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EMERGING TECHNOLOGIES AND THE PRIVATE STEWARDSHIP OF MARINE RESOURCES

Michael De Alessi

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EXECUTIVE SUMMARY

Until recently, the prevailing notion among regulators was that fisheries should be open and available to everyone. This assured that fisheries were subjected to the tragedy of the commons, and led to their global decline.

Maintaining open access to marine resources encouraged fishermen to develop technologies that "vacuumed" the seas. Regulating technologies or fishing seasons does nothing to discourage fishermen from harvesting as many fish as they can. In most other industries, innovations develop to protect and increase the value and/or supply of resources, but at sea they have only hastened the depletion of fisheries.

Slowly, scholars and regulators are beginning to understand that if fisheries are to survive, access to them must be limited. People will only work to conserve resources when they have a vested interest in them. This can be accomplished either partially or wholly by:

- creating government enforced rights to a share of fishery catches known as Individual Transferable Quotas (ITQs);
- creating common property rights in fisheries, or allowing them to develop; or
- creating private property rights in fisheries, or allowing them to develop.

Government intervention has not allowed common and private property rights to develop, and so government control has been the norm. Even though governments are beginning to create rights to fisheries, these rights do not encourage conservation as well as private rights. Common property promotes conservation, but as resources increase in value and/or scarcity, private property rights offer the greatest rewards for protecting resources. The control afforded by property rights over resources is not anti-competitive, it is anti-destructive.

In order to be effective, private property rights must be well defined, enforceable, and transferable. Private property rights encouraged entrepreneurs in the frontier American West to develop and adapt technologies to protect their property, and as fishermen secure rights to resources, they will do the same. Technologies exist today that could be used to enforce ownership in the marine environment,

just as innovations such as branding and fencing did in the American West. These technologies include:

- sonar systems such as the Integrated Undersea Surveillance System;
- tagging systems, such as the Passive Integrated Transponder tag;
- sonar and satellites that monitor areas;
- Autonomous Underwater Vehicles (AUVs) that can patrol areas;
- artificial reefs that create and enhance habitat; and
- aquaculture systems that farm fish inland, at sea, and on shore that can reduce pressures in unowned fish stocks.

These technologies all offer a promising avenue for fishermen to exert control over marine resources. Allowing private ownership in the oceans would encourage their development and increase the private stewardship of marine resources.

Open-access to valuable resources results in disaster. The only solution is to limit access and enclose ocean resources, either privately or by government action. Private conservation is becoming more and more feasible as emerging technologies increase the ability of owners to control marine resources. The challenge that lies ahead is to delineate control of the marine environment, creating owners who will be encouraged to conserve resources and to harvest and develop the full potential of advances in technology.

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The Georges Bank off of New England was once one of the world's richest fishing grounds. Now, like so many other once-productive fisheries around the world, its fish stocks are horribly depleted. The United Nations Food and Agriculture Organization (FAO) estimates that 70 percent of the world's fisheries are either depleted or near collapse.[1] On the Georges Bank, there are hardly any valuable cod left, forcing fishermen to eke out what living they can on species like spiny dogfish (see charts on page 2). Dogfish used to be considered a "trash fish" that was not worth keeping, but now these types of fish are making up larger and larger portions of fish catches as other alternatives disappear.

The crash of so many fisheries underscores 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."[2] Hardin did not single out fisheries as an example, but there is little doubt that in the "tragedy of the commons" he identified the reason for the decline of the world's fish stocks.

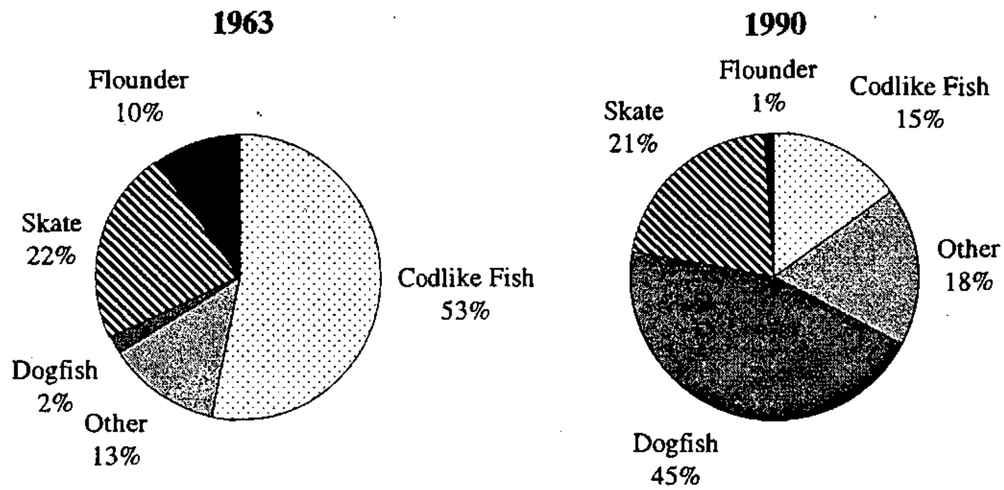
In a system of open-access to valuable resources, "ruin is the destination toward which all men rush."

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 the pressure on the fishery grows, so does the potential for depletion. Without any rights to fish in the water, fishermen realize that what they leave behind may be caught by someone else, and without any reason to exercise restraint, they try to harvest all that they can. This reduces fish populations and harms the fishery, but, since the harmful effects of each fisherman's actions are shared by all the participants, fishermen ignore them (at least in the near future). Depleting resources and destroying livelihoods may make no sense in the aggregate, but when fishermen cannot monitor each other, it is rational for them to catch fish at an unsustainable rate, and ruin *is* inevitable.

The depletion of open-access fisheries is often hastened by technological advances that allow fishermen to increase their catches. On land, technological innovations normally result in increased productivity, but in the oceans the opposite is true. Turning technology away from destruction toward conservation is one of the greatest rewards from mitigating the tragedy of the commons. Technology need not be a negative force; it is also capable of facilitating private stewardship in the seas.

It is generally accepted that the only way to stem the tragedy of the commons is to limit access to the fishery, thereby assigning some kinds of property rights. This paper addresses property rights and private stewardship in four sections. First it examines the nature of property rights and how they are allocated by the institutional arrangements of government control, common property, and private property. The second section addresses how ownership is related to resource conservation and technological innovation and illustrates through the experiences of the frontier American West how they might allow private property rights in the oceans to develop. Innovations in the West helped to create and define private property, and the last two sections concern specific technologies that may do the same in the marine environment.

Figure 1 - Georges Bank Catch Composition, 1963 and 1990



Source: World Resources Institute, World Resources 1994-95 *(Oxford University Press: Oxford, 1994).*

Property Rights and Property Institutions

Property Rights

Property rights are bundles of rights to such things as the use of a resource, the income derived from a resource, and the ability to transfer part or all of these rights. Only under open-access are there no property rights at all. 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 the norm.

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.[3] Growing populations (of both people and fishermen) and advanced technologies for catching fish have rendered this characterization untenable hundreds of years after it was first postulated, yet it underlies the political aversion to excluding anyone from traditional fishing grounds.

Until recently government control of marine resources has ignored the problems of open-access and instead relied on limiting catches through restrictions on gear.

Until recently government control of marine resources has 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 labor employed in lobstering represent an uneconomic use of factors."[4] The Alaskan halibut fishery is another example of regulatory failure; at one point the annual halibut season was only two days long. Government controls created this race for fish to save the stocks, but improvements in the way they fished allowed the boats in the Alaskan halibut fishery to catch as many fish in two days as they ever did before. Fishermen and fishing technologies always seem to stay one step ahead of the limitations imposed on them. Regulating technologies or fishing seasons does nothing to discourage fishermen from harvesting as many fish as they can.

Fishery managers now realize that traditional restrictions have failed because they maintained open-access.

In other fisheries, controls to hold the race for fish in check have stymied and in some cases even caused regression in fishing technologies. The Maryland oyster fishery is a good example; it is the only commercial fishing fleet left in the country still predominantly powered by sail. Another example is the Washington state salmon fishery. 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 favor of labor-intensive ones that allowed more people to fish for salmon but did nothing to stem the depletion of the stock itself.[5] Even today, commercial salmon fishing productivity in Washington is only a fraction of what it was shortly after the turn of the century.[6] Government managers are finally turning away from unproductive restrictions, but as long as solutions rely on regulatory controls, productivity will remain low.

Fishery managers now realize that traditional restrictions have failed because they maintained open-access, and so 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 are privately owned and 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 pros and cons of this approach.

Creating ITQs addresses open-access problems, but fails to divorce politics from conservation.

New Zealand paua were being decimated by overfishing, but once ITQs for them were created, fishermen began to practice conservation, limit harvests, and invest in research.[7] 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."[8] But the ITQ system was government controlled, which 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."[9] Political battles introduced uncertainty into the fishery, devalued the paua licenses, and damaged the industry.

As ITQs gain popularity in this country, the same problems will arise. In fact, they already have. In 1993 Alaskan fishermen got a taste of the politics of ITQs when the Arctic Alaska Company was awarded a large share of the newly created quota for Pacific Whiting, a fish used to make imitation crab meat.[10] Arctic Alaska is owned by Tyson Foods, which has been accused of receiving regulatory favors due to its longtime support of President Clinton. More recently an Alaskan newspaper chronicled the politicking surrounding an upcoming "high stakes" Alaskan "fish lottery."[11] Political allocations like ITQs are always coveted and rarely secure, introducing uncertainty and harming the fishery. Political entities rarely recognize ITQs as secure private property rights.

The control afforded by property rights over resources is not anti-competitive, it is anti-destructive.

ITQs will also cause problems because their owners will have a vested interest in maintaining the status quo. Much like the owners of taxi cab medallions, whose assets are government enforced privileges, ITQ owners will become an entrenched political force intent on limiting competition and stifling innovation. Technologies that might make fishing easier or the final product less expensive would impose costs on ITQ owners, who would encourage their government managers to limit them.

Creating ITQs addresses open-access problems, but 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 succeeded in maintaining 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.[12] Private rights encourage sensible harvest and conservation, but regulations have sabotaged efforts to use these rights to manage fisheries more rationally.[13]

Many successful common property institutions form around close knit groups, such as the lobstermen of New England.

The control afforded by property rights over resources is not anti-competitive, it is anti-destructive. Texas shrimpers continue to compete with shrimpers from around the world. This competition puts a premium on their harvest, and unless they can realize the benefits of conservation, they are encouraged to decimate the shrimp populations.

Government control over property rights to 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 likely develop to limit access and encourage conservation and innovation.

Common Property

Some communities have avoided the tragedy of the commons through the institution of common property, whereby a group 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 the group to steward and conserve their resources.

Common property can be optimal under a number of conditions, ranging from nearly open-access to a system of strict controls and rules.[14] The level of control typically 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. Differences among group members can range from attitudes toward risk and discount rates to simply how people get along with each other.

In order to be effective, private property rights must be well-defined, enforceable, and transferable.

Thus many successful common property institutions form around close knit groups, such as the lobstermen of New England. Even though they cannot own areas underwater, the lobstermen form "harbor gangs" that mark territories and turn away outsiders.[15] As a result, lobstermen in these gangs have higher catches, larger lobsters, and larger incomes than lobstermen who fish outside of controlled areas.[16]

Törbel, Switzerland, which has successfully managed a grazing commons since the Middle Ages, uses both common and private property arrangements.[17] For the commons the village has absolute rules on the transfer of rights and the use of these resources, which include grazing meadows, forests, and paths and roads. However, the villagers have private lots to grow grains, fruits, vegetables, and hay for the winter. Common property rights remain when parceling them is difficult and/or the returns from them are low. Otherwise, as resources grow in value and/or monitoring becomes easier (usually by innovation), private property becomes increasingly attractive.[18]

Common property regimes create boundaries similar to those created by private property. One anthropologists who studied successful common property fisheries provides a clue to how private property might develop in the oceans.

"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."[19]

Private Property

In order to be effective, private property rights must be well defined, enforceable, and transferable.[20] Private property rights are not static; their form and bundling evolve depending on the costs of defining, enforcing, and transferring them, and technology and innovation play a large role in this process.

The work of those few who have considered the institution of private property in the marine environment suggest that these institutions would evolve out of the tragedy of the commons to improve marine resource management.[21] Heterogeneous owners will still have difficulties reaching agreement, but private property rights make contracting easier, which makes working around these differences easier.[22] Private property rights give owners a vested interest in conserving and protecting their resources, unlike open-access exploiters who are encouraged to deplete resources because they are not rewarded for practicing conservation.

The positive effects of ownership on oyster beds was demonstrated by Richard Agnello and Lawrence Donnelley, economists at the University of Delaware.[23] They looked at oyster beds in Maryland, Virginia, and some of the Gulf states, and compared 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, unlike the common beds, where oysters left to mature might simply 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, unheard of behavior before some measure of private property was instituted.[24] In both cases, private property rights encouraged individuals not only to use but to protect fishery resources by rewarding stewardship and innovation.

Ownership, Protection, and Innovation

Private Stewardship

Under the common law doctrine of nuisance, owners are entitled to compensation for any harm done to their property. Regrettably, common law responses to pollution problems 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.[25] The 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 their right to clean water.

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 U.S.] today, the common law often sets standards far tougher than those set by statutes."[26] As resources become more valuable, the rights to them also increase in value; the common law allows owners to expend more effort defining and enforcing these rights.

The rights to a resource do not have to be complete to encourage innovation and protection under the common law.

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 Angler's Cooperative 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."[27] Similarly, owners of fishing rights in Scotland successfully sued polluters and were fighting for clean water twenty years before the environmental movement began.[28] 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 Scottish rivers and point out the danger of relying on statutory limitations.[29]

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 decimated by effluent, primarily from pulp mills. One state official concluded "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]."[30] 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.[31] Similarly, Dan'l Markham, Executive Director of the Willapa Alliance (a consortium of local conservationists in southern Washington), believes that private ownership, primarily by oystermen, is a major factor behind the health of Willapa Bay.[32] These oystermen have not used the common law to fight for clean water, but their efforts still demonstrate that ownership and stewardship are closely related.

Improved branding technology allowed cattlemen to identify, protect, and monitor a valuable roaming resource.

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 protection, not only legally, but 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 more scarce 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.[33] It is a case worth examining in greater detail.

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.[34] But in the West there was not enough material to build fences, livestock intermingled, and as settlement increased, water became scarce. Defining private property by physical barriers was desirable, but the raw materials to do so were not there. Once cattlemen realized they could not define ownership in traditional ways, frontier entrepreneurs developed new mechanisms to define and enforce property rights that improved resource allocation.

The evolution of private property rights to marine resources has been precluded by government actions

Cattle in the West moved over large areas which were often common lands.[35] They were often left unattended and herds intermingled. To avoid confusion as the numbers of both 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 secure, they encouraged and 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. It made it easier to enclose property and exert private ownership. Innovations like barbed wire that developed during the westward expansion of the 1800s illustrate how private property rights encourage innovation. It is often difficult to envision alternative methods of managing natural resources, especially in the marine environment, but with private property rights, incentives exist to develop methods of "fencing" and "branding" to protect valuable resources.

Yet even with imperfect institutions, emerging technologies offer hope for the enclosure of ocean resources.

Kent Jeffreys has pointed out that "the only true limits [to private ownership in the oceans] are... technology and human ingenuity."[36] In a favorable institutional setting, open-access commons should give way to private property rights as resources become more valuable and monitoring and fencing technologies reduce the costs of protecting these rights. In the American West, the institution of private property encouraged settlers to develop branding registries and barbed wire, which allowed them to better define and protect their property. The evolution of private property rights to marine resources has been precluded by government actions, but if these institutions were allowed to develop, technologies already exist that could be used to define and protect these rights, 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. Even partial ownership will have a positive effect. From satellite technology to artificial reefs to fish farming, technologies are being developed that make private ownership more and more feasible. In some cases, new technologies are the result of the basic demand for improved management of valuable resources. In others, private actors are developing technologies that will enable them to profit from private management approaches. Although today's developing technologies are 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 monitoring animals or catching high seas poachers has been virtually impossible. Yet even with imperfect institutions, emerging technologies offer hope for the enclosure of ocean resources. The potential applications of today's technologies are similar to two of the innovations that revolutionized the American West, branding and fencing. Technologies such as tagging methods and unmanned submersibles can identify and protect resources by effectively branding them. Artificial reefs and aquaculture fences in oceanic resources, and sonar and satellites have applications for both branding and fencing. All of these approaches provide the potential for the evolution of private property rights in the marine environment.

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 different layers of temperature and salinity in much of the world's oceans that trap certain acoustic waves, such as those from submarines, underwater earthquakes, or cetaceans (the group of mammals that includes whales) and allows them to be detected from afar, sometimes even thousands of miles away.[37] According to Bob Smart, who is helping convert military technology to environmental applications at the U.S. 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."[38] The IUSS was the source 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 song-like 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."[39] 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.

Electronic tags could be used to alert boaters to manatees in the water.

With remote and nearly constant monitoring a real possibility, it becomes much easier to enforce private property rights in whales. If whales could be owned they would be assured much greater protection than they are today, 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 (also, ownership of whales would provide an incentive to invest in IUSS so it would not be eternally dependant on 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 NOAA satellite to follow slow moving manatees.[40] The manatees have a belt attached to then with a platform-transmitter that emits an ultra-high frequency signal. Using GPS (Global Positioning System) 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 the greatest threat 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 to track marine species. However, more conventional tagging technologies offer less comprehensive, but also less expensive mechanisms for monitoring some fish populations. Tagging of this kind usually involves inserting small computer chips into the fish, which are identified and recorded when the fish pass by a monitor. Due to the need for a monitor, live tagged fish can only be measured when they pass through a small area, and 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).

The virtual fences created by sonar arrays could facilitate protecting and defending valuable resources within them.

Salmon are already ranched like cattle, except their owners have no control over what happens to their fish once they are at sea, and so there is 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 and to protect their salmon. Ranchers might work out agreements with fishermen and/or fish packers so that the owners would be compensated when their fish are caught at sea. As soon as ranchers can capture more of the returns from this kind of venture, the more encouragement they will have to redouble their efforts.

More high-tech tags have been developed recently that allow fish to be remotely identified. Called PIT tags (for Passive Integrated Transponder), they are nine millimeter-long electronic devices that send out signals when activated by a scanner.[41] They are ineffective at sea, but fish in rivers or ponds can be identified by 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.[42] 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.[43] 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, and by altering water temperatures, distinct patterns can be made for later identification of the fish. Edward Brothers of EFC Consulting in Ithica, New York, spaced the bands out to spell LT (for lake trout) in Morse code.[44] So far this technique has been applied only to hatchery fish and currently has limited applications because there is no way to examine live fish. Nonetheless these internal brands could allow different stocks of fish to be easily identified, 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.[45] Using otoliths, scientists can tell where a fish has lived and when it has been subjected to pollutants, which could open up a whole new avenue for common law suits against polluters by fishermen who could prove where and why their fish had been harmed.

Genetic research provides much of the same information as otolith research. Through a process known as electrophoresis, which is also known as genetic fingerprinting, scientists can determine the origins of anadromous fish, and in some cases even the very stream that the fish hatched in.[46] 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,[47] but like otoliths, it offers great hope for branding stocks of fish or individual mammals.

Ownership schemes encourage investment in this kind of research. 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 else ever 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,"[48] demonstrating the importance of ownership to direct science and technology toward practical applications.

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, and it does this amazingly well. The IUSS system is so sensitive that it can identify individual ships by the characteristic swish of their propellers.[49] The system locates the origin of a sound by comparing and triangulating information from hydrophones throughout an array, which effectively form a fence around a large coastal area, picking up and identifying any distinct noises within that area. Once ships are identified, logs of the ships that crossed an area can be kept and if any unauthorized behavior takes place, the offenders can be tracked down. The virtual fences created by these sonar arrays could facilitate protecting and defending valuable resources within them.

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 information that sonar delivers could drastically lower the costs of remote monitoring, making it easier to detect poaching and exert control over an area.

AUVs could transform schools of fish into something like herds of sheep

Satellites provide information on ship 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.[50] When a ship tows a net, it's engines work harder, and this is reflected in the heat profile of the ship, which is detected by the satellites. These entrepreneurs have made their proposal to the government to use this technology to prevent poaching, but fishermen who controlled offshore areas would be even better clients.

Using the satellite-based GPS technology mentioned earlier, fishing vessels know exactly where they are at sea. Consequently, British fishermen are considering installing "black boxes" that linkup with satellites to monitor where the ships are fishing.[51] 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 sanctioned activities. This strong anti-poaching device could revolutionize the ability of owners to protect and conserve resources.

Currently, the only satellite technology that is widely used by fishermen comes from firms like Ocean Imaging, which allows fishermen to receive maps detailing the heat profiles of the ocean's surface.[52] Commercial fishermen and sport fishing charter boat captains pay a premium for this service because it provides accurate clues to the whereabouts of certain species of fish. One of the greatest obstacles to exerting control over fish is not knowing where they are, but the information provided by heat profiles of the ocean's surface may eliminate 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,[53] but autonomous underwater vehicles (AUVs) are changing this. 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, but, more importantly, they could help manage fisheries and monitor pollution.[54]

One of the most promising areas for underwater ownership lies in the creation of artificial reefs.

AUVs could transform schools of fish into something like herds of sheep; the AUVs would act just like intelligent sheep dogs, herding schools of fish toward optimal feeding grounds and sounding the alarm of any unauthorized fishing. This would be perfect for valuable but elusive species such as whales or the giant Bluefin Tuna. Giant Bluefin Tuna routinely fetch up to $30,000 at the Tokyo seafood market.[55] Such incredible 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.[56]

One reason that tuna are so far-ranging is their very efficient propulsion system, and one AUV research effort is copying the tuna for just this reason. 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 patrol spawning grounds or remote shellfish beds, staying at sea for up to six months.

Work is also underway at MIT and Boston University on a lobster-sized robot that will duplicate the lobster's keen chemical-sensing abilities. 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. "Robo-lobster" could also identify pollutants and offer a new approach for common law solutions to marine environmental problems. The information these machines will provide about the terrain, currents, and other characteristics of the seas will make it easier to keep track of property in the oceans, which will increase the potential for private stewardship.

Artificial Reefs

One of the most promising areas for underwater ownership lies in the creation of artificial reefs. Such reefs typically serve one of two purposes, either to attract and propagate fish stocks or to provide sites for SCUBA divers. Studies have shown that artificial reefs do not affect established populations on natural reefs; rather, they create a recruitment site for larvae and juveniles that otherwise would not find a place to settle.[57] The creation of artificial reefs therefore increases marine life not by taking it away from other areas, but by providing habitat for additional organisms. Artificial reefs have been made from such disparate things as a bus, milk crates, and tires filled with concrete.

Allowing private ownership of these reefs would foster an even greater incentive to invest in and protect coastal resources.

The efforts of many private fishing and diving clubs, often working in conjunction with local governments, demonstrate an interest and willingness to invest in artificial reefs. In Canada, the Artificial Reef Association of British Columbia was allowed to sink a warship in the barren, cold waters around Sechelt, British Columbia.[58] This completely private venture has brought an influx of tourist business to the surrounding area as divers flock to the attraction. The community did not own the wreck, but it did control access, which enabled the community to gain from enhancing the area and attracting diving business. Even partial ownership encourages protection and innovation.

Currently, oyster beds are the only privately held reefs in the United States. Oyster growers protect their beds and lay cultch (substrate) for oysters to grow on to make them more productive, creating artificial reefs in the process. Extending private ownership beyond just oyster beds would encourage artificial reef development, as it does in Japan. There, artificial reefs and the fishery resources around them are the property of the reef owner. Japanese fishing cooperatives invest in artificial reef technology, and have built large and effective structures to create habitat for fisheries.[59] Without the incentive of private ownership in the U.S., 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 permitting process 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, and then hope to keep the location secret. Satellite systems, such as GPS, allow fishermen to return to their exact location at sea. A secret location allows for limited exclusion, and so fishermen can capture some of the returns on their investment. As a result of artificial reef production, Alabama produced 33 percent of the recreational red snapper catch in the Gulf states in 1992, even though it has only 3 percent of the Gulf shoreline.[60]

Aquaculture allows for the most well-defined private property rights to marine resources

Allowing exclusive ownership of artificial reefs, or even ownership of the right to fish at such reefs, would provide even greater encouragement for reef creation and maintenance. Gulf states interested in enhancing habitat and creating biodiversity would be wise to enact laws that allowed for private reef ownership. Allowing private ownership of these reefs would foster an even greater incentive to invest in and protect coastal resources.

Artificial reefs not only provide habitat, but can also be an attractive alternative to conventional waste disposal. In the Gulf states, particularly Texas, oil companies participate in a program called Rigs-to-Reefs, which turns the framework of defunct oil rigs into artificial reefs.[61] 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.[62]

Aquaculture may one day alleviate the fishing pressure on wild stocks

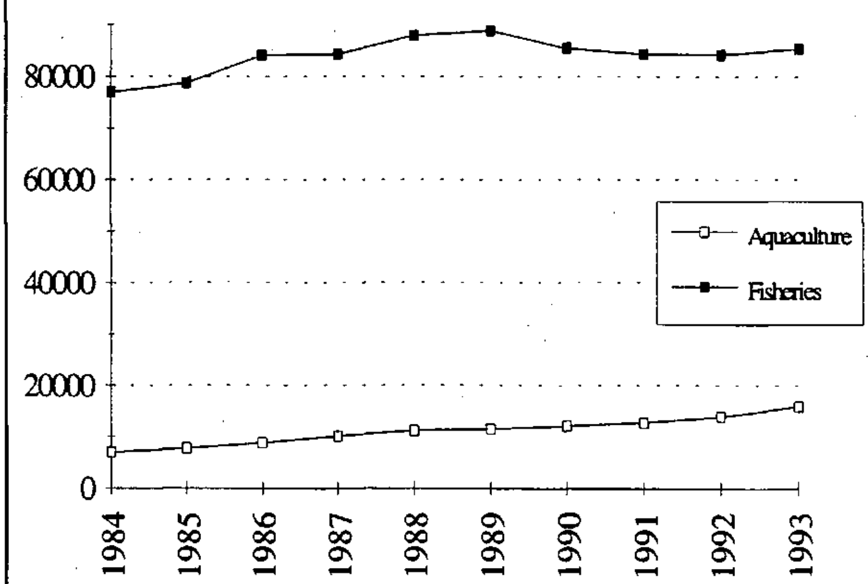
Artificial reefs do not have to be immense, expensive structures to be effective. Reef Ball Development Ltd. markets a kit for making artificial reefs out of concrete using a fiberglass mold and an inflatable bladder. These reefs are durable, inexpensive, and easy to deploy, unlike the structures used in the latest government-run artificial reef program, in which old tanks worth thousands of dollars on the scrap market are dumped in the Gulf of Mexico and off of New Jersey.[63] Allowing ownership of artificial reefs would encourage not only stewardship and protection, but encourage fishermen and divers to turn to innovative companies like Reef Ball to develop reef structures less cumbersome and expensive than a tank.

Farming the Oceans

Aquaculture allows for the most well-defined private property rights to marine resources, and not surprisingly it has experienced rapid growth and technological advancement. Aquaculture currently generates $28.4 billion in revenues worldwide and is one of the world's fastest growing industries.[64] In 1991, the world aquaculture production was approximately 13 millions tons, double what it was seven years before.[65] It is one reason why the worldwide fish catch has remained relatively constant at 100 million tons, even though wild stocks are declining (see charts and box, on page 15).

Some of the more common species bred in captivity include catfish, tilapia, and salmon; a majority of the fish grown are finfish (approximately 70 percent), mollusks such as oysters and clams (24 percent), and crustaceans, mostly shrimp (6 percent) make up the rest.[66] Part of the success of aquaculture stems from the survival rate of juveniles; only ten percent of salmon fry survive in the wild but in captivity the number jumps to almost ninety percent.[67] Aquaculture may one day alleviate the fishing 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.[68]

FIGURE 2 - WORLD FISH PRODUCTION COMPARED WITH AQUACULTURE, 1984-1993



Source: Food and Agriculture Organization of the United Nations, The State of World Fisheries (FAO: Rome, 1995).

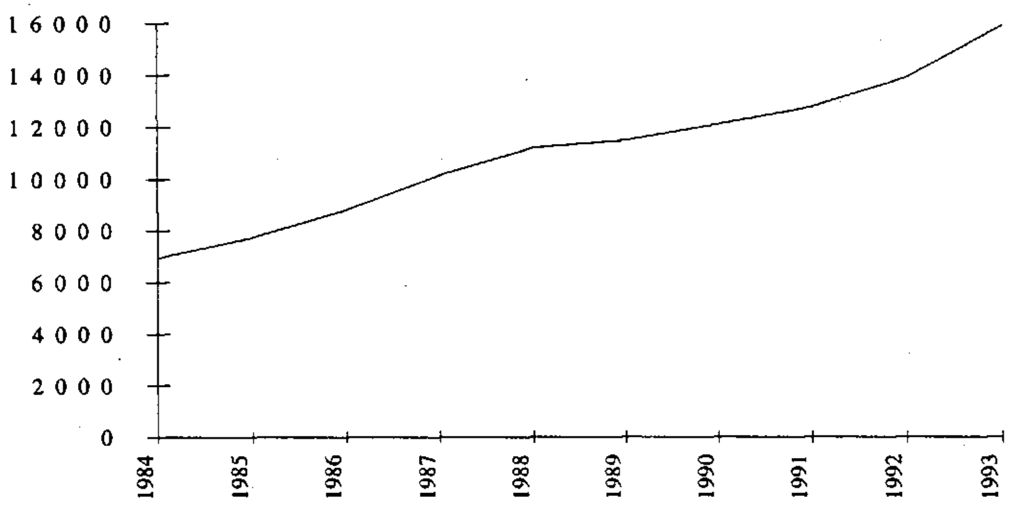
One reason for the increase in aquaculture production is genet-

Gains in Productivity for Aquaculture and Agriculture

As interest in aquaculture has increased, it has experienced gains in productivity similar to those in agriculture (figure 3). When property rights are secure, the investment in innovation rises and huge gains in productivity result as owners use new technologies to protect and increase the productivity of their resources.

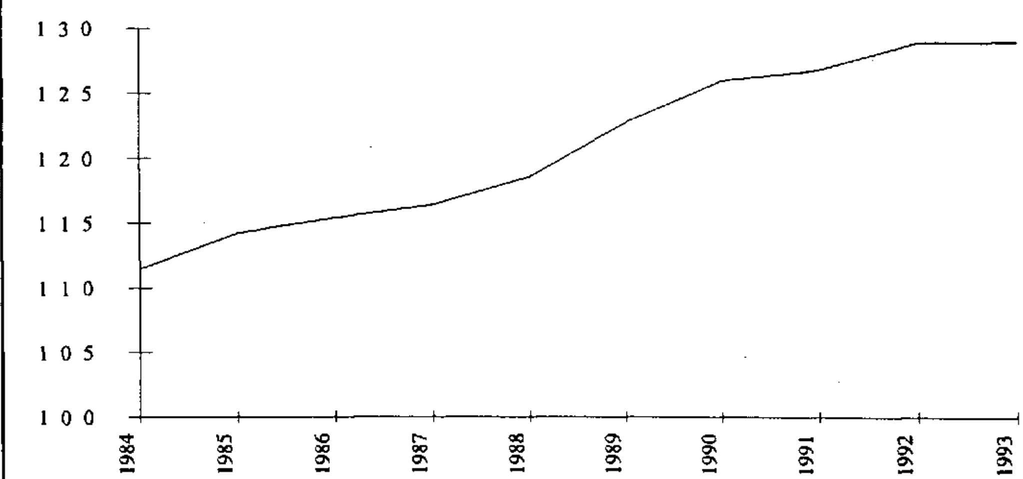
Wild fisheries, on the other hand, offer very little reward for innovation, except to deplete fish stocks more quickly (see figure 2, previous page). When resources are unowned, exploiters develop technologies that vacuum the seas and lower productivity, as was the case on the Georges Bank. The losses are even worse that they appear because as stocks decline, fishermen substitute lesser quality fish (figure 1 on page 2). The Georges Bank was once one of the world's richest fishing grounds, but in late 1994 it became so badly depleted that fishing operations virtually shut down.

Figure 3 - Aquaculture Production, 1984-1993 (1,000 metric tonnes).



Source: Food and Agriculture Organization of the United Nations, The State of World Fisheries (FAO: Rome, 1995).

Figure 4 - Agriculture Production Index, 1984-1993 (1979-81 = 100).



Source: Food and Agriculture Organization of the United Nations, FAO Production Yearbook *(FAO: Rome, 1994).*

ic research. The genetics of domesticated animals have been selected by thousands of years of breeding, while fish, in general, have simply been hunted in the wild.[69] 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 are prolific breeders (a single fish normally produces thousands of potential offspring). The absolute ownership of aquaculture farms encourages this kind of technological innovation.

Private conservation is becoming more and more feasible and practical as emerging technologies increase the ability of owners to control marine resources.

Most aquaculture (approximately two-thirds) occurs near the coast or in shallow estuaries. One of the most successful aquaculture ventures is salmon farming, particularly in Norway and Chile. In 1980, the total worldwide catch of salmon (wild and farmed) was just over 10,000 metric tons.[70] 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 half of what it was in 1980.[71] This drop in price is even more dramatic when coupled with the rapid depletion of wild stocks, in part because of the discovery and open-access exploitation of Atlantic Salmon breeding grounds off the coast of Greenland. In the United States, Oregon, Washington, Alaska, and Maine all contain coastal fish farms where various species of salmon are reared.

Aquaculture is not without its problems. Salmon farms close off sections of shallow bays and create a problem because these bays harbor fish wastes and oxygen-poor water created by quick-growing algae. Also, fish density is so high that diseases can run rampant in a short time. Many of the problems of inshore aquaculture (external problems of pollution and land use, and internal problems of disease and poor water quality) can be solved by moving operations offshore where water circulation is better, or to even more controlled environments where water circulates artificially.

Deep-sea aquaculture is a real possibility. Submersible, open-ocean cages, made out of strong, lightweight materials in the shape of a geodesic dome provide plenty of circulation and are hydrodynamic and sturdy enough to withstand the violent forces of the open sea.[72] These cages offer hope for open-ocean aquaculture. Scientists at Trident Aquaculture in Ontario, Canada and at the Environmental Systems Development Company in Falls Church, Virginia are working on egg-shaped cages with netting attached to an aluminum or composite framework, which allows the cages to be both lightweight and extremely durable.[73] The netting is very tight, which means that predators — both sea birds and other fish — cannot get into the structure. These cages offer protection and control over valuable, roaming resources, just like barbed-wire fences did in the frontier American West.

The design of these cages 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 fish 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.[74] Moving aquaculture operations offshore resolves conflicts in 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 investment in and the success of offshore aquaculture.

Although they are more complicated and expensive, completely self-contained, indoor aquaculture facilities allow for complete control. A firm in Massachusetts, Aquafuture, has already had some success in raising striped bass in a closed tank system. The process uses hardly any water, produces wastes easily converted to fertilizer, and reportedly yields tastier fish than conventional fish farms.[75] Regulating the temperature of the water affects the growth cycle of the fish. They can be grown to market size in half the time it takes in the wild or in twice the time, depending on the current market.

An enclosed environment is more sanitary, and without so much disease, Aquafuture's mortality rate 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.[76] 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 because there is always an accurate count of the number of fish.[77] Aquafuture already produces close to one million pounds of fish annually, and the owners have plans to build plants ten times that size. Indoor aquaculture and offshore mariculture 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."[78]

Conclusions

Open-access to valuable resources results in disaster, both for resources and the people using them. The only solution to this problem is to limit access and enclose ocean resources, either privately or by government action. Government intervention has precluded the evolution of private property rights, and so has been the norm, in part because both technological limitations and a belief in government interference have hindered private efforts to limit access and control resources through private property rights. Today, government regulation has proved to be a failure while the technological limitations of yesterday are fast disappearing.

Private conservation is becoming more and more feasible and practical 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 delineate control of the marine environment, creating owners who will be encouraged to conserve resources and to harness and develop the full potential of advances in technology.

About the Author

Michael De Alessi is a research associate at the Competitive Enterprise Institute and coordinator of the Center for Private Conservation. He specializes in marine resource issues. He received a B.A. in Economics and an M.S. in Engineering Economic Systems from Stanford University and an M.A. in Marine Policy from the Rosenstiel School of Marine and Atmospheric Science at the University of Miami. His articles and letters on marine resources have appeared in the *Washington Times,* the *Journal of Commerce,* the *International Herald Tribune*, and the *Wall Street Journal.*

Much of the groundwork and initial research for this project was done by Kelly Glenn when he was research director at the Competitive Enterprise Institute.

ENDNOTES

[1]FAO, quoted in "Business and the Environment," *Financial Times* (March 22, 1995).

[2]Garrett Hardin, "The Tragedy of the Commons," *Science*, vol. 162 (1968), pp. 1243-1248.

[3]This view was first popularized by Hugo Grotius in the 1600's in his treatise *Mare Liberum*, but remains relevant today.

[4]Frederick W. Bell, "Technological Externalities and Common-Property Resources: An Empirical Study of the U.S. Northern Lobster Fishery," *Journal of Political Economy*, vol. 80 (1972), pp. 148-158.

[5]Robert Higgs, "Legally Induced Technical Regress in the Washington Salmon Fishery," *Research in Economic History*, vol. 7 (1982), pp. 55-86.

[6]Higgs.

[7] Rodney P. Hide and Peter Ackroyd, *Depoliticising Fisheries Management: Chatham Islands' Paua (Abalone) as a Case Study*. Unpublished report, Centre for Resource Management, Lincoln University, New Zealand (1990).

[8]Hide and Ackroyd.

[9]ibid.

[10]Al Ota and Don Hamilton, "Fish ruling aids Clinton backer," *Seattle Times* (April 17, 1993).

[11]Greenwire, December 15, 1994.

[12]Ronald A. Johnson and Gary Libecap, "Contracting Problems and Regulation: The Case of the Fishery," *American Economic Review*, vol. 72(5) (1982), pp. 1005-1022.

[13]Steven F. Edwards, Allen J. Bejda, and R. Anne Richards, *Sole Ownership of Living Marine Resources*, NOAA technical Memorandum NMFS-F/NEC-99 (1993).

[14]For a detailed analysis of successful common property regimes, see Elinor Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge, MA: Cambridge University Press, 1990).

[15]James M. Acheson, "The Lobster Fiefs Revisited" in *The Question of the Commons* (University of Arizona Press: 1987).

[16]Acheson.

[17]Ostrom.

[18]Harold Demsetz, "Toward a Theory of Property Rights." *American Economic Review* 57 (1967), pp. 347-359; and Louis De Alessi, "The Economics of Property Rights: A Review of the Evidence," *Journal of Law and Economics*, vol. 2 (1980), pp. 1-47.

[19]John Cordell, *A Sea of Small Boats* (Cambridge, Massachusetts: Cultural Survival, Inc., 1989).

[20]Terry L. Anderson and Donald R. Leal, *Free Market Environmentalism*, (San Francisco: Pacific Research Inst. for Public Policy, 1991).

[21]For example, see H. Scott Gordon, "The Economic Theory of a Common-Property Resource: The Fishery," *Journal of Political Economy,* vol. 62 (1954), pp. 124-142; Anthony Scott, "The Fishery: The Objectives of Sole Ownership," *Journal of Political Economy,* vol. 63 (1955), pp. 116-124; Elmer A. Keen, "Common Property in Fisheries: Is Sole Ownership an Option?" *Marine Policy* vol. 7 (1983), pp. 197-211; Kent Jeffreys, *Who Should Own the Ocean?* (Washington, D.C.: Competitive Enterprise Institute, 1991); and Edwards, et al. (1993).

[22]For a discussion on heterogeneity and contracting, see Johnson and Libecap.

[23]Richard R. Agnello and Lawrence P. Donnelley, "Property Rights and Efficiency in the Oyster Industry," *Journal of Law and Economics,* vol. 18 (1975), pp. 521-533.

[24]Hide and Ackroyd.

[25]Bruce Yandle, "Community Markets to Control Agricultural Nonpoint Source Pollution," in *Taking the Environment Seriously* (Lanham, Maryland: Rowman and Littlefield Publishers, Inc. 1993).

[26]Roger E. Meiners and Bruce Yandle, "Clean Water legislation: Reauthorize or Repeal?" in *Taking the Environment Seriously* (Lanham, Maryland: Rowman and Littlefield Publishers, Inc., 1993).

[27]Brian Williams, and T.D. Solicitor, "The A.C.A. and the Common Law," speech presented to the Anglers' Cooperative Association Water Protection Officers' Seminar at the National Water Sports Center, Holme Pierrepont, Nottingham.

[28]Williams.

[29]Roger Bate, "Water Pollution Prevention: A Nuisance Approach," *Economic Affairs* (April 1994).

[30]Milo Moore, Director of the Washington State Department of Fisheries, 1957 Quoted in E.N. Steele, *The Immigrant Oyster* (Olympia, Washington: Warren's Quick Print: 1964), p.150.

[31]Tim Smith, personal communication (January 1995).

[32]Dan'l Markham, personal communication (December 1994).

[33]Terry L. Anderson and P.J. Hill "The Evolution of Property Rights: A Study of the American West." *Journal of Law and Economics,* vol. 12 (1975), pp. 163-179.

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

[35]Anderson and Hill.

[36]Jeffreys, p. 23.

[37]Clyde E. Nishimura, "Monitoring Whales and Earthquakes by Using SOSUS," *1994 NRL Review* (Washington, D.C.: Naval Research Laboratory, 1994).

[38]Peter Grier, "The greening of military secrets," *Christian Science Monitor* (March 21, 1994).

[39] William J. Broad, "Navy listening system opening world of whales," *New York Times* (August 23, 1993).

[40]Thomas J. O'Shea, "Manatees," *Scientific American* (July 1994).

[41]"Bass Poachers Hooked by Bug." *Science,* vol. 267 (1994), pp. 1765.

[42]Gene Mueller, "High-tech sleuthing pays off for Md. DNR in investigation," *Washington Times* (March 1, 1995).

[43]Suzanne Kingsmill, "Ear Stones Speak Volumes to Fish Researchers," *Science,* vol. 260 (1993), pp. 1233-1234.

[44]Kingsmill.

[45]Kingsmill.

[46]"Genetic Fingerprints," *Pacific Fishing* (November 1989).

[47]For a rebuttal, that in some cases the tests could not persuasively differentiate between even whale and dolphin meat, see Natalie Angier, "DNA tests find meat of endangered whales for sale in Japan," *New York Times,* September 13, 1994, for the controversial report that claimed researchers had found samples of banned whale meat sold in Japan by using genetic fingerprinting on samples they bought there and Alan Macnow, "A blatant misuse of science," *Wall Street Journal,* Letters to the Editor, October 5, 1994.

[48]Sam Fosdick and Peggy Fosdick, *Last Chance Lost?* (1994).

[49]Grier, 1994.

[50]Mark H. Freeberg, E.A. Brown, and Robert Wrigley, "Vessel Localization using AVHRR and SAR Technology," Presented at Marine Technology Society Annual Meeting, Washington, D.C., October 19, 1992.

[51]John Deans, "Tightening the net; Spy-on-the-bridge could curb rogue EU trawler skippers," *Daily Mail* (March 20, 1995).

[52]Drew Silvern, "For company, space data is catch of the day," *San Diego Union-Tribune* (October 10, 1992).

[53]Robert J. Fricke, "Down to the Sea in Robots," *Technology Review* (October 1994).

[54]Fricke.

[55]John Seabrook, "Death of a giant: stalking the disappearing Bluefin Tuna," *Harper's Magazine,* (June 1994).

[56]Jules Crittenden, *The Boston Herald* (October 30, 1994), p. A16.

[57]R.B. Stone, H.L. Pratt, R.O. Parker, Jr., and G.E. Davis, "A Comparison of Fish Populations on Artificial and Natural Reefs in the Florida Keys," *Marine Fisheries Review* (1979), pp. 1-11.

[58]Jamie Lamb, "Success of private enterprise is giving our MLAs that old sinking feeling," *Vancouver Sun* (January 30, 1995).

[59]*Restoring and Protecting Marine Habitat: The Role of Engineering and Technology* (Washington, D.C.: National Academy Press, 1994).

[60]Eric Cisar, "Artificial Reefs: Making something from nothing," *Tide* (November/December, 1993). *Tide* is a magazine of the Coastal Conservation Association.

[61]Sue Anne Pressley, "Oil rigs convert to fish condominiums," *The Washington Post* (September 4, 1993).

[62]C.D. Stephan, et al, *Texas Artificial Reef Fishery Management Plan*, Fishery Management Plan Series Number 3, Texas Parks and Wildlife Department.

[63]Jennifer Weitzman, "Tanks take on new role as artificial reefs to attract fish," *New York Times* (December 4, 1994).

[64]Hubert B. Herring, "900,000 Striped Bass, and not a fishing pole in site," *New York Times* (November 6, 1994).

[65]FAO, *Aquaculture Production 1985-1991* (Rome: Food and Agriculture Organization of the United Nations, and FAO, 1993); *Aquaculture production 1984-1990* (Rome: Food and Agriculture Organization of the United Nations, 1992).

[66]FAO.

[67]Nina Munk, "Real fish don't eat pellets," *Forbes* (January 30, 1995).

[68]From statistics in the World Resources Database, DSC Data Services (Washington, D.C.: World Resources Institute, 1994).

[69]Emily T. Smith, Andrea Durham, Edith Terry, Neil Gilbride, Phil Adamsak, and Jo Ellen Davis, "How genetics may multiply the bounty of the sea," *Business Week* (December 16, 1985).

[70]Fleming Meeks, "Would you like some salmon with your Big Mac?" *Forbes* (December 24, 1990).

[71]Meeks.

[72]Michael A. Champ and Michael D. Willinsky, "Farming the oceans," *The World and I* (April, 1994).

[73]ibid.

[74]ibid.

[75]Herring.

[76]ibid.

[77]ibid.

[78]Meeks.

The Center for Private Conservation

The Center for Private Conservation (CPC) is a project of the Competitive Enterprise Institute that seeks to expand the knowledge and information base surrounding the ability to advance environmental objectives privately, absent government control or influence. The Center researches and documents successful private efforts to conserve resources and ecologically sensitive lands, and analyzes how various legal and social institutions assist or hinder the ability of private individuals and associations to protect their environment. The Center seeks to publicize its findings through publications, speeches, roundtables, and work with interested organizations.

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For more information, contact:

The Center for Private Conservation
c/o the Competitive Enterprise Institute
1001 Connecticut Ave, NW
Suite 1250
Washington, D.C. 20036
Phone: (202) 331-1010
Fax: (202) 331-0640
e-mail: cpc@cei.org