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Perspectives

Aquaculture and the Future: Why Fisheries Economists Should Care

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Abstract *This paper explores the relationship between traditional fisheries, fisheries enhancement (ranching), and aquaculture. It evaluates why they are different and why fisheries economists have largely neglected aquaculture issues, despite the fact that most of the growth in fish supply over the past two decades has been the result of aquaculture development. It is argued that the core difference between aquaculture and traditional fisheries is the degree of control; control of the environment, production, and marketing systems. It is further argued that the degree of control is closely related to the strength of property rights. Three examples are presented to provide empirical support for the propositions. They focus on the salmon, lobster, and shrimp industries.*

Key words Aquaculture, fisheries, property rights, salmon, lobster, shrimp.

Introduction

Imagine a meeting of town managers in 1903. They are trying to think of innovative ways to create property rights that will internalize the externalities created by the waste left by horse-drawn carriages in town. As they are deliberating, a noisy new gasoline powered Oldsmobile Curved-Dash Runabout interrupts their debate. They pause for a minute, then resume talking. They have heard and seen the future of transportation and the new problems it will bring, but they continue to discuss the soon-to-be past.

Now, fast forward to the present day and consider a meeting of fisheries experts. They debate fisheries management and innovative solutions to the great open-access problems. When they break to eat dinner, it is likely to consist of salmon and/or shrimp. Yet they seem oblivious to the fact that the seafood they are consuming is farmed. They eat the future of fisheries, but continue to discuss its past. This analogy may be a bit unfair, but I don't think it is that far from the truth.

It surprises me that many fisheries managers and/or economists seem to think there are few interesting issues in aquaculture and that it has little to contribute to the fisheries management problem. Is aquaculture so different from fisheries that fisheries managers can essentially ignore it? Are aquaculture technologies, practices, and management unrelated to fisheries management? What is fundamentally different about aquaculture compared to traditional fisheries? I will argue that the difference distills down to the degree of control …. control of inputs; control of feed; control of exposure to the elements: cold/heat, light, predators, and disease; control of harvest, growth rate, and size; control of location; control of technology; and con-

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trol of the species harvested. The naïve perspective of the traditional open-access fisheries is that there is essentially no control, and that with aquaculture there is nearly complete control. In most of the real world, this is not the case. This paper offers the notion that there is a continuum between fishing and aquaculture, defined basically by the degree of control. This degree of control, at its core, is largely defined by the strength of property rights.

Before moving forward with my perspective, it is advisable to consider the relative importance of aquaculture in the harvest of fish and aquatic products. On a global scale, aquaculture accounts for approximately 26% of all fish harvests; however, as seen in figure 1, aquaculture represents 33% of all "food fish" (excluding *Clupeiformes*) harvest (FAO 2001).[1] In either case, most of the growth in global fish supply is derived from aquaculture. The importance of aquaculture becomes more apparent when we consider some specific examples:

- In Norway, both the landed value and quantity of farmed Atlantic salmon exceeds its traditional Atlantic cod harvest (FAO 2001).
- In the US, farmed catfish is now second in harvest quantity (excluding menhaden) behind Alaska pollock. Furthermore, farmed catfish is now the number one finfish landed (by value) ahead of hatchery-dominated salmon and Alaska pollock. In fact, Mississippi (US) is now the second largest fish producer after Alaska (USDC 2001).
- In Canada, based on landed value, farmed salmon is the number one species harvested in British Columbia, despite a moratorium on site licenses through most of the 1990s (BC Fisheries 2000).
- In Thailand, the most valuable fish harvested is farmed shrimp (FAO 2001).
- During the past five years, the fastest-growing seafood imports into the US are farmed Atlantic salmon, farmed mussels, and farmed tilapia (USDC 2002).

A useful comparison of the trend toward aquaculture and/or more controlled fisheries is observed in US per capita seafood consumption in 1987 and 2000, found in table 1. Consumption of farm-related species, such as shrimp, salmon, and catfish, has increased, while consumption of cod, flatfish, and scallops has lost ground. Per capita consumption of Alaska pollock has increased. However, as this fishery became dominated by the US in the 1990s (previously dominated by distant-water fleets from countries such as Japan), it has been continually moving toward rights-based fishing, such as cooperatives. This evolution has changed the character of the Alaska pollock fishery as the cooperatives have increased control. Ed Richardson (2001), the economist for the At-Sea Processors Association (APA), put it this way, "we don't chase fish anymore, we just mow the lawn." The fishery has lost many of its "hunter" aspects. Fishermen now know where the fish are, their size, and their level of maturity. They harvest them cooperatively, which results in improved efficiency, timing, and yield. There is much more control than in a traditional fishery.

Aquaculture, Ranching, and Fisheries

What makes aquaculture, aquaculture or a fishery, a fishery? In an effort to provide an answer to this question, an index (the Aquaculture, Ranching, Fishing Index [ARF Index]) of the degree that an operation is aquaculture, ranching, or fishing has

[1] However, the data on China's fish harvest are known to contain irregularities and are generally considered to be overstatements, particularly with regard to wild fisheries (Watson and Pauly 2001). Therefore, the aquaculture share may possibly be greater.

Table 1
Top 10 Seafoods Consumed in the US
(edible kg per capita) 2000 and Percent Change 1987–2000

Seafood	Kg Per Capita	Percent Change 1987–2000
Tuna	1.64	3%
Shrimp	1.45	39%
AK Pollock	0.77	93%
Salmon	0.73	265%
Catfish	0.51	89%
Cod	0.35	–54%
Clams	0.22	–27%
Crab	0.21	40%
Flatfish	0.20	–39%
Scallops	0.13	–13%
Other	0.88	–59%
TOTAL	7.09	–4%

Source: NFI 1988, 2001

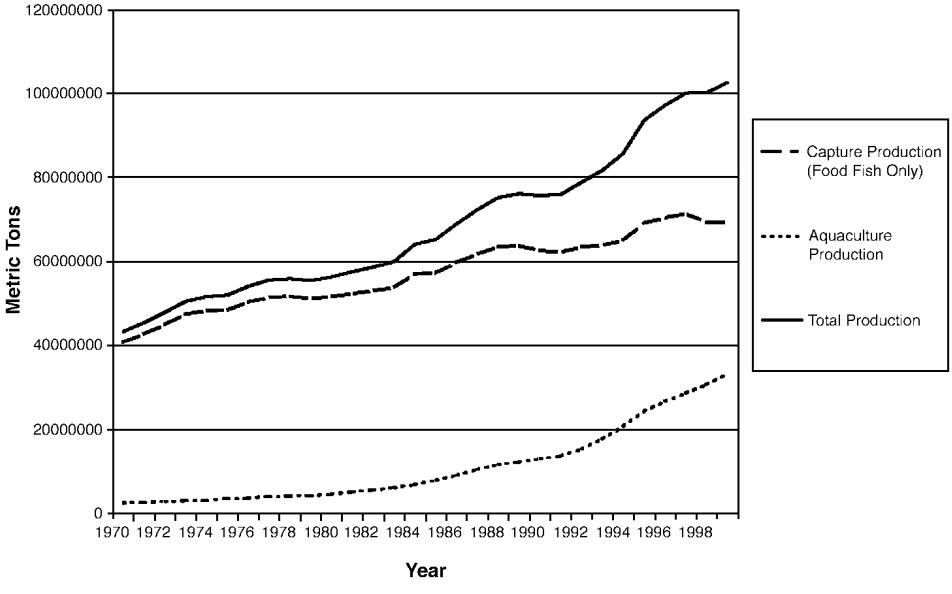

Figure 1. Capture and Aquaculture Production 1970–99 (Food Fish Only)

been developed for this analysis. It is composed of an equally weighted average of five factors. Broadly speaking, the factors are classified as follows: (*a*) degree of dependence on wild fish stock for brood stock and/or juveniles; (*b*) degree of dependence on wild fish stock for feed; (*c*) degree of confinement; (*d*) degree of control of the environment/habitat; and (*e*) degree of harvest and market management. All of these factors relate to different aspects of the operator's, firm manager's, and/or fishermen's control of the organism's life cycle, environment/habitat, and business decisions. Each factor is weighted equally, and the ARF Index is determined by an average of the factor scores.

Each of these factors is scaled as follows:

Dependence on Wild Fish Stock for Brood Stock and/or Juveniles

1. All operations are dependent on wild brood stock and/or juveniles.
2. Most operations are dependent on wild brood stock and/or juveniles.
3. About half of the operations are independent of wild brood stock and/or juveniles.
4. Most operations are independent of wild brood stock and/or juveniles.
5. Operations are completely independent of wild brood stock and/or juveniles.

Dependence on Wild Fish Stock for Feed

1. Fish survival depends on feed derived from wild fish, organisms, and/or plants naturally available in the fish's habitat.
2. The dominant ingredient in the feed is derived from wild fish, organisms, and/or plants (*e.g.*, fishmeal & oil), which is provided by the manager or is available naturally.
3. A significant ingredient in the feed is derived from wild fish, organisms, and/or plants (*e.g.*, fishmeal & oil), but may be substituted with farm-grown crops (*e.g.*, soybean meal).
4. The dominant ingredient in the feed is derived from farm-grown crops (*e.g.*, soybean meal).
5. Feed is completely independent of wild fish, organisms, and/or plant-based feeds (*e.g.*, fishmeal & oil).

Degree of Confinement

1. Organism is completely unconfined prior to harvest.
2. Organism is periodically confined and fed (*e.g.*, lobster traps).
3. Organism growout occurs largely in the environment, critical early growth stages are in a hatchery or confinement facility (*e.g.*, salmon ranching/enhancement).
4. Organism is confined during the growout stage; critical early life stages occur in the environment (*e.g.*, wild postlarvae used in some shrimp aquaculture).
5. Organism is completely confined during the entire life cycle.

Degree of Control of the Environment/Habitat

1. No aspect of the environment influencing the organism is controlled.
2. Habitat, pollution, and other factors influencing the organism are managed.
3. Environmental conditions are marginally controlled by the manager. For example, the manager may control the size, depth, and water flow, but little else.
4. The manager largely controls environmental conditions, except for events such as severe storms and/or seasonal variations.
5. The manager controls all environmental conditions.

Degree of Harvest and Market Management

1. Timing of harvest and sale of the product are determined completely by external regulators and non-producer interest groups.
2. Timing of harvest and sale of the product are mostly controlled by regulators and non-producer interest groups.
3. Timing of harvest and sale decisions are shared by the operator, regulators, and non-producer interest groups.
4. Timing of harvest and sale of the product are mostly controlled by the operator, but external factors, such as regulation, impose some restrictions.
5. Timing of harvest and sale of the product are completely controlled by the operator.

Clearly, if an operation receives all 5s, it would be considered the model of closed-cycle aquaculture operation. If it receives all 1s, it clearly is a traditional fishery. As the score moves from 5 to 1, the operations would change from intensive aquaculture systems, to semi-intensive systems, to extensive systems/ranching systems, to habitat management/fishing systems, to various degrees of traditional fishing. The ARF Index for several operations can be found in table 2. Scores above 4 would be considered aquaculture by most, and scores below 2 would be considered fishing by most. However, there is a range between 2 and 4 that is more similar to ranching or stock enhancement and/or range/habitat management. Some operations that fall into this range include the hatchery-based salmon fisheries in Japan, the US, and Canada; scallop sowing culture in Japan; oyster farming in Connecticut; the inshore lobster fishery in New England; and extensive shrimp culture in Ecuador.

Property Rights

A Property Rights Index (PR Index) is developed to help formalize the discussion of the relationship between aquaculture, ranching, and fisheries, and the strength of the associated property rights. The PR Index for fishing/aquaculture industries is an equally weighted average of five indexes, specified below. The first four indexes indicate the degree of transferability, exclusivity, security, and durability for the property rights grants for the fishery/aquaculture sector. The fifth index is derived from *The Index of Economic Freedom* (O'Driscoll, Holmes, and O'Grady 2001), which reflects economic freedom in the country where the fishery/aquaculture sector is located. Note that these indexes are dynamic and change with environmental, fishery and aquaculture regulations, as well as technology. The property rights considered may be assigned to an individual, group, cooperative, or community.

Transferability of the Property Right

1.	None	Not Transferable.
2.	Very Weak	Transferable under highly restrictive and very limited conditions.
3.	Moderate	Transferable within a defined group (*i.e.*, fishermen).
4.	Strong	Fully transferable with poor/illiquid market institutions.
5.	Very Strong	Fully transferable with well-established, efficient market institutions.

Table 2
Aquaculture, Ranching, Fishery (ARF) Index

	Depend on Wild Broodstock/Juveniles	Depend on Wild Feed	Control of Environment/ Habitat	Degree of Confinement	Harvest and Market Management	Aquaculture Ranching Fishery Index
Coastal Artisanal Fishery: Guyana	1.00	1.00	1.00	1.00	1.50	1.10
Red Snapper: Quota Mgt – Gulf of Mexico, US	1.00	1.00	1.00	1.00	1.10	1.02
Clam Fishery: RI, US	1.00	1.00	1.20	1.00	1.30	1.10
Sport Trout: Public, Hatchery-Based	5.00	2.50	3.80	4.20	1.50	3.40
Bluefin Tuna: US NW Atlantic	1.00	1.00	1.00	1.00	1.40	1.08
Scallop Fishery: US NW Atlantic	1.00	1.00	1.20	1.00	1.00	1.04
Salmon: Alaska Wild	1.00	1.00	1.20	1.00	1.50	1.14
Salmon: Alaska Coop, Hatchery-Based	1.70	1.70	2.20	2.90	3.00	2.30
Shrimp: Ecuador Extensive	1.00	2.00	2.00	3.00	3.90	2.38
Lobster: New England, US	1.00	2.00	1.70	2.00	3.50	2.04
Halibut: US Individ. Quota	1.00	1.00	1.20	1.00	3.90	1.62
Oyster Aqua: CT, US	1.40	1.20	1.90	1.50	4.20	2.04
Scallop: Sowing Culture w/Dredge Harvest – Japan	4.00	2.00	2.40	2.30	4.20	2.98
Scallop: Hanging Net Aquaculture – Japan	4.00	2.80	3.60	4.20	4.70	3.86
Chum Salmon: Coop Hatchery Based – Japan	2.00	2.00	2.20	3.10	3.50	2.56
Shrimp: Ecuador Semi-Intensive	3.20	2.30	3.00	3.60	4.90	3.40
Salmon: Cage System – Maine, US	4.70	2.50	3.90	4.20	4.70	4.00
Clam Farm: SC, US	2.80	2.50	2.80	2.50	4.20	2.96
Salmon: Cage System – Norway	4.90	2.50	4.00	4.20	4.60	4.04
Salmon: Cage System – Chile	5.00	2.50	4.00	4.20	5.00	4.14
Hybrid Striped Bass: Closed System	4.00	3.00	4.90	4.80	4.70	4.28
Catfish: Pond	5.00	3.80	4.10	4.10	4.90	4.38
Trout: Raceway – Idaho, US	5.00	2.50	4.70	4.70	4.90	4.36

Exclusivity of the Property Right

1. None	Completely unrestricted open access.
2. Weak	Right holder has limited control over inputs, outputs, and harvest management.
3. Moderate	Some inputs and outputs are controlled, and harvest is managed by the right holder.
4. Strong	Most property management is in the right holder's control.
5. Very Strong	All decisions and access to the property are controlled by the owner.

Security of the Property Right

1. None	No security. Rights are not protected by any means.
2. Weak	Rights are only minimally protected by law or are protected only by private security forces. There is high political uncertainty.
3. Moderate	Theft is common or rights are at risk with changes in administration.
4. Strong	Reasonably protected by enforcement and legal system. Theft is not significant and/or security of rights generally survives changes in government administration.
5. Very Strong	Well-enforced rights through enforcement and the legal system.

Duration of the Property Right

1. None	None/Daily
2. Weak	Seasonal
3. Moderate	1-to-5 years
4. Strong	5-to-10 years
5. Very Strong	> 10 years to perpetuity

Index of Economic Freedom in the Country

Property rights are dependent on the institutional setting and economic conditions in a given country. Therefore, an index that reflects the overall economic freedom of the nation within which the aquaculture/fishery industry operates is incorporated into the PR Index. The Heritage Foundation/*Wall Street Journal, Index of Economic Freedom*'s score of the country where the fishing/aquaculture occurs is the fifth component used to define the *Property Rights Index* for the fishery/aquaculture industry (O'Driscoll, Holmes, and O'Grady 2001). This *Index of Economic Freedom* includes 10 broad institutional factors of economic freedom. They include:

- Trade policy
- Fiscal burden of government
- Government intervention in the economy
- Monetary policy
- Capital flows and foreign investment
- Banking and finance
- Property rights
- Regulation
- Black market activity

A detailed discussion of these factors is found in O'Driscoll, Holmes, and O'Grady (2001). The scale used for the Heritage Foundation/*Wall Street Journal, Index of Economic Freedom* ranges from 1–5, where:

Economically Free — countries with an average overall score less than or equal to 1.95.
Mostly Free — countries with an average overall score greater than 2.00 and less than or equal to 2.95.
Mostly Unfree — countries with an average overall score greater than 3.00 and less than or equal to 3.95.
Economically Repressed — countries with an average overall score equal to or greater than 4.00.

To be consistent with the scaling used in this paper, the scale of the Heritage Foundation/*Wall Street Journal, Index of Economic Freedom* has been reversed. For example, a ranking of 1 in the *Index of Economic Freedom* became a five in the scale used in this paper.

Property Rights Index scores less than 1 are considered weak, and scores above 4 are considered strong. The Property Rights Index for the aquaculture/ranching/fishing operations previously considered are found in table 3. Note that all the operations with strong property rights are aquaculture systems, while weak property rights are associated with regulated, open-access traditional fisheries. In figure 2, the Property Rights Index values are plotted against the Aquaculture, Ranching, Fishery Index. There is a distinct, positive relationship between stronger property rights and greater ARF index values. Strong property rights are related to the degree of control. It can be hypothesized that: a) strong property rights are a necessary condition for intensive aquaculture or, conversely, intensive aquaculture does not exist under weak property rights; and b) traditional fisheries will not exist under conditions of strong property rights or, conversely, weak property rights are necessary for traditional fisheries. Hypothesis (b) will probably be viewed with skepticism. It suggests that as society moves toward rights-based fishing, the nature of fisheries will fundamentally change as more control is applied, and fisheries will evolve into ranching/enhancement/habitat management systems producing for the market instead of hunting systems emphasizing yield and regulation avoidance.

The Strengthening of Property Rights and Taking Control

In regulated, open-access fisheries, operators attempt to take control by adopting technology which facilitates winning the 'chase for the fish' and efforts to influence the workings of the governing institutions. The emphasis is on gaining access to the harvest. The perspective is generally short term. Little attention is given to the market, the long-term sustainability of fish stocks, or the industry itself. The result is manifest in overcapitalization, rent dissipation, overfishing, poor quality, market gluts and shortage, poor market development, wasteful stakeholder/government negotiations, and rent-seeking behavior.

As property rights are created, strengthened, and assigned to individuals, groups, cooperatives or communities, the effort to gain control takes on a different character. Efforts to reduce cost, increase efficiency, and produce for the market intensify. Additionally, a longer-term perspective begins to appear. What should we then observe in fisheries where this is the case? All else constant, we should observe changes in gear/fishing methods and timing of harvest, increased yield, new market development, increased quality, changes in industry structure, investment in produc-

Table 3
Property Rights (PR) Index

	Exclusivity	Security	Transferability Marketability	Durability	Index of Economic Freedom [a]	Property Rights Index
Coastal Artisanal Fishery: Guyana	1.08	1.24	1.40	1.40	1.80	1.38
Red Snapper: Quota Mgt – Gulf of Mexico, US	1.08	1.08	1.16	1.32	3.20	1.57
Clam Fishery: RI, US (1990s)	1.40	2.60	1.00	2.20	3.20	2.08
Sport Trout: Public, Hatchery-Based – US	1.80	3.40	1.00	1.80	3.20	2.24
Bluefin Tuna: US NW Atlantic	1.80	2.60	1.40	2.20	3.20	2.24
Scallop Fishery: US NW Atlantic	2.20	2.60	1.60	2.20	3.20	2.36
Salmon: Sockeye – Alaska, US	2.20	2.70	1.60	3.30	3.20	2.60
Salmon: Coop, Hatchery-Based – Alaska, US	2.60	3.10	1.60	4.20	3.20	2.94
Shrimp: Extensive – Ecuador	3.20	2.80	3.40	3.80	1.55	2.95
Lobster: New England, US	3.20	3.80	2.20	3.80	3.20	3.24
Halibut: US Individ. Quota	2.60	2.60	3.40	4.20	3.20	3.20
Oyster Aqua: CT, US	4.00	3.20	3.00	4.20	3.20	3.52
Scallop: Sowing Culture w/Dredge Harvest – Japan	3.80	3.40	2.60	4.80	2.55	3.43
Scallop: Hanging Net Aquaculture – Japan	4.60	4.20	3.00	4.80	2.55	3.83
Chum Salmon: Hatchery-Based – Japan	3.80	4.00	2.60	4.60	2.55	3.51
Shrimp: Semi-Intensive – Ecuador	4.60	3.30	4.20	4.60	1.55	3.65
Salmon: Cage System – Maine, US	4.30	3.60	4.20	4.40	3.20	3.94
Clam Farm: SC, US	4.20	3.40	4.20	4.90	3.20	3.98
Salmon: Cage System – Norway	4.00	4.60	4.60	4.90	2.55	4.13
Salmon: Cage System – Chile	4.70	4.40	4.60	4.90	3.15	4.35
Hybrid Striped Bass: Closed System	4.70	4.90	4.60	5.00	3.20	4.48
Catfish: Pond – Mississippi, US	4.80	4.70	4.80	5.00	3.20	4.50
Trout: Raceway – Idaho, US	4.90	4.90	4.80	5.00	3.20	4.56

[a] (Derived From O'Driscoll, Holmes, and O'Grady 2001)

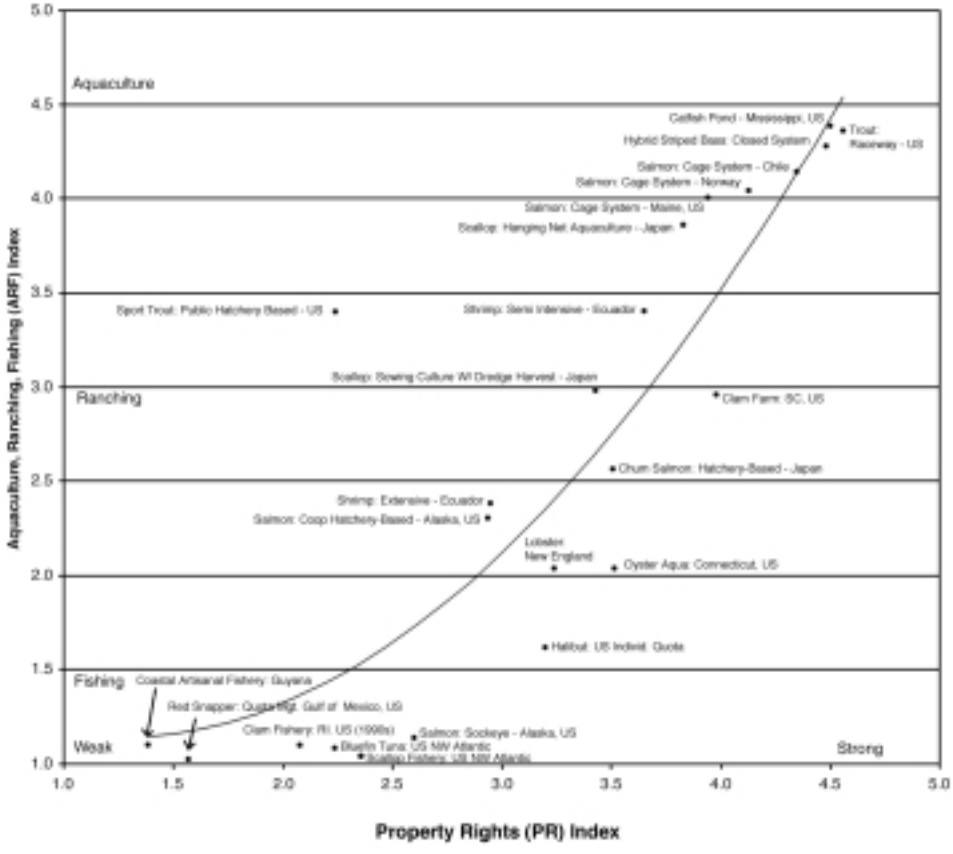

Figure 2. Property Rights versus Aquaculture, Ranching and Fishing

tivity enhancing technology, and a tendency toward integration. One might also expect to observe less volatility in price and quantity as operators exercise greater control and manage harvest for the market.

Salmon

Salmon provides us with an opportunity to observe the transition of an industry from that of open-access to one dominated by pen-raised aquaculture. In North America, the salmon fishing sector is managed by various limited entry schemes, area licensing, and area closures to assure escapement goals. The Alaska sockeye fishery is one that could be classified as having relatively weak property rights (PR Index is 2.6). As a result, there is little control (ARF Index is 1.14) by the harvesters, the catch is highly variable, production technology is constrained by regulation, marketing efforts are poor, quality is generally marginal, and the fishery tends to bounce between boom and bust. The volatility of the harvests is indicated in figure 3, which illustrates the harvest of Alaska's Bristol Bay sockeye salmon.

In Japan, the traditional salmon fishery has essentially been nonexistent for decades, having been replaced primarily by a hatchery-based chum salmon fishery/ranching (ARF Index, 3.51). Japanese production of chum salmon is almost entirely

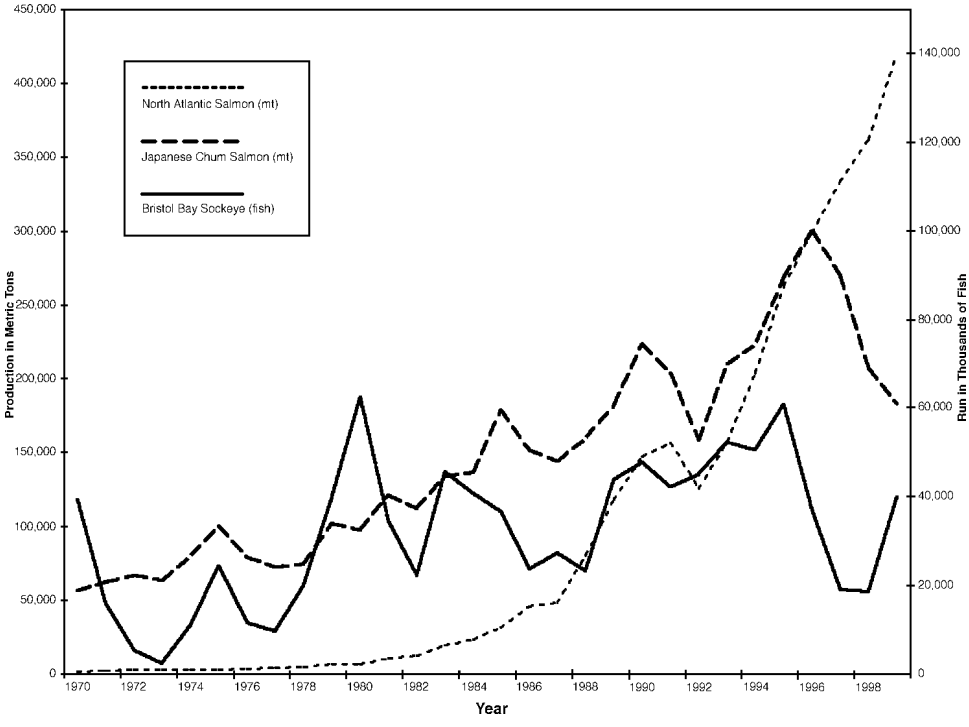

Figure 3. Harvest of Norwegian Atlantic Salmon, Japanese Chum Salmon, Bristol Bay In-Shore Sockeye 1970–99

dependent on hatchery stocking. Japan has more than 300 chum salmon hatcheries and 262 rivers managed specifically for artificial propagation. Since 1960, Japanese chum production has increased nearly 500 percent, mostly because of these successful hatchery programs (Johnson *et al.* 1997). Most of the hatcheries and all of the harvest are managed predominantly by fishery cooperative associations (FCAs) (Matsuda 1992). These FCAs have greater control (PR Index, 2.56) of production decisions. Although the critical stages of hatching and juvenile growth occur in the hatchery, reducing mortality in the early part of the life cycle, most of the life cycle occurs in the open ocean, subject to all the associated uncertainty. However, a volatile but relatively consistent increasing trend is observed for this chum fishing/ranching sector (figure 3). Japan's hatchery-based fishery/ranching has made it a major producer. It is worth mentioning that Japan's FCAs and government programs are ranching over 80 species, ranging from scallops to sea bream.

Similar systems of hatchery-based fishing/ranching have become dominant features of North American fisheries. Increases in chum and pink salmon harvests in Alaska have been largely the result of fishermen's cooperatives operating hatcheries. In 2000, 73% of the Alaska commercial chum salmon harvest (traditional fishery plus hatchery cost recovery harvest), 52% of the Alaska commercial pink salmon harvest, 30% of the Alaska commercial coho salmon harvest, 27% of the Alaska commercial chinook salmon harvest, and 5% of the Alaska commercial sockeye salmon harvest were from hatchery-raised fish (McNair 2001). Statewide, 43% of the total salmon harvest was from hatcheries. In 1995, only 16% of Alaska's commercial salmon harvest came from hatcheries. Although these hatchery-based fish-

ing/ranching systems are characterized by slightly stronger property rights (PR Index, 2.94) and greater control (ARF Index, 2.3), these systems suffer from most of the characteristics of regulated open access. In Alaska, these hatcheries are subsidized, contributing to overproduction. Since these hatchery-based systems have emerged in an environment of related open access without well-established property rights for wild fisheries, they have had a well-documented negative influence on native salmon stocks (Hilborn 1992). Furthermore, in many cases, such as Columbia River salmon, the fishery sector and hatchery management are somewhat decoupled due to the fact that the hatcheries were built to mitigate negative environmental activities, such as habitat destruction and the construction of dams. Despite these problems, traditional and hatchery-based salmon fisheries made salmon the most valued finfish fishery in the US until 1997, when it was eclipsed by farmed catfish (USCD 1998).

In the 1980s, pen-raised farmed salmon began to be noticed in the international market. Led by Norway and rapidly followed by Canada, Chile, Scotland, and others, the industry grew in an environment furthered by relatively strong property rights (PR Index: Norway, 4.13; Chile, 4.35; Maine, US, 3.94). The presence of strong property rights fostered investment in technology, feed development, disease management, and market research and development. The farmed product was more consistently available and handled and processed better. By the early 1990s, it had largely displaced ocean-caught salmon in Europe and most of the US. In the late 1990s, farmed salmon replaced cod as Norway's largest fish harvest (figure 4). This, despite trade barriers such as the antidumping duties placed on farmed salmon from Norway and Chile in the US and Alaska's permanent moratorium on for-profit salmon aquaculture enacted in 1988.

Figure 4 clearly shows how consistent the growth of Norway's farmed Atlantic salmon has been, the result of relatively controlled production and market management. The degree of control is further indicated by the consistent decline in cost of production, as seen in figure 5. These gains were the result of investment in technology, breeding programs, nutritional improvement, better farm management, and disease control. Both survival and growth rates improved (Asche 1997). Note the clear difference in volatility in the Bristol Bay sockeye fishery and the Japanese hatchery-based chum salmon fishery. Although pen-raised salmon now dominates the market, while inefficiently managed salmon fisheries struggle, the farmed salmon sector's production could still increase considerably.

After two decades of attempting to ignore the pen-raised salmon industry, the fishing sectors, especially segments in Alaska, are finally coming to terms with it. In a January 6, 2002 article that appeared in the *Anchorage Daily News* entitled, "Alaska Fishermen Propose Co-op to Save Salmon Industry," it was reported that fishermen in Chignik are proposing a 'radical' idea to the Alaska Board of Fisheries. The article states,

> Fishermen believe they must cut costs to compete in a new era of abundant, cheap, farmed salmon, that's where the Chignik proposal comes in. It would allow .. boats to join a cooperative where the fleet would hire only a few boats to do the actual fishing. The rest would bow out to save expenses and collect their share of the proceeds at the end of the season…This is a big departure from the norm in Alaska where all boats generally race one another for the fish. … the proposal has other important benefits that can increase the value of Alaska salmon… when fishermen race, they can't pay attention to quality. The salmon are handled roughly or languish on boats for hours before making it to the packing plant. With the co-op, fishermen can better time the harvest and even deliver live fish to insure maximum freshness.

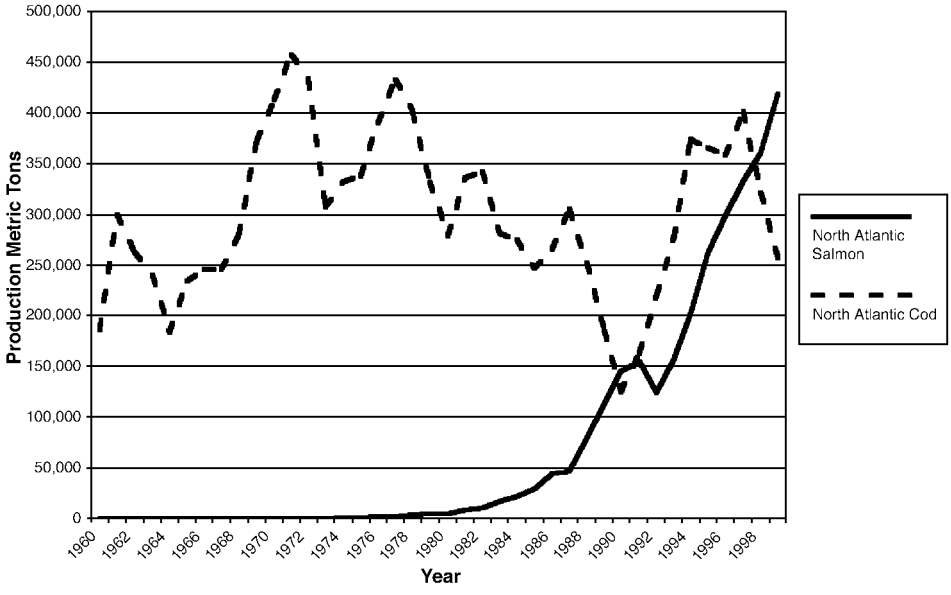

Figure 4. Production of Norwegian Atlantic Salmon and Cod

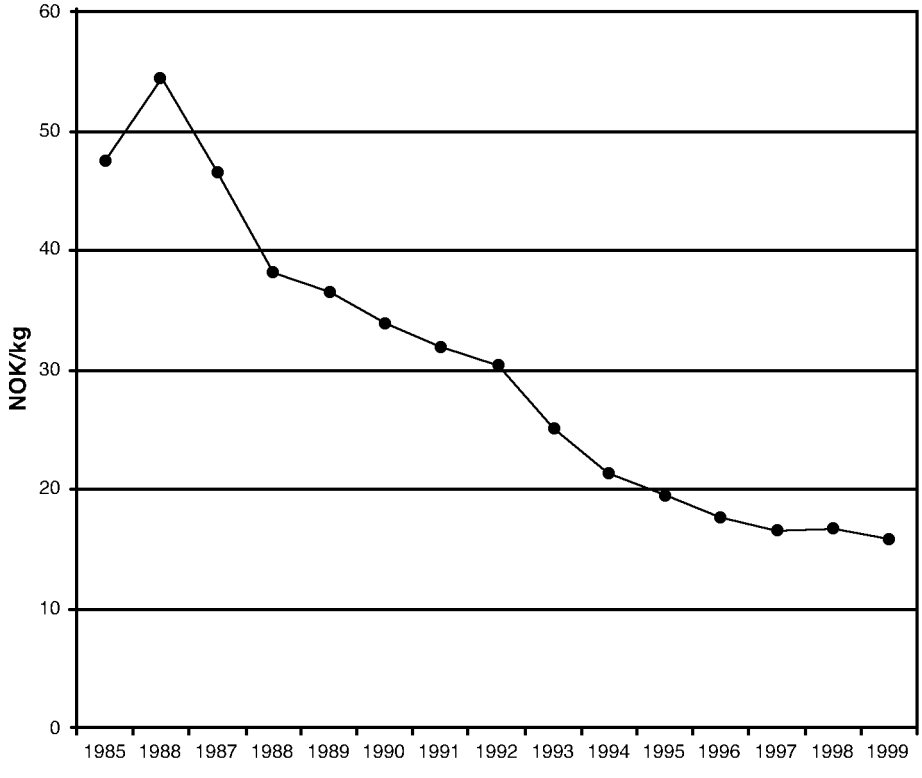

Figure 5. Operating Costs: Norwegian Farmed Atlantic Salmon 1985–99 (1997 NOK/kg)

There were also proposals to the Alaska Board of Fisheries for the return of fish traps, plus the ubiquitous permit buyout to reduce capacity. The Board of Fisheries approved the Chignik Cooperative Fishery Management Plan, but while the cooperative will increase both fishermen's property rights and control, it may be much too little, much too late. We are witnessing a natural experiment that is testing an idea developed several years ago that the farmed salmon industry may force the ocean harvest industry to improve its management through competition, where professional fisheries managers, economists, and stakeholders have failed (Anderson 1985). Some empirical evidence of the influence of farmed salmon on the traditional salmon fishery has been documented in works such as Asche, Bremnes, and Wessells (1999). However, one might be led to conclude that, whether or not the North American salmon ocean fishing/ranching industry ever establishes a management system based on well-defined property rights may, in the grand scheme of things, be largely irrelevant. Given the current productive capacity of the pen-raised salmon sector; the potential for technological, genetic, and disease management advances; and the potential for market development, the growth of this industry is still potentially enormous. This may render the traditionally managed commercial ocean harvest sector noncompetitive in most markets.

American Lobster

The Maine lobster harvest broke an all-time record in 2000. In addition, the fishery has shown remarkably low volatility year-to-year relative to other fisheries (figure 6), despite expectations by fisheries experts for over two decades that the fishery was headed for imminent decline (Anthony and Caddy 1980 or *Status of Fishery Resources of the Northeast United States*, any issue after 1985). According to Steneck and Auster (2001), it is the "only species in the world that has been targeted more than 15 years and is more abundant today than ever in the past." The reasons why this has occurred are still unclear. Habitat has been identified as an important limiting factor, as have the size of the spawning population and other environmental factors (Wahle and Steneck 1992; Caddy 1986). However, the presence of implicit property rights (PR Index, 3.24) maintained by tradition and individual enforcement is likely to contribute to the fishery's success. Lobstermen working a given area (*e.g.*, bay) tend to belong to the same community and tend to know one another. This arrangement can lead to effective enforcement of management rules and a set of pseudo-property rights. Lobstermen will know if one of their peers is keeping lobsters that are too small or bearing eggs. They will also know if a person is working too many traps or is inside a restricted area. The group is often self-correcting/disciplining when it comes to these types of violations, leading to an increased security in the property right. In 1995, Maine passed a law allowing for the implementation of lobster co-management zones. This has further shifted property rights and the responsibility of managing the fishery to the lobstermen themselves.

Lobstermen further control (ARF, 2.04) the fishery through providing shelter (traps) and feed. Steneck has studied the role of traps on the ecology of lobsters. He found that about 80% of the lobster's diet comes from trap bait (Houtman and Lignell 1996; Steneck 2002). When fishermen control site access and provide shelter and feed, the operation is closer to extensive aquaculture than traditional fishing. In fact, it is not much different than extensive shrimp farming, which relies exclusively on wild post-larvae, undertakes limited supplemental feeding, provides protection from predators, and is often harvested with traps or cast nets. As fishermen are given stronger property rights, one might expect them to invest in habitat management/enhancement, possibly stock enhancement, more research targeting specific concerns, and market development.

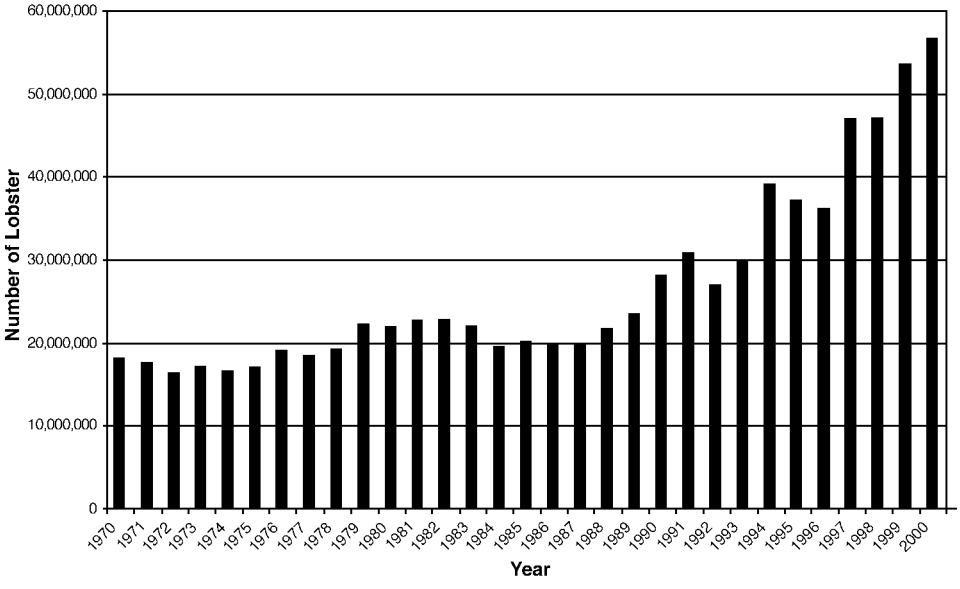

Figure 6. Harvest of American Lobster: Maine

The concept that fishermen's behavior is more like that of an extensive aquaculturalist than a hunter does not generally sit well with fisheries biologists. As stated by Acheson and Steneck (1997), "Although many state and federal biologists know their models have not predicted changes in lobster catch, they are reluctant to abandon models that are state of the art and have worked well in other fisheries, ..." The weakness of the yield-effort models as predictors of landings in the lobster fishery was also pointed out nearly two decades ago by Townsend (1986). The fact remains that there has not been the appropriate research undertaken to determine the impact of the extensive lobster aquaculture (*i.e.*, partial broodstock, habitat [shelter], predator and feed management) on lobster harvest. If research was cast in terms of the extensive aquaculture model instead of traditional yield-effort fishery model, it would be directed more toward understanding the production relationship between inputs (ex., habitat [natural and traps], predator protection, feed, exogenous environmental factors) and output. As stronger property rights are assigned to the lobstermen, it is likely that the research will shift in this direction.

Shrimp

The shrimp industry, like the salmon industry, is another case where there concurrently exists a complete range of production systems, ranging from open-access fisheries to intensive aquaculture. Shrimp aquaculture accounts for about 30% of world production, and at least 65% of international trade (FAO 2001; Anderson and Fong 1997). Shrimp aquaculture explains virtually all the growth in global production and international trade.

Shrimp farming is carried out using a broad range of systems and is generally divided into three groups: Extensive shrimp farming (stocking density less than 25,000 postlarval shrimp per hectare); semi-intensive (stocking density is 100,000 –

300,000 postlarval shrimp per hectare); and intensive (more than 300,000 postlarval shrimp per hectare) (Rosenberry 1999). Extensive systems (ARF Index, 2.38) rely on naturally provided postlarval shrimp, the tide for water exchange, and supplemental feed by fertilizing the ponds. They also have little environmental or predator control and generally are harvested with cast nets or traps. The property rights associated with these operations are relatively weak. Vietnam, Guyana, Bangladesh, and Indonesia are a few of the countries where this technique is used. Semi-intensive systems (ARF Index, 3.40) employ relatively large (2-30 hectares) ponds, formulated feeding, pumping for water exchange, and are harvested by draining the pond. This practice is common in countries such as Ecuador, Honduras, and Mexico. Intensive culture (ARF Index, 4.08) involves small ponds (0.1-1.5 hectares) or raceways, substantial feeding, aeration, and a high degree of environmental control. This form of shrimp aquaculture is practiced primarily in countries such as Thailand, Taiwan, and Japan.

Shrimp farming has been plagued by problems of disease control and pollution (from external sources and the farms themselves). This is a relatively new industry based on a species that has characteristics that are considerably different than vertebrates. Genetic advances, nutritional and environmental requirements, and disease management all have a long way to go. However, consider the harvest trends found in figure 7. As the degree of control and the strength of the property rights change from Thailand's black tiger shrimp farming industry (semi-intensive or intensive aquaculture), to Ecuador's white shrimp farming industry (mostly semi-intensive), to the US Gulf of Mexico brown shrimp fishery (limited entry), some distinct trends emerge. It is clear that the trend in shrimp farming is positive, where the harvest from the traditional fishery demonstrates a relatively stable, expected value, but with a relatively high variance. Note that the Ecuadorian producers have relatively poorly defined property rights partially because the national government is unstable, and property rights are not well protected between governments. The instability limits the incentive of producers to invest in improved production techniques, disease management, and adoption of a long-term perspective. The significant downturns in Ecuador's production were the result of disease outbreaks associated with management practices, environmental, and other external factors. Taura syndrome caused a decrease in production between 1992 and 1993, and white spot disease caused declines in 1999 and 2000. In the more intensively managed Thailand shrimp farming industry, there appears to be somewhat less volatility. However, the noticeable downturn in 1994-1997 was caused by white spot disease.

With relatively strong property rights in shrimp farming, there is expected to be increased efforts to internalize externalities related to pollution and disease transmission, and investment in research on feed, disease, and site management. Experts see this coming. As stated by Chamberlain (1997), "shrimp farming is in a state of transition to a more controlled, efficient and environmentally sustainable form, which will position it for substantial growth in the next century."

Conclusions

This paper attempted make several points:

- There is a continuum between open-access fishing and intensive aquaculture. The continuum is directly related to the degree of control. The degree of control, at its core, is related to the strength of property rights.
- Aquaculture or ranching is becoming, or has already become, the dominant factor in fish supply.

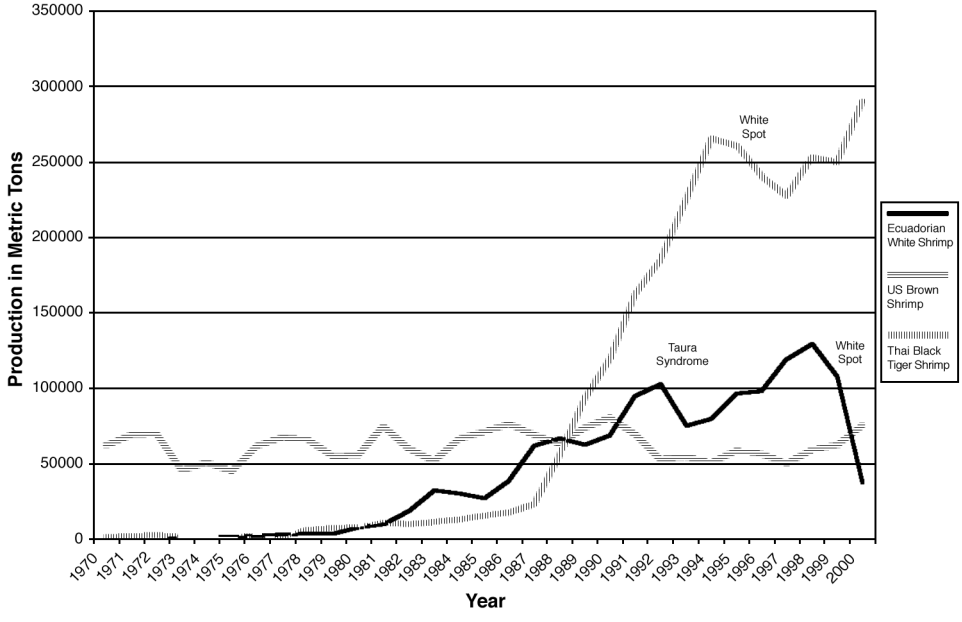

Figure 7. Shrimp Production 1970–2000: US, Thailand, and Ecuador

- Traditional fishing exists under weak property rights, and intensive aquaculture exists under strong property rights.
- As property rights strengthen, firms become more forward looking, invest in new technology, and attempt to gain control of their production and marketing systems.
- In fisheries, as property rights are strengthened, it is expected that firms will adopt more efficient technology (which may include aquaculture systems) and industrial organization, will look to enhance habitat and fish stocks, will improve marketing efforts, and pursue ways to gain control of production and markets. This will change the character and community associated with traditional fisheries.
- As the prominence of aquaculture, rights-based fishing, and ranching systems increases, fisheries that are valuable and remain in open access or similarly inefficient management systems will ultimately be forced to adopt improved management practices with strengthened property rights or be driven into minor niche markets or become uncompetitive and possibly driven out commercial production.

So, why should fisheries economists care about aquaculture? Aquaculture is where future growth will come from, aquaculture is the focus of pivotal policy decisions regarding ownership and management in aquatic environments, aquaculture will have an increasing influence on wild fish stocks and the aquatic environment, aquaculture will dominate the international trade and marketing of many species (especially high-valued species), and competition from aquaculture is an increasingly important catalyst for change in fisheries management. Finally, as the rights- or self-governance-based fisheries management systems that many fisheries economists advocate are put into place, many fisheries may begin to more closely resemble extensive aquaculture or ranching than the traditional hunter fisheries.

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