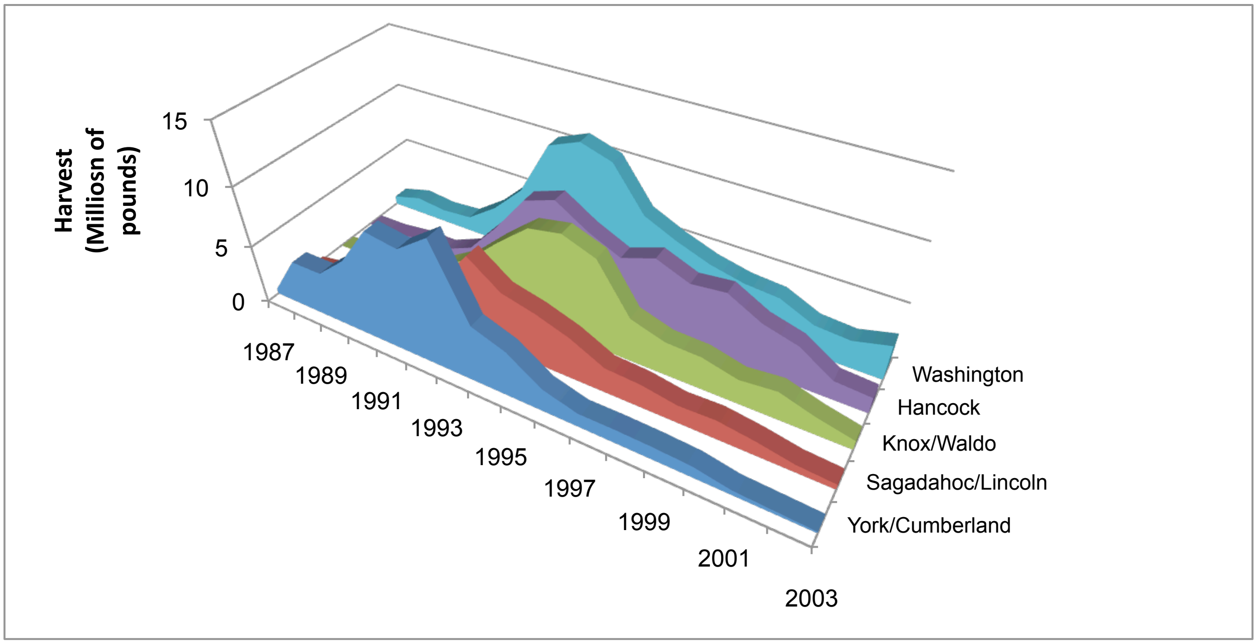

Figure 1a: Maine sea urchin harvests by county from 1987-2003 showing the progression of the fishery from west (York/Cumberland) to east (Washington). The boundary between Zone 1 and Zone 2 is roughly between Waldo and Hancock counties. Data source: Maine Department of Marine Resources.

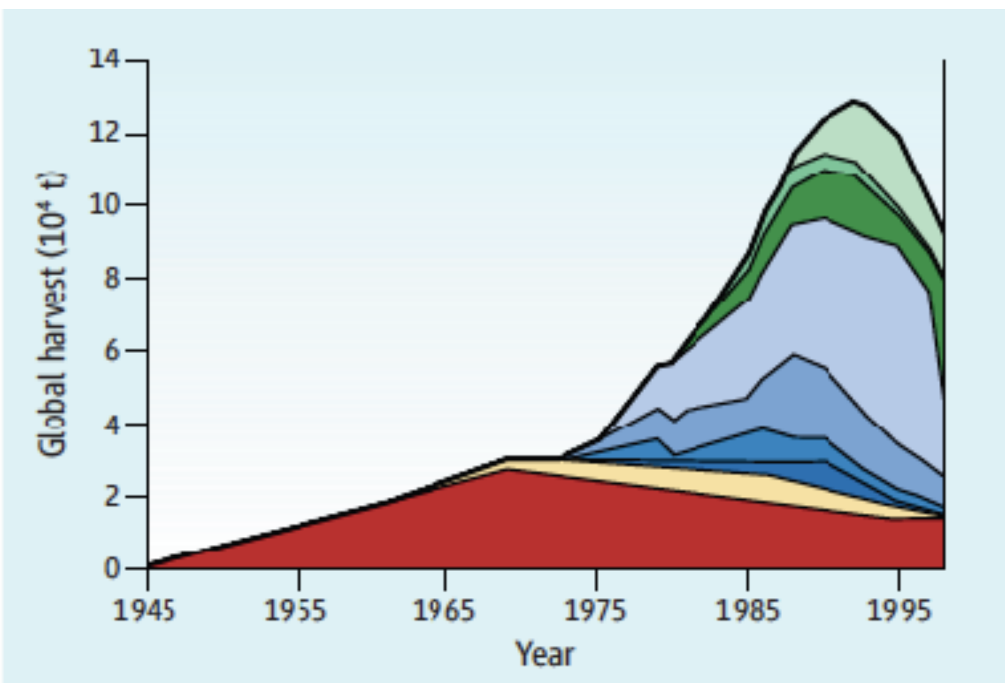

Figure 1b: Global sea urchin harvests over time. Color coded by region, in chronological ascending order: Japan; Korea; Washington and Oregon; Baja, Mexico; California; Chile; NE Pacific (Alaska and British Columbia); Russia; NW Atlantic (Maine, Nova Scotia, New Brunswick). Figure taken from Berkes et al. (2006). All data are from Andrew et al. (2002).

METHODS AND APPROACH

In this study, we adopted an ethnographic approach, relying on semi-structured interviews, as well as our collective, long-term experience and observation of fishermen and the fishery in this region. Overall, we sought to understand the multi-scale, social and biophysical conditions that influence the way fishermen learn and compete and the implications of this for the design of institutions for successful collective action. The immediate purpose of the interviews was to understand the biophysical and social processes of the fishery so that they could be incorporated in a computational model of adaptive behavior (Wilson, Yan, and Wilson 2007; Holland 1986)

Recognizing that cultural information is not uniformly distributed throughout the population (Bernard 2006), we conducted interviews with past and current Maine sea urchin fishermen and a buyer. All individuals were key informants (Bernard 2006); they are considered leaders in the fishery, with knowledge and experience of the fishery since its inception here in the late 1980s. These individuals represented the major gear types and operations, and provided insight about fishing from both management zones. The fishermen included three divers and one dragger; one diver and the dragger also work as tenders (individuals who oversaw divers' operations from their boat). We focused on divers because in this fishery 80% of all landings are from divers (Taylor 2004). At one time or another, all individuals interviewed were active members or participants in the Sea Urchin Zone Council, the industry advisory panel at the heart of the co-management system introduced in 1996. In addition, we interviewed two government scientists involved in the science and management of the fishery. These interviews ranged from 1.5 to 3 hours and were guided by general questions about the mechanics of fishing operations and markets and changes in the fishery over time as it shifted from abundance to scarcity. These interviews allowed us to understand fishing strategies and operations at multiple scales, from the diver on the bottom, the captain on the boat, the buyers at the dock, and ultimately to the global market based in Japan. All interviews were recorded and detailed notes taken from these recordings; only parts of interviews were transcribed. In addition, discussions with two academic fisheries scientists and a number of less extensive informal conversations with other divers and draggers provided additional insight into the dynamics of this fishery.

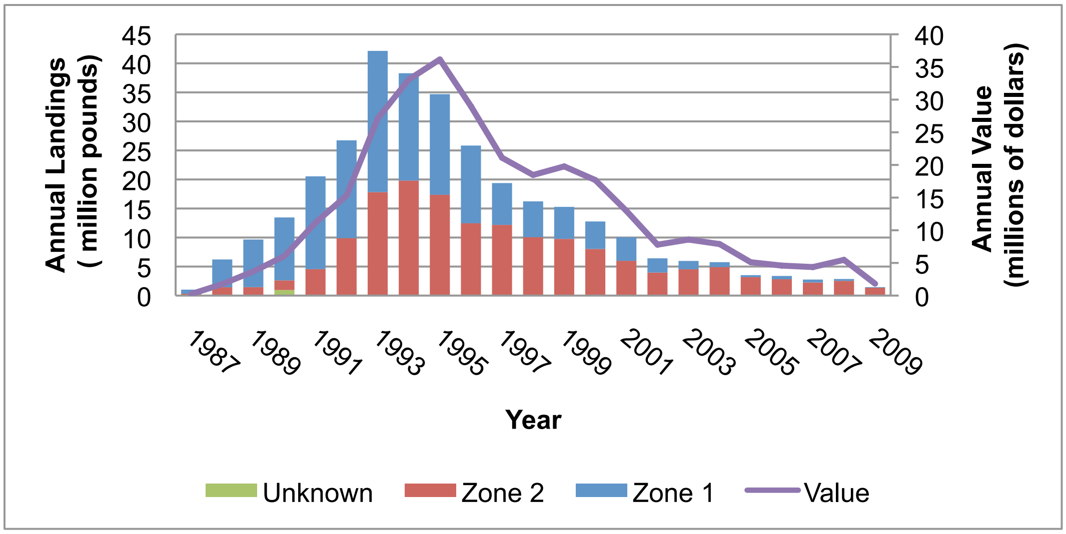

Figure 2: Maine sea urchin landings and value by Zone from 1987 to 2009. Source: Maine Department of Marine Resources.

BACKGROUND AND CONTEXT

In this section, we briefly describe the aspects of the biology and ecology and management of the sea urchin, *Strongylocentrotus droebachiensis*, most relevant to understanding the learning problem fishermen face in this coupled human and natural system. These factors, we believe, strongly influence the nature of the feedback fishermen receive from their interaction with the resource. It is this feedback that drives their individual fishing strategies, their response to change, and the conditions under which they are likely to cooperate or engage in collective action.

Basic biology and life history

Sea urchins range from 0 to 300 meters in depth, although they are most common in the subtidal zone from 0 to 50 meters and in tide pools in the low intertidal zone. Urchins are patchily distributed; they are found in rocky bottom areas, but also on gravel bottoms in deep water and occasionally on sand (Scheibling and Hatcher 2007). Scientists and divers also report finding them on mud. Densities decrease with depth to about 20-30 meters, which is often the lower limit of the rocky subtidal zone. Their upper limit varies seasonally with wave action and ice scouring (Scheibling and Hatcher 2007).

As one might expect, both the types and amount of food affect urchin growth and reproduction. Urchins are generally omnivores; they exhibit clear food preferences for large brown algae, although this is variable (Scheibling and Hatcher 2007). Urchins can detect food from a distance of several meters and aggregate around it in response (e.g., Vadas and Beal 1999). Urchins are most commonly associated with laminarian kelp, which forms their primary diet either as attached fronds or detritus. The ability to feed on detritus allows them to survive in areas where their preferred food does not grow (e.g., in places below the photic zone where kelp detritus might collect). In the absence of macroalgae, they can survive by feeding on other items, but with reductions in growth and reproduction (Scheibling and Hatcher 2007).

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; spawning occurs in the spring. In Maine, the timing of spawning varies by about 8 weeks along the coast, beginning in the southwest; this provides rationale for zone management (Vadas and Beal 1999). The roe is most valuable in the late fall when it is the color, texture, and taste favored by the Japanese market. Urchins usually spawn beginning at age 3, when their diameter is 1-1.5". Females can produce up to 2 million eggs. Urchin roe color, texture, size, and taste vary with what urchins eat, their sex, time of year, and habitat conditions. The Japanese market prefers large, firm, light-yellow roe; some buyers or processors will pay premium for higher quality roe.

The strong interaction between urchins and kelp communities is well documented (Steneck et al. 2002; Steneck, Vavrinec, and Leland 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 at this time, their growth and reproduction remains high. Eventually, with a reduction in feed and an increase in the local population, the nutritional state of the urchins declines leading to reductions in growth, reproduction (i.e., they are referred to as "starving"), a situation that is called an urchin barren. The barrens state persists until urchins are removed by wave action, ice scouring, or harvesting. Once urchins are eliminated, macroalgae grows rapidly; kelp beds can be reestablished within 2-3 years if urchins do not repopulate the ledge. The relevant spatial scale of these processes is on the order of tens to a couple of hundred meters. In an unharvested system the state of nearby ledges can differ substantially due to the differing effects of storms and ice. Harvesting, however, tends to create a more uniform environment because the activities of fishermen occur at a broader scale.

Recolonization of the kelp beds by urchins occurs via larval settlement and, if they are present migration of sea urchins from deeper waters. Miller and Nolan (2008, 929), for example, describe urchins as forming "a slow-moving belt from deep water to the edge of macrophyte beds where harvesting takes place" (also see Scheibling, Hennigar, and Balch 1999). There does not appear to be any shortage of spat production, even in areas where shallow water urchins are near economic extinction. Repopulation of ledges, however, can be limited due to predation on new recruits (Scheibling 1996). Steneck et al. (2002) describe such a local system flip that occurred in Maine as a result of urchin removal via intensive harvesting that allows for the recovery of kelp forests, which further provides habitat favorable for large crabs, which then prevents urchin recruitment.

The Maine sea urchin fishery and its co-management

As described earlier, the "gold rush" for sea urchins began in 1987 in response to increasing demand from the Japanese market that consumes the roe of this species as a delicacy (uni). As demand increased and prices rose, new fishermen entered the fishery and landings increased dramatically. The fishery began primarily in Western Maine, with a small fishery Downeast; however, effort shifted eastward as abundances declined in the west. Seasonal shifts also followed roe production from west to east. Higher quality roe usually fetched higher prices, but some processors/urchin buyers also sought volume.

The resource is primarily harvested by licensed divers (using SCUBA) and draggers (using light bottom trawl gear). Tenders who take out divers are also required to have a license. Divers account for about 80% of the catch. Dragging is more common in eastern Maine, where strong tidal currents and resulting turbulence make it more difficult to dive for urchins. Divers have slightly more opportunity to be selective; they can cull for size and some quality attributes on the bottom. Nevertheless, it is difficult for divers to select for high quality urchins. Divers and buyers uniformly agree that short spines are a sign of quality and that urchins found near the top of ledges are likely to be better fed (apparently because storms, ice, and harvesting reduce grazing pressure giving seaweed a chance to grow, attracting "starving" urchins from lower depths).

Prior to the boom fishery, landings and value were low; there was a slight bump in landings in 1966 at about 143,000 pounds valued at a little over $4,000. The boom in the fishery began in 1987 when 1.4 million pounds were landed at a total value of $236,391. No landings were recorded in the previous two years. Total landings in the fishery peaked in 1993 at around 42 million pounds, while revenues peaked in 1995 at $35.5 million. By 1994, nearly 3,000 licensed divers and draggers were targeting the resource (Figure 3). Landings and harvesters declined as the resource was depleted (Chen and Hunter 2003; Figure 3).

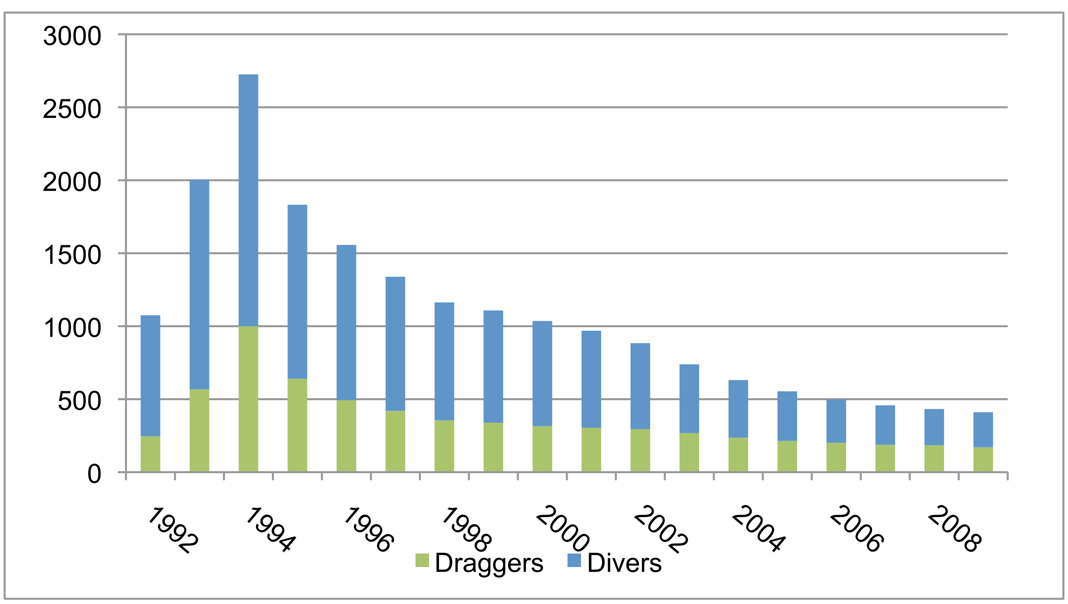

Figure 3: Numbers of Maine sea urchin fishermen from 1992-2009. Source: Maine Department of Marine Resources.

In response to concerns about the fishery, the Maine Department of Marine Resources, the agency responsible for the State's fisheries, first implemented management rules in 1992 by requiring a special permit to harvest urchins. The following year more rules came into effect, including a 2" minimum size, a tender license requirement, a closed season during the summer, and size limit on urchin drag gear. In 1994, the State implemented a moratorium on licenses and created two fishing zones with seasons. Zone 1 ends in the middle of Penobscot Bay, while Zone 2 begins there and ends at the Canadian border (Figure 4). More significantly, a co-management system was established in 1996 with the creation of the Sea Urchin Zone Council. This advisory board consists of approximately 15 members of the industry and two independent scientists and is charged with providing advice for managing the fishery. In the same year, the number of fishing days was also first established (Zone 1, 150; Zone 2, 170). Since that time, the fishery has been managed primarily through input controls, such as closed seasons, reductions in allowable fishing days, and minimum and maximum size limits. The fishery has not been managed with total or individual catch limits or closed areas. Specific regulations vary by Zone due to geographic differences in abundance and timing of reproduction.

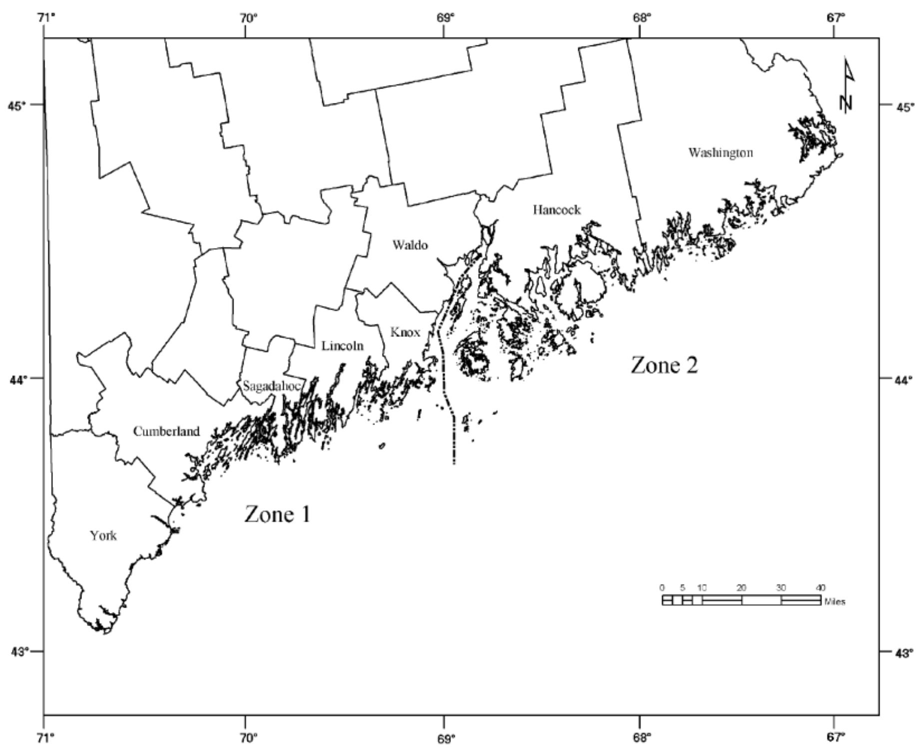

Figure 4: Map of the Sea Urchin Zone Council boundaries, taken from Chen and Hunter (2003).

The co-management system that was created to protect this fishery is widely recognized as a failure. The system did not stop and certainly has not reversed the decline in the fishery. When the co-management started in 1996 statewide landings were 25.8 million pounds, valued at $29 million. In the years 2000-2004, landings averaged 8.2 million pounds, with an average value of $11 million per year. On average, 2.8 million pounds were landed from 2005-2009, averaging $4.2 million in value. In 2009, only 1.45 million pounds were landed, valued at $1.8 million (Figure 2). In that year, 411 divers and draggers targeted the resource (Figure 3). Most landings are now taken from Zone 2 as urchins are nearly economically extinct from western Maine (Figure 2).

Maine is not the only place to attempt co-management of sea urchins. Area-based (or habitat-based) management of sea urchins was attempted in Nova Scotia, but failed due to disease. Other efforts at community-based or co-management of sea urchins has occurred in Japan, Chile, Baja California, and Mexico (Andrew et al. 2002; Miller and Nolan 2008).

RESULTS

Here we report on the major themes that emerged from the interviews.

Based on our interviews, we describe a conceptual model of the resource that many fishermen (divers) appear to share. The key elements of this model consist of finding high quality urchins in their preferred habitat and then the replenishment of ledges as urchins move up from deeper water or, at least, locations where feed is less available. This view of the resource is consistent with that described elsewhere (Miller and Nolan 2008). Although we cannot yet say how widespread this view is among scientists (or other fishermen for that matter), several scientists interviewed also describe such a “conveyor belt.”

Informants describe “starving urchins” in the barrens at the beginning of the fishery. At this time urchins were so abundant that the kelp and seaweed beds were denuded, leaving urchins with little to feed on. This, in turn, meant the roe of these urchins was of very low quality. One buyer explained that this was why fishermen received such low prices at that time; 0.10 — 0.20 $/lb. In the early days, fishermen took just about everything they could find as many did not understand the quality issues. As the fishery reduced the size of the urchin population, the quality of the remaining urchins improved due to less competition for food. As one fisherman explained, “If you get too many [urchins] on the bottom, you’re just going to have a lot of junk. You’ll bring in a lot…but you’re not going to get paid much.”

Divers describe harvesting urchins preferentially from ledges, particularly at the feedline, where urchins feeding on kelp or other seaweeds would be of high quality roe. One fisherman explained to us, “There’s a certain type of bottom you look for when you dive. Sometimes you find [urchins] on mud, but most of the time they’re going to be on the hard bottom.” One diver explained how the “urchins would come across the barrens…and they would eat the feed. They would get good [improve their quality]…I would always just run the feedline, take all of the urchins along the feed.”

They further report that as urchins are removed from the feedline, new urchins from deeper water replenish the area as they move up to feed; this is the “conveyor belt.”

One informant explained of divers: “[They would] take the ones feeding from the front of the feeding front, and then leave it alone for a couple of weeks and then go back.” Similarly, one diver explained, “You had to really selectively pick only the size urchins that you wanted and that was it. You had to leave some behind so that in a month or two you could come back to that spot to reharvest it.”

Another diver explained the same strategy:

> “We would leave the ones down below the feedline. They would move up into feed. Even a couple of months later, they would be harvestable. And then, I think, as the feed became more plentiful, there was so much drift feed around that it drifted to the urchins below [in deeper water].

According to one diver, “Those were never any good [urchins at 60-70 feet deep]. They were where the urchins were piled 12 inches deep and those were the ones that would come in and replace the ones we were harvesting.”

Another fisherman described a similar diver’s strategy, which reflects a particular view of the resource:

> “[They] started taking the [urchins]; looking for the feedline, take the better [urchins], leave the not so good [urchins], [then] move up into or down the feedline…In some of the places, they cleaned them right up and the new vegetation is growing in, but they’ll come back and take over the places, if they get the right conditions.”

Although, “[t]he better divers would pick one at a time and leave the bigger ones and the little ones alone,” not all fishermen were selective. Many would “rake everything up into a bag and send them up and then cull on the boat; a lot of those little ones wouldn’t make it.” This was referred to as “straight raking.” And in the beginning of the fishery, before fishermen had a good understanding about roe quality, they would take whatever urchins they could find. This strategy was possible because of processor demands for volume, and the seemingly little difference in price between high and low quality urchins. One fisherman explained that they would often “get 4 or 5 trays of the not so good stuff [low quality], but then go get the good stuff so it averages out.” The draggers, of course, could not select for quality until the urchins were aboard the boat.

Two major harvesting strategies evolved for divers. The most common is a strategy that emphasizes volume with a minimum acceptable level of quality. This appears perfectly rational in this fishery given the incentives created by the market and the management system. The determination of quality (and hence price) of urchins is very complex. Some buyers will crack a few urchins open and from that estimate the quality of a diver’s catch, and hence the price they are willing to pay. Some divers are paid at the moment of sale based on this quick estimate of roe quality. Others are paid a day or so later after a more accurate estimate of roe quality is possible, but in that case the divers are not able to witness the process of roe quality determination. In our interviews, we heard stories of games being played both ways between urchin buyers and processors on the one hand and harvesters on the other. We also heard that, with the exception of those sold to the live market, prices were nearly identical regardless of quality (although there was minimum level of acceptability). If the price for high quality urchins is the same as low quality urchins, it makes sense for fishermen to harvest for volume. In addition, the essentially open access nature of the resource means that urchins left behind are likely to be taken by others, so there is little incentive to leave any behind. One diver stated, “If you know where it is, you take it. In the later years [when urchins were less abundant], that’s what it boiled down to.”

There was a perception among fishermen that other fishermen did not care about the future of the resource, and therefore that most fishermen could not be trusted to not take small or low quality urchins that are left behind. One fisherman explained:

> “I know there would be people who would say, ‘I’m going to take every last one and then I’m going to do something else.’…People would say, ‘Why prolong this? Let’s just clean it up and move on.’ And they did.”

Similarly, some fishermen generalize that an unselective harvesting strategy is also an attribute of particular fishermen’s operations. They suggest small boat fishermen (20-30 ft vessels), also sometimes referred to as “wolf packs” or “the mosquito fleet,” are limited in where they can fish due to the size of their boat. They must fish closer to shore compared to larger vessels, and they do not do well in high wind conditions. One diver suggested because of these limitations, they are more likely to be less selective and therefore are more likely to “straight rake.” After taking whatever they find, they can then cull on the boat. It is in their best interest to take what they can find, when they can find something; they can always dump the low quality urchins later if they come across better ones, but at least they are able to bring in something to the market at the end of the day.

A second deliberately selective harvesting strategy was pursued by some divers. Some of these divers selectively harvested for the live market in which urchins were air freighted to Japan. Buyers shipping to the live market appear to have paid a substantial premium for consistently good quality urchins. It is significant that they also appear to have established fairly persistent long term relationships with a small group of divers. Selective harvesting is more consistent with conservation, but so long as other harvesters are gathering for a non-discriminating market there is little reason, beyond the cost of culling, for anyone to leave any urchins behind. On the other hand, they might likely leave some urchins behind if they believed that there might be a good chance of returning to the same urchins later before others were able to find them, but a strategy like this would appear to work only when the density of both divers and urchins was low. Nevertheless, some fishermen are selective and conservation-minded despite that others around them are not. One diver spoke about the reputation that urchin fishermen have as caring only about money and not the resource. He suggests that he is one of the exceptions:

> “It was true to a great extent. I went through spells like that where I thought, ‘No one else is taking care of this, why should I? No one else is worried about the smalls.’ But I couldn’t do that. I wanted to make money the following year. I don’t disturb the smalls because I hope they’ll be there next year.”

DISCUSSION

An expected finding from interviews is the apparent absence of information sharing among fishermen about fishing locations. The location of likely urchin habitat is readily apparent from any navigation chart and urchins are almost completely sedentary. Thus, a fisherman’s knowledge at this scale is durable and widely available and, consequently, of little competitive value. It is the finer scale knowledge of the current state of particular ledges that a diver acquires by direct observation that enhances his competitive position. Oversimplifying somewhat, a harvester might encounter one of three very different local resource states: (1) An urchin barren in which starving or underfed urchins literally cover the bottom. When the fishery is in this state, the value of knowledge about the resource is close to zero because anyone can find urchins. (2) A kelp dominated ledge in which harvesting has caused a local “system flip.” The ledge is dominated by seaweed, urchin predators and an absence of urchins. This is a long-lived and well known state in which the value of knowledge is also close to zero.

The most relevant state (3) is one in which a ledge has not ‘flipped’ but the urchins on the ‘top’ have been harvested, scoured off by ice, or cleared off by storms. Any of these disturbances lead to the growth of seaweed and start the ‘conveyor belt‘ in which ‘starving’ urchins from deep water gradually move up to replace urchins that have been removed from the top of the ledge. After a few weeks the starving urchins develop good roe and are marketable. Whether a ledge is ripe for harvesting depends upon timing of recent harvest activity, the rate of growth of seaweed, and the speed of urchin movement to the ‘top‘ of the ledge, which can take about one to two months, apparently depending on the local topography and the time of year.

For a fisherman, the harvestable state of a ‘conveyor belt’ ledge is hard to determine except by direct observation. How quickly urchins move up the conveyor belt depends upon the local topography, storms, water temperatures, and probably a number of other factors. Among the most important determinants, of course, are the activities of harvesters. Fishermen appear to have a hard time keeping track of the activities of other harvesters; consequently, their decision about where to fish on any particular day depends on their own knowledge of their own recent activities and costly, quick searches of ‘conveyor belt’ ledges they have not worked recently. For example, in the current fishery harvesting is permitted for a limited number of days, 10 in the west (Zone 1) and 45 in the east (Zone 2). Consequently, search time reduces valuable harvesting time. Fishermen adapt to these circumstances by searching on days when the fishery is closed and, especially, by developing search methods that allow them to quickly assess a ledge, such as motoring over a ledge at low tide, using glass bottom buckets and, when necessary, popping in and out of the water in short dives. Fishermen seem to keep a substantial list of good places to search in their head; the duration of that knowledge is rather long but the value of any particular ledge can only be confirmed by direct observation. Quick search techniques appear to substitute for the ability to exclude others. Consequently, if a fisherman encounters a good place to harvest while searching, the search is terminated and harvesting begins. Because of de facto open access at the scale of any ledge the value of knowledge about good places to fish at any time is rather short lived. In these circumstances, any sharing of information would be, as one of our informants put it, like “handing the guy my wallet.”

In short, the biological, physical, and social circumstances of the fishery are not conducive to cooperation while harvesting. There appear to be no long term or even short term cooperative relationships that are important to efficient harvesting. If there is any biophysical basis for cooperation it is in the management of the ‘conveyor belt’ on each ledge. But the scale of the ‘conveyor belt’ is far smaller than the relevant scale of an individual harvesting operation (which might be on the order of 10 to 15 ledges) and certainly much smaller than the 100 or more mile extent of each of the urchin zones.

Consequently, just as government control and privatization do not always work to circumvent the tragedy of the commons, co-management, too, sometimes fails. The co-management of the Maine sea urchin fishery failed because the scale was inappropriate for the scale of the biology, maintaining for all practical purposes an open access system even though the fishery had all the trappings of co-management, limited entry, and scientific support.

Based on our analysis of this fishery, we have identified key biophysical conditions relevant to sustainable processes in the fishery. These conditions occur at a scale much finer than current management. These circumstances would seem to imply that individual ‘leaseholds’ might be an appropriate way to manage this resource. In Atlantic Canada, this approach was tried (Miller and Nolan 2008), but with, at best, mixed results. Leaseholders were given exclusive access to an area of the ocean and the responsibility for managing the stock in their zone. They were required to participate in monitoring and enhancement, but were not subjected to seasons or catch limits. Enhancement included moving kelp to locations where urchins were overcrowded or starving and adjusting harvesting intensity necessary to maintain the feedline (or grazing front) at an acceptable depth. Leaseholders fished selectively, but engaged in minimum stock enhancement. It is not clear from the Canadian reports whether the leasehold approach was unsuccessful because the biophysical circumstances were inappropriate (disease, for example, seemed to be a problem), because the approach was not economical (distance to organized markets or buyers appears to have been large in most instances), or because there are subtle, fine scale differences in the biophysical environment that are not recognizable from Maine, but which are nevertheless important. From the Maine perspective knowledge of the system at this fine scale is necessary if we are to assess the feasibility and desirability of changes in our management institutions.

Finally, from a modeling perspective, these interviews and the accompanying scientific literature are fairly clear that the factors affecting sustainability in this fishery have to be modeled at a relatively fine scale. The mechanisms that eventually emerge as widespread depletion occur at the scale of the individual ledge. When viewed from this perspective, the usual broad scale perspective of the overfishing problem is not meaningful except as a broad statistical description unconnected to the actual process. Rather overfishing is a relatively fine scale process that removes, piece by piece, discrete, local aggregations. Consequently, modeling the fishery at broader scales is not a way to capture the dynamics affecting sustainability and, as the history or the fishery has shown, is clearly not the scale at which modeling might provide insights for practical management.

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