Technologies for Sequestering and Monitoring Ocean Property

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The problems currently facing the salmon fisheries of the Pacific Northwest are, sadly, a reflection of the state of countless other fisheries around the world. Both the Georges Bank off New England and the Grand Banks off Newfoundland, once some of the world's richest fishing grounds, are now horribly depleted. Fishers there eke out what living they can on "trash fish" that until very recently were not even worth keeping.

The troubles that fisheries face underscore the foresight of Garret Hardin in 1968 when he first described the "tragedy of the commons": In a system of open access to valuable resources, "ruin is the destination toward which all men rush" (Hardin 1968: 1244). There is little doubt that the tragedy of the commons is responsible for the decline in many salmon runs as well as for the decline of many other fisheries around the world.

In an open-access commons, the only way to own or benefit from fish is to extract them from the sea. This does not cause problems when fish are plentiful and catches are small but, as pressure on a fishery grows, so does the potential for depletion. Since no one fisher has rights to any of the fish in the water, what is left behind may be caught by someone else. There is no reason to exercise restraint, so fishers try to harvest as much as they can. Depleting resources and destroying livelihoods may make no sense in the aggregate, but when fishers cannot monitor each other, it is rational for them to catch fish at an unsustainable rate, and ruin is inevitable.

Fisheries depletion is often hastened by technologies that allow fishermen to increase their catches. On land, technological innovations usually result in increased productivity but, for the oceans, the opposite is true as these technologies are adapted for exploitation, not conservation. If marine resources could be privately owned, however, advanced technologies would only facilitate private stewardship.

In this chapter, I shall address property rights and private stewardship in four sections. First, I shall examine the nature of property rights and how they are allocated by the institutional arrangements of government control, common property, and private property. In the second section, I shall examine how ownership is related to resource conservation and technological innovation. The experiences of the frontier American West, where technological innovations helped to create and define private property, illustrate how private property rights in the oceans might develop. In the last two sections, I shall describe some of these specific technologies.

Property rights and property institutions

Property rights

Only under open access are no property rights assigned. Any attempt to exert control over resources is an attempt to define property rights. Institutional arrangements determine whether property rights are controlled by government, held in common by a group (common property), or parceled out among individuals (private property rights). Because rights to marine resources have rarely been allowed to develop among groups or individuals, government control has been standard.

Government control

Regulations that maintain open access to marine resources rely on a belief that the oceans are the "common heritage of mankind," inexhaustible and owned by everyone.[1] Growing populations (of both people and fishers) and advanced technologies for

1 This view was first popularized by Hugo Grotius in the 1600s in his treatise *Mare Liberum*. See Grotius 1633/1916.

catching fish have rendered this description untenable hundreds of years after it was first formulated, yet it still underlies much of the political aversion to excluding anyone from fishing.

Until recently government control of marine resources ignored the problems of open access and instead relied on limiting catches through restrictions on gear, effort, and seasons. This resulted in overcapitalization, inefficient harvesting techniques, dangerous races to harvest fish, and little or no progress in stemming the depletion of fisheries. When Frederick Bell studied the northern lobster fisheries in the United States, he estimated that "over 50 percent of the capital and labour employed in lobstering represent an uneconomic use of factors" (1972: 156). The Alaskan halibut fishery is another example of regulatory failure: at one point the annual halibut season was only two days long. Fishers and fishing technologies invariably stay one step ahead of the limitations imposed on them, and regulating technologies or fishing seasons does nothing to discourage fishers from harvesting as many fish as they can.

When fishery regulations target specific technologies, the result is often gross inefficiency. The Maryland oyster fishery is a classic example: it is the only commercial fishing fleet left in the country still using sailboats. The Washington state salmon fishery is another example. Earlier in this century, the reluctance of the state of Washington to limit entry into the salmon fishery caused productivity and salmon stocks to decline rapidly. The regulatory response to this decline was to outlaw efficient methods of fishing in favour of labour-intensive methods that allowed more people to fish for salmon, but did nothing to stem the depletion of the stock itself. Today, the productivity of commercial salmon fishing in Washington is only a fraction of what it was shortly after the turn of the century (Higgs 1982).

Fishery managers are finally realizing that traditional restrictions have failed, in part, because they maintained open access, and for that reason they are beginning to consider limited-access schemes like the Individual Transferable Quota (ITQ) system. Under an ITQ system, government officials set annual catch limits, but rights to a percentage of this catch can be traded, allowing the market to allocate them.

New Zealand has been a leader in implementing ITQ programs, and the paua (abalone) fishery there demonstrates both the advantages and the disadvantages of this approach. New

Zealand paua were being depleted by overfishing, but after the ITQ system was introduced into the paua fishery, fishermen began to practice conservation, limit harvests, and invest in research (Hide and Ackroyd 1990). Instead of competing with each other for a greater share of the scarce paua catch, ITQ owners in the Chatham Islands formed the Chatham Islands' Shellfish Reseeding Association "to foster and promote the enhancement of the fishery stock in the Chatham Islands" (Hide and Ackroyd 1990: 43). The ITQ system was government controlled, however, and this left an opportunity to gain access to the fishery through the political process. Eventually this meant that "the spectre of too many fishermen chasing too few fish [was] removed by the ITQ system only to be replaced by special interest groups fishing politically on land for a share of the resource" (Hide and Ackroyd 1990: 1). Political battles introduced uncertainty into the fishery, devalued the paua licenses, and damaged the industry.

Creating ITQs addresses open access problems, but it fails to divorce politics from conservation. Under an ITQ system, government managers and the vagaries of politics affect the value of fishing rights by adjusting the allowable fishing quotas, which leaves fishermen without secure, private rights to resources. ITQs specify a rigid definition of rights that may not be the most desirable. In many cases rights to an area are preferable to rights to specific species.

Fishermen have tried to assert rights to marine resources in the past, but were rebuffed by regulators who refused to allow the institutions of common and private property to develop. In the 1930s, shrimpers in Texas formed a union, excluded outsiders, and successfully maintained the health of the fishery. But newcomers who wanted to enter the fishery used the Sherman Anti-Trust Act to break the union and, consequently, stop the conservation efforts of the shrimpers (Johnson and Libecap 1982). Private rights encourage sensible harvests and conservation, but regulations have sabotaged efforts to use these rights to manage fisheries more rationally (Edwards, Bejda and Richards 1993).

The control afforded by property rights over resources is not anti-competitive; it is anti-destructive. Texas shrimpers compete with shrimpers from around the world, and unless they can realize the benefits of conservation, they are encouraged to deplete the shrimp populations.

Government control over fisheries has been the most common response to the failure of open access and, arguably, the least successful. Regulators failed to stem depletion where private stewards with a vested interest in conservation might have succeeded. Without government interference, common property and private property institutions would develop mechanisms to limit access and encourage conservation and innovation.

Common property

> It is one thing to contemplate the inshore sea from land's end as a stranger, to observe an apparently empty, featureless, open-accessed expanse of water. The image in a fisherman's mind is something very different. Seascapes are blanketed with history and imbued with names, myths, and legends, and elaborate territories that sometimes become exclusive provinces partitioned with traditional rights and owners much like property on land. (Cordell 1989:1)

The tragedy of the commons can be avoided through the institution of common property, whereby a group (often a homogenous community) controls both access to the resource and admission into the group. Exclusion allows group members to capture the benefits of conservation and forces them to take the negative effects of exploitation into account; this encourages stewardship and conservation.

The optimal allocation of common property rights can range from nearly open access to a system of strict controls and rules.[2] The level of control normally depends on the balance between the value of the resource and the costs of monitoring the group and excluding outsiders. A heterogeneous group makes it more difficult to reach agreements and manage common property resources.

Many successful common property institutions form around closely knit groups like the lobstermen of New England. Even though they cannot own areas underwater, the lobstermen form "harbour gangs" that mark territories and turn away outsiders. As a result, lobstermen in these gangs have higher catches, larger lobsters, and larger incomes than lobstermen who fish outside of

2 For a detailed analysis of successful common property regimes, see Ostrom 1990.

controlled areas (Acheson 1987). As resources grow in value and/or monitoring becomes easier (usually by innovation), private property becomes increasingly attractive (Demsetz 1967; De Alessi 1980).

Private property

Rights to private property offer owners the greatest rewards for conserving and protecting resources. In order to be effective, private property rights must be well defined, enforceable, and transferable (Anderson and Leal 1991). Private property rights are not static; their form and bundling evolve depending on the costs of defining, enforcing, and transferring them. Technology and innovation play a significant role in this process.

The work of those few who have considered the institution of private property in the marine environment suggests that these institutions would evolve out of the tragedy of the commons to improve marine resource management (Gordon 1954; Scott 1955; Keen 1983; Jeffreys 1991; Edwards, Bejda, and Richards 1993). Heterogeneous owners will still have difficulties reaching agreement, but private property rights make contracting to work around these differences easier (Johnson and Libecap 1982).

Ownership, protection, and innovation

Private stewardship

The positive effects of private ownership in the marine environment were demonstrated by Richard Agnello and Lawrence Donnelley (1975), economists at the University of Delaware. They looked at oyster beds in Maryland, Virginia, and some of the Gulf states, comparing those managed by state regulators with those owned by private leaseholders. They found that the leased oyster beds were healthier, better maintained, and produced better quality oysters. Leaseholders allowed their oysters to mature without fear that someone else might take them; in the common beds, oysters left to mature could be taken by someone else. Similarly, on shellfish beds in New Zealand, even the marginal ownership in an ITQ system encouraged owners to invest in seeding cooperatives, behaviour not seen before some measure of propriety was instituted Hide and Ackroyd 1990). In both cases, a sense of ownership encouraged individuals not only to exploit but also to protect fishery resources by rewarding stewardship and innovation.

Before it was bankrupted by trade restrictions, the Cayman Turtle Farm in the Cayman Islands provided a wealth of information on the breeding habits and life history of the green sea turtle. Scientists at the farm learned about the turtles faster than anyone had before. Even their detractors, who objected to the commercialization of the turtles, admitted that the farm was "of real importance to conservation as well as biology" (Fosdick and Fosdick 1994), demonstrating that ownership directs science and technology toward practical applications.

The common law

Paired with the common law doctrine of nuisance, private resource ownership is often a far better protector of the environment than any regulation. Nuisance law entitles owners to redress any time their property is damaged in any way. Unlike regulations and statutes, which force owners to accept a politically determined level of pollution, the common law evolves over time and has a rule of strict liability. "Even in its limited role [in the United States] today, the common law often sets standards far tougher than those set by statutes" (Meiners and Yandle 1993). As resources become more valuable, the rights to them also increase in value and, as they do, common law allows owners to expend more effort defining, enforcing, and protecting these rights.

Common law dictates that owners of water rights have an undisputed right to clean water. In the event of pollution upstream, downstream owners can sue for damages because the pollution is a trespass against this right. Regrettably, common law responses to pollution have been undermined by government intervention and statutory law. Prior to the development of national statutes, all kinds of pollution in rivers (including agricultural runoff), were limited by the common law (Yandle 1993).[3]

The rights to a resource do not have to be complete to encourage innovation and protection under the common law. In England and Wales, there are private rights to salmon in rivers, and as a result, the owners of these rights have a legal recourse when pollution harms their fisheries. The Anglers' Cooperative

3 See Elizabeth Brubaker, Beyond Quotas: Private Property Solutions to Overfishing (this volume), for a more complete treatment of the common law approach to pollution prevention.

Association (ACA) has prosecuted "more than fifteen hundred cases of pollution and recovered hundreds of thousands of dollars in damages to enable riparian owners to restore their fisheries" (Williams: n.d.). Similarly, owners of fishing rights in Scotland successfully sued polluters and were fighting for clean water twenty years before the environmental movement began (Williams: n.d.). The pollution in these rivers often came from the same local authorities responsible for enforcing anti-pollution statutes. The efforts of the ACA demonstrate the importance of the common law to the pristine health of many English rivers and point out the danger of relying on statutory limitations (Bate 1994).

In Washington State, oyster growers have also fought for many years for clean water. By the 1950s, large areas of prime oyster habitat in Washington had been depleted by effluent, primarily from pulp mills. In 1957, an official with the Washington State Department of Fisheries concluded that "there is an ever-growing feeling that our governmental and industrial planners have not followed a direction that would wisely preserve these [oyster beds and other marine resources]" (Steele 1964: 150). Because they had a vested interest in clean water, oystermen organized and successfully fought pollution. Tim Smith, the Executive Director of the Pacific Oyster Grower's Association in Lacey, Washington, is convinced that the good health of much of the watersheds in northern Washington is due to the efforts of oystermen who own tidelands and have taken action to preserve them (Smith 1995). Similarly, Dan'l Markham, Executive Director of the Willapa Alliance (a consortium of local conservationists in southern Washington), believes that private ownership, primarily by oystergrowers, is a major factor behind the health of Willapa Bay (Markham 1994). These oystergrowers have not used the common law to fight for clean water, but their efforts demonstrate the close relationship between ownership and stewardship.

Technological innovation and the American West

The rapidly changing landscape of the American West at the turn of the century showed how private property rights encourage resource protection, not only legally but also by fostering the development of innovative technologies and approaches to resource management. At first, land in the West seemed boundless and plentiful, and no one could imagine depleting its vast resources. But as the West became settled, its water and grassy lands became progressively scarcer and more valuable. The research of Terry Anderson and P.J. Hill shows that, as the rights to these resources became more valuable, more effort went into the enforcement of private property rights, which brought innovation and resource conservation (Anderson and Hill 1975).

Law in the East was not well suited to the West because it presumed that cattle could be fenced and that water would be plentiful enough to allocate it according to riparian doctrine.[4] But in the West there was not enough material to build fences, so livestock intermingled and, as settlement increased, water became scarce. Defining private property by physical barriers was desirable, but the raw materials were not available. Once cattlemen realized they could not define ownership in traditional ways, frontier entrepreneurs developed new mechanisms to define and enforce private property rights, which improved resource allocation and facilitated conservation.

Cattle in the West moved over large areas that were often common lands (Anderson and Hill 1975). They were often left unattended and herds intermingled. To avoid confusion as the numbers of settlers and cattle increased, cattlemen devised branding systems to identify their animals, and institutions such as cattlemen's associations developed to standardize and register these brands. Improved branding technology allowed cattlemen to identify, protect, and monitor a valuable roaming resource, and it was private ownership that provided the impetus for this innovation.

Once land owners in the West felt that their private property rights were relatively secure, they invested in the development of new technologies to make them even more secure. The 1870s brought an innovation that radically altered the ability to define private property: barbed wire. Barbed wire was inexpensive and effective at marking territory, excluding interlopers, and keeping in livestock. In short, barbed wire made it easier to exert private ownership. New technologies like barbed wire that developed during the westward expansion of the 1800s illustrate how

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4 The riparian doctrine dictates that all riverine owners receive equal allocations of water, and was well suited to the East where water was plentiful and easily accessible.

private property rights encourage innovation. It is often difficult to imagine alternative methods of managing natural resources, especially in the marine environment, but, given the chance, private owners will find ways to protect valuable resources by "fencing" and "branding" them wherever they are located.

Kent Jeffreys has pointed out that "the only true limits [to private ownership in the oceans] are … technology and human ingenuity" (Jeffreys 1991: 23). In a favourable institutional setting, the open access commons should give way to private property rights as resources become more valuable, and as monitoring and fencing technologies reduce the costs of protecting these rights. The evolution of private property rights to marine resources has been precluded by government actions, but if such rights were allowed to develop, technologies already exist that could be used to define and protect them just as branding and barbed wire did in the frontier American West.

Technological innovation and the oceans

The oceans today are, in many ways, similar to the frontier American West. Unowned resources are rapidly being depleted, and property institutions that encourage innovation are crucial to ensure their conservation. From satellite technology to artificial reefs to fish farming, technologies are developing that could make private ownership feasible. In some cases, new technologies come from the demand for improved management of valuable resources. In other cases, private actors are developing technologies that will enable them to profit from private management approaches. Although existing technologies are already impressive, the rate of innovation will accelerate if human ingenuity is encouraged by property rights institutions.

The territorial waters of the United States extend over a million square miles of ocean and, to date, monitoring animals or catching poachers on the high seas has been virtually impossible. Yet even with imperfect institutions, emerging technologies offer hope for the enclosure of ocean resources. Tagging methods and unmanned submersibles can identify and protect resources by effectively branding them. Artificial reefs and aquaculture can fence in oceanic resources. Sonar and satellites can both brand and fence resources. All of these technologies provide the potential for the evolution of private property rights in the marine environment and for improved management.

Branding technologies

Sonar

With the end of the Cold War, military technologies such as the Integrated Undersea Surveillance System (IUSS) are becoming available for environmental monitoring and research. The IUSS is a cohesive network of fixed and mobile acoustic devices for monitoring the oceans. It takes advantage of the different layers of temperature and salinity in much of the world's oceans. These layers trap certain acoustic waves, such as those from submarines, underwater earthquakes, or cetaceans (the group of mammals that includes whales) and allows these sounds to be detected from afar—sometimes even thousands of miles away (Nishimura 1994). According to Bob Smart, who is helping convert military technology to environmental applications at the United States National Oceanic and Atmospheric Administration (NOAA), "in the cold war, the Navy threw away more information every year regarding whales than the civilian marine-mammal community has gleaned in its entire existence" (Grier 1994: 11). The IUSS was the source of most of this information.

In 1993, scientists at Cornell used the IUSS to track a single blue whale for nearly 43 days without the use of tags or radio beacons. The songlike sounds of whales are as distinct as human voices, so that individual whales can be identified in almost the same way that voice prints identify people. Dr. Christopher Clark, a Cornell biologist, said the system will "rewrite the book on whale distribution and movement" (Broad 1993: A12). The IUSS will help scientists determine concentrations and numbers of whales worldwide, and their individual songs, like brands, could make it possible to identify and monitor them, and therefore to lay claim to them.

With remote and nearly constant monitoring of whales—a real possibility—it becomes much easier to enforce rights to whales. If whales could be owned, they would be assured much greater protection than they are today while roaming the ocean commons. In the same way that ranchers protect their cattle or, more likely, because of their greater scarcity and value, in the way that some environmental groups are caretakers for habitat, whales would be fiercely protected by their owners. The efforts of cattlemen in the American West to protect their cattle indicate that owners would be innovative stewards of their whales. Ownership of whales would also provide an incentive for individuals to invest in IUSS, so that it could continue without government funding.

Tagging

Satellite technology allows scientists and others to view the earth from extremely high altitudes and to track anything that emits the proper signal. Scientists in Florida are using transponders and a satellite owned by the National Oceanic and Atmospheric Administration to follow slow moving manatees (O'Shea 1994). The manatees are tagged with a belt holding a platform-transmitter that emits an ultra-high frequency signal. Using Global Positioning System (GPS) and radio telemetry, a satellite passing over a manatee detects the signal and records the identity of the manatee, the water temperature, and the angle at which the transmitter is tipped. This information allows researchers to track manatees and determine their migration paths.

Similar electronic tags could be used to alert boaters to manatees in the water. Currently boating accidents are one of the greatest threats to manatees—slow moving "sea cows" that have difficulty getting out of the way of speed boats. Many waterways in Florida have speed limits but they are ineffectual. Advances in tagging could make monitoring and enforcement easier and could allow for a system of private property rights to protect the manatees.

Prices of satellite information have been slowly declining over the last few years, but it is still too expensive for anyone but the government to use for tracking marine species. However, more conventional tagging technologies offer less comprehensive but less expensive mechanisms for monitoring some fish populations. Tagging of this kind usually involves inserting small computer chips into the fish; the chips are detected, identified, and recorded when the fish pass by a monitor. Due to the need for a monitor, live tagged fish can only be measured as they move around a small area, so this method has limited applications. It is currently most effective in determining the success of hatchery programs for anadromous fish (fish like salmon that return to their native streams to spawn).

Because salmon return to their native streams, salmon hatcheries can expect a reasonable number of fish to return after they are released into the wild. This practice is known as "salmon ranching," although, unlike cattle ranchers, salmon ranchers have no control over their fish once they are at sea. There is, therefore, little work being done to develop technologies to track them. Allowing ownership of salmon at sea would encourage ranchers to devise branding technologies to exert control over and to protect their salmon. Ranchers might work out agreements with fishermen and fish packers so that the owners would be compensated when their fish are caught at sea. Salmon ranching could be a boon to the salmon population throughout the world. Salmon ranchers in the past have required only from as low as one-half percent to three percent return to make their efforts worthwhile, and if they could also benefit from wild catches of their fish, no doubt they would redouble their efforts.

Advanced tags that allow fish to be identified remotely have already been developed. These Passive Integrated Transponder (PIT) tags are nine millimeter-long electronic devices that send out signals when activated by a scanner (*Science* 1994). They are ineffective at sea, but fish in rivers or ponds can be identified with PIT tags. Recently the state of Maryland apprehended four men who had illegally taken protected largemouth bass from the Potomac to sell to wholesalers out of state (Mueller 1995). Many of the fish were tagged with these small electronic tags, which allowed police to identify the fish and catch the thieves.

Biologists are also learning that fish have their own natural tagging system, a bone in the fish's inner ear called the otolith (Kingsmill 1993). These small bones aid in balance and grow in concentric layers, producing daily rings much like those produced annually on a tree. These rings are influenced by the surrounding environmental conditions: fishery scientists at the Washington State Department of Fish and Wildlife have "branded" salmon by altering water temperature to produce distinct growth patterns in the otoliths of hatchery salmon. The patterns permit the identification of the fish when they are dissected (Volk 1994). These patterns form a "bar code" on the otolith that we may one day be able to scan just as today we scan groceries at the checkout counter. So far this technique has been applied only to hatchery fish and has limited application because there is no way to examine live fish. Nonetheless, these internal brands could allow different stocks of fish to be identified easily and, therefore, branded by their owners.

Otoliths also contain trace elements from the water that the fish has lived in, recording the surrounding environmental conditions. "Otoliths are like CD-ROMs," says David Sector of the Chesapeake Biological Laboratory in Solomons, Maryland (Kingsmill 1993: 1233). Using otoliths, scientists can tell if a fish has been subjected to pollutants, which could open up a new avenue for common law suits against polluters by fishermen who could prove where and when their fish had been harmed.

Genetic research provides much of the same information as otolith research. Through a process known as electrophoresis (also known as genetic fingerprinting) scientists can determine the origins of anadromous fish and, in some cases, even the very stream in which the fish hatched (Cone 1989). As the sensitivity of this process improves, branding fish by their genetic makeup will become more and more of a possibility. Genetic fingerprinting has a long way to go before it is reliable[5] but, like otoliths, it offers great hope for branding stocks of fish or individual mammals.

Recent progress has also been made on a non-lethal procedure that uses salmon scales to identify the origin of fish caught at sea. Elemental Research, a firm in Vancouver, British Columbia, uses a technology known as laser ablation, inductively coupled plasma mass spectrometry (ICPMS) to pick up trace elements in fish scales (Brown 1996). These elements form a "signature" that can be matched with specific hatcheries or spawning sites.

Fencing technologies

Sonar and satellites

Although the Navy's underwater sound surveillance system is good at tracking whales, it was designed to monitor ship movements, which it does very well. The IUSS system is so sensitive that it can identify individual ships by the characteristic swish of their propellers (Grier 1994). The system locates the origin of a sound by comparing and triangulating information from hydrophones throughout an array, which, in effect, forms a fence around a large coastal area, picking up and identifying any distinct noises within that area. Ships are identified and logs of their crossings are kept: if any unauthorized behaviour takes place, the offenders can be tracked down.

Recently, scientists at NOAA picked up the early rumblings of an undersea volcanic eruption using the IUSS. A ship rushed to the site and was able, for the first time, to monitor an undersea eruption from its inception. The kind of precise, real-time infor-

5 See Angier 1994 for a controversial example, a report claiming that researchers using genetic fingerprinting had found whale meat from protected species for sale in Japan. Others (Macnow 1994) claim that the test used could not even differentiate between whale meat and dolphin meat, let alone identify certain species of whales.

mation that sonar delivers could greatly lower the costs of remote monitoring. The virtual fences that they create could make it easier to detect poaching and to defend valuable an area.

Satellites provide information on a ship's location and the ship's activity. Scientists at Natural Resources Consultants and the Pacific Remote Sensing Alliance in Spokane, Washington, have developed satellite hardware to monitor ships on the open ocean. These two private firms use Advanced Very High Resolution Radiometry (AVHRR) and Synthetic Aperture Radar (SAR) to tell whether ships are towing nets or not (Freeberg, Brown, and Wrigley 1992). When a ship tows a net, its engines work harder; this is reflected in the heat profile of the ship, which is detected by the satellites. These entrepreneurs have proposed that the government use this technology to prevent poaching, but fishermen who controlled offshore areas would be even better clients.

Using the satellite-based Global Positioning System (GPS), fishing vessels know exactly where they are at sea. Consequently, British fishermen are considering installing "black boxes" that link up with satellites to monitor where the ships are fishing (Deans 1995). Boats legitimately fishing would be identified by the signals from the box. Combined with the ability to tell whether ships are towing nets or not, monitors would have exact information on the position of ships in a given area and whether they were engaging in permitted activities. This strong antipoaching device could revolutionize the ability of owners to protect and conserve resources.

The only satellite technology that is widely used at the moment by fishermen comes from firms like Ocean Imaging, which sends fishers maps detailing the heat profiles of the ocean's surface (Silvern 1992). Commercial fishers and the captains of sportfishing charter boats pay a premium for this service because it provides accurate clues to the location of certain species of fish. Popular sport fish like marlin are often found at the interface between warmer and cooler waters. Warmer waters afford these large predators better visibility to catch their prey, which often stray from the cooler, nutrient-rich waters in which they are more commonly found. Not knowing where fish are has been one of the greatest obstacles to exerting control over them, but the information provided by heat profiles of the ocean's surface could remove this obstacle.

Submersibles

So little is known about the oceans that we know more about Venus, Mars, and the dark side of the moon than we do about the deepest ocean depths (Fricke 1994), but autonomous underwater vehicles (AUVs) are beginning to change that. AUVs can explore and map the oceans without the drawbacks of ships, submarines, and remotely operated (but tethered) vehicles, which are limited in their range and mobility. AUVs can be built cheaply and deployed continuously in large numbers. Communicating over networks similar to those for cellular telephones, AUVs will be able to share data with each other and with surface buoys that will relay messages to land via satellite. Scientists will be able to talk back to the AUVs, sending information and instructions. Using these features AUVs could assist oil operations and aid in marine salvage. More importantly, they could help manage fisheries and monitor pollution (Fricke 1994).

AUVs could transform schools of fish into something like herds of sheep: the AUVs might act just like intelligent sheep dogs, herding schools of fish toward optimal feeding grounds and sounding the alarm for any unauthorized fishing. This would be perfect for valuable but elusive species such as whales or the Giant Bluefin tuna, which routinely fetch up to US$30,000 at the Tokyo seafood market (Seabrook 1994). Such high prices leave little doubt that, given the opportunity, owners would develop ways to monitor and protect these tuna. “We herd cows. Why not fish?” asks David Barret, a hydrodynamic researcher at MIT (Crittenden 1994: A16).

One reason that tuna are so far-ranging is their very efficient propulsion system, and one research project developing AUVs is copying the tuna. Scientists at MIT are experimenting with a “robo-tuna” that could be thrown into Boston Harbor, swim out to the mid-Atlantic Ridge, take measurements, and then swim home. These energy-efficient modules could stay at sea for up to six months, making them perfect for monitoring and protecting remote spawning grounds or shellfish beds.

Work is also underway at MIT and Boston University on a lobster-sized robot that will duplicate the lobster’s keen ability to sense chemicals. Powered by 16 AA batteries, the “robo-lobster” can swim and turn almost like a real lobster and track down sources of chemical emissions. This AUV could be used to monitor shellfish beds for toxic algal blooms, allowing them to be managed and harvested with less uncertainty. The robo-lobster could also identify pollutants and offer a new approach for common-law solutions to marine environmental problems. In addition, the information that these machines will provide about the terrain, currents, and other characteristics of the seas will make it easier to manage property in the oceans, encouraging private stewardship.

Artificial reefs

One of the most promising areas for underwater ownership lies in the creation of artificial reefs, which have been made from such disparate objects as a bus, milk crates, and tires filled with concrete. Such reefs provide habitat that attracts some species of fish and provides an environment for the propagation of others. Some artificial reefs do not affect established populations on natural reefs but, on the contrary, create a recruitment site for larvae and juveniles that otherwise would not find a place to settle (Stone, Pratt, Parker, and Davis 1979). Other reefs may serve only to attract more motile species, and there is some debate about which attribute has the stronger influence. While the effect of each artificial reef may be slightly different, they clearly create habitat and enhance marine life.

Artificial reefs are popular with SCUBA divers and sports fishermen, and the efforts of many private fishing and diving clubs—often working in conjunction with local governments—demonstrate their willingness to invest in artificial reefs. In Canada, the Artificial Reef Association of British Columbia was allowed to sink a warship in the cold waters around Sechelt, British Columbia (Lamb 1995). This private venture has brought an influx of tourist business to the area as divers flock to the attraction. The Sechelt community does not own the wreck but it does control access, and this enables it to gain from enhancing the area and attracting business from divers. Even partial ownership encourages protection and innovation.

Oyster beds are, at present, the only privately held reefs in the United States. Oyster growers protect their beds and lay cultch (substrate) for oysters to grow on, making the beds more productive and, in effect, creating artificial reefs in the process. Extending private ownership in the United States to fishing areas other than oyster beds would encourage the development of artificial reefs, as it does in Japan, where artificial reefs and the fishery resources around them are the property of the reef owners. Japanese fishing cooperatives invest in artificial reef technology, and have built large and effective structures to create habitat for fisheries (National Research Council 1994). In the United States, without the incentive of private ownership there has been little private development of reefs as a fishery resource.

Currently, Alabama has the most lenient laws allowing artificial reef creation in the United States. The reefs cannot be owned outright, but the process for granting permits is very liberal, and permit holders do not have to specify the exact location of their reef. The fishermen sink large objects to form artificial reefs and attract fish, hoping to keep the location secret. Satellite systems like GPS allow fishermen to return to their exact location at sea. A secret location allows for limited exclusion, so that fishermen can capture some return for their investment. As a result of artificial reef production, in 1992, Alabama produced 33 percent of the recreational red snapper catch from the states touching the shoreline of the Gulf of Mexico, even though it has only 3 percent of the shoreline (Cisar 1993).

Allowing exclusive ownership of artificial reefs, or ownership of the right to fish at such reefs, would provide even greater encouragement for reef creation and maintenance. States along the Gulf of Mexico that are interested in enhancing habitat and creating biodiversity would be wise to enact laws that permitted ownership of private reefs. Allowing private ownership of these reefs would foster a greater incentive to invest in, and protect, coastal resources. Oil companies in Louisiana and Texas and other Gulf states participate in a program called "Rigs-to-Reefs," which turns the framework of defunct oil rigs into artificial reefs (Pressley 1993). The metal structures offer a durable and effective home for a vast array of marine life, oil companies save money on disposal costs, and commercial fishermen gain fishing grounds. Both interests benefit from this program and support it wholeheartedly (Stephan, Danby, Osburn, Matlock, Riechers, and Rayburn 1990), but mostly because it is a cost-effective method of disposal. If these reefs were created on private grounds, then habitat enhancement would become the most important factor in their placement.

Artificial reefs do not have to be immense, expensive structures to be effective. Reef Ball Development Ltd. of Doraville, Georgia markets a kit for making artificial reefs out of concrete using a fiberglass mold and an inflatable bladder. These reefs are durable, inexpensive, and easy to deploy, unlike the structures used in the American government's latest artificial reef program, in which old tanks worth thousands of dollars on the scrap market were dumped into the Gulf of Mexico and the ocean off New Jersey (Weitzman 1994). Allowing ownership of artificial reefs would not only encourage fishermen and divers to practise stewardship and protection, but it would also prompt them to turn to innovative companies like Reef Ball for reef structures less cumbersome and expensive than tanks.

Farming the oceans

Aquaculture permits the most well-defined private property rights to marine resources and, not surprisingly, it has experienced rapid growth and technological advancement. Aquaculture currently generates US$28.4 billion in revenues worldwide and is one of the world's fastest growing industries (Herring 1994). In 1991, the world aquaculture production was approximately 13 million tons, double the amount produced seven years earlier (FAO 1992, 1993). Aquaculture has helped to keep the worldwide fish catch relatively constant at 100 million tons, even though wild stocks are declining.

Some of the more common species bred in captivity include catfish, tilapia, and salmon. A majority of the fish grown are finned fish (approximately 70 percent); mollusks such as oysters and clams (24 percent), and crustaceans, mostly shrimp (6 percent) make up the rest (FAO 1992, 1993). The success of aquaculture stems in part from the survival rate of juveniles: only 10 percent of salmon fry survive in the wild, but in captivity almost 90 percent survive (Munk 1995). Aquaculture may one day alleviate the pressure on wild stocks, but today, even though it is growing rapidly, aquaculture still accounts for less than one-fifth of the world's fish catch (DSC Data Services 1994).

One reason for the increase in aquaculture production is genetic research. The genetics of domesticated animals have been selected by thousands of years of breeding, while fish, in general, have only been hunted in the wild (Smith, Terry, Gilbride, Adamsak, and Davis 1985). Researchers are now manipulating the genetic traits of fish and shellfish, searching for hardier organisms that grow faster. Genetic research is especially promising for fish cultivation, because fish have short life spans and breed prolifically—a single fish normally produces thousands of offspring. The absolute ownership of aquaculture farms ensures that this fecundity will be taken advantage of.

Most aquaculture (approximately two-thirds) occurs near the coast or in shallow estuaries. One of the most successful aquaculture ventures is salmon farming, particularly those in Norway and Chile. In 1980, the total worldwide catch of salmon (wild and farmed) was just over 10,000 metric tons (Meeks 1990). In 1990, farmed salmon from Norway, Chile, Scotland, Canada, and Iceland amounted to over 220,000 metric tons. As a result, in real terms, the retail price of salmon in 1990 was about one-half of the price in 1980 (Meeks 1990). This drop in price is even more dramatic when one considers the rapid depletion of some wild stocks. In the United States, the states of Oregon, Washington, Alaska, and Maine all have coastal fish farms where various species of salmon are reared.

Aquaculture is not, however, without its problems. Salmon farms close off sections of shallow bays, where fish wastes concentrate and the oxygen in the water is depleted by quick-growing algae. Further, because the density of fish is high, diseases can spread rapidly. Finally, land use on the shore and pollution from shore-based activities can also harm salmon farms. Many of these problems affecting inshore aquaculture can be solved by moving operations offshore where water circulation is better, or to more controlled environments where water is circulated artificially.

Deep-sea aquaculture is a real possibility. Submersible cages made out of strong, lightweight materials in the shape of a geodesic dome provide plenty of circulation and are sturdy enough to withstand the violent hydrodynamic forces of the open sea (Champ and Willinsky 1994). Scientists at Trident Aquaculture Ltd. in Ontario, Canada and at the Environmental Systems Development Co. in Falls Church, Virginia are working on egg-shaped cages with netting attached to an aluminum or composite framework. This design allows the cages to be both lightweight and extremely durable (Champ and Willinsky 1994). The mesh of the netting is very close, so that predators—both sea birds and other fish—cannot get into the structure. These cages offer protection and control over valuable, roaming resources, just as barbed-wire fences did in the frontier American West. The design of these cages also makes it easy to discard dead fish and to harvest live ones when they reach the appropriate size, and have been most successful in producing Arctic charr, a member of the salmon family. Although the charr generally matures in six to eight years, when it is fed on a regular schedule and protected from predation it can grow to maturity in only 18 months (Champ and Willinsky 1994).

Moving aquaculture operations offshore resolves conflicts with other users of coastal areas, but it allows for only partial exclusion: outsiders cannot take fish from cages, but they cannot be kept out of the surrounding environment. Allowing ownership of undersea areas would greatly increase the incentive to invest in offshore aquaculture and the likelihood of its success.

Although they are more complicated and expensive, completely self-contained, indoor aquaculture facilities have the advantage of allowing complete control. A firm in Massachusetts, Aquafuture, has already had some success in raising striped bass in a closed tank system. The process uses very little water, the wastes produced are easily converted to fertilizer, and is reported to yield tastier fish than conventional fish farms (Herring 1994). Regulating the temperature of the water affects the growth cycle of the fish, which can be grown to market size in one-half the time it takes in the wild or in twice the time, depending on the current demands of the market.

An enclosed environment is more sanitary, and the mortality rate at Aquafuture is half the industry average. Traditional fish farms use about 1,000 gallons of water per pound of fish produced while Aquafuture uses only about 150 gallons (Herring 1994). Filtering out fish wastes and excess feed is a relatively simple task, and most of the waste is used by local farmers as fertilizer. Fish ponds use about 2.5 pounds of feed per pound of fish, whereas the indoor system uses 1.4 pounds because there is always an accurate count of the number of fish (Herring 1994). Aquafuture already produces close to one million pounds of fish annually, and the owners have plans to build plants ten times the size of the present operation. Indoor and offshore aquaculture demonstrate that when marine resources are owned and fenced, stewardship and technological advances rapidly follow.

The success of aquaculture operations has led one reporter to conclude that "a decade ago, a fish Malthusian might have predicted the end of salmon as a food. Human ingenuity seems to have beaten nature once again" (Meeks 1990).

Conclusions

Open access to valuable resources commonly results in disaster, both for the resources and for those using them. The only solution is for private parties or governments to limit access to, and enclose, ocean resources. Government intervention has been allowed to limit the evolution of private property rights to marine resources because both technological limitations and a belief in government interference have hindered private efforts to limit access and control resources. Today, government regulation has proved to be a failure while the technological limitations are fast disappearing.

Adapting government institutions so that they mimic private solutions is a step in the right direction, but fails to eliminate the other shortcomings of regulatory programs. Instituting individual transferable quotas (ITQs) for salmon is a good idea, but a purely private approach is far superior.

Private conservation is becoming more and more practicable as emerging technologies increase the ability of owners to control marine resources. If private property rights are allowed in the oceans, stewardship and technological innovation will boom. Just as settlers in the frontier American West developed branding and fencing technologies to define and protect their property, sonar, satellites, tagging technologies, unmanned submersibles, artificial reefs, and aquaculture will allow owners of marine resources to do the same today. The challenge that lies ahead is to re-allocate control of the marine environment, creating private owners who will be encouraged to conserve resources and to harness and develop the full potential of advances in technology.

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