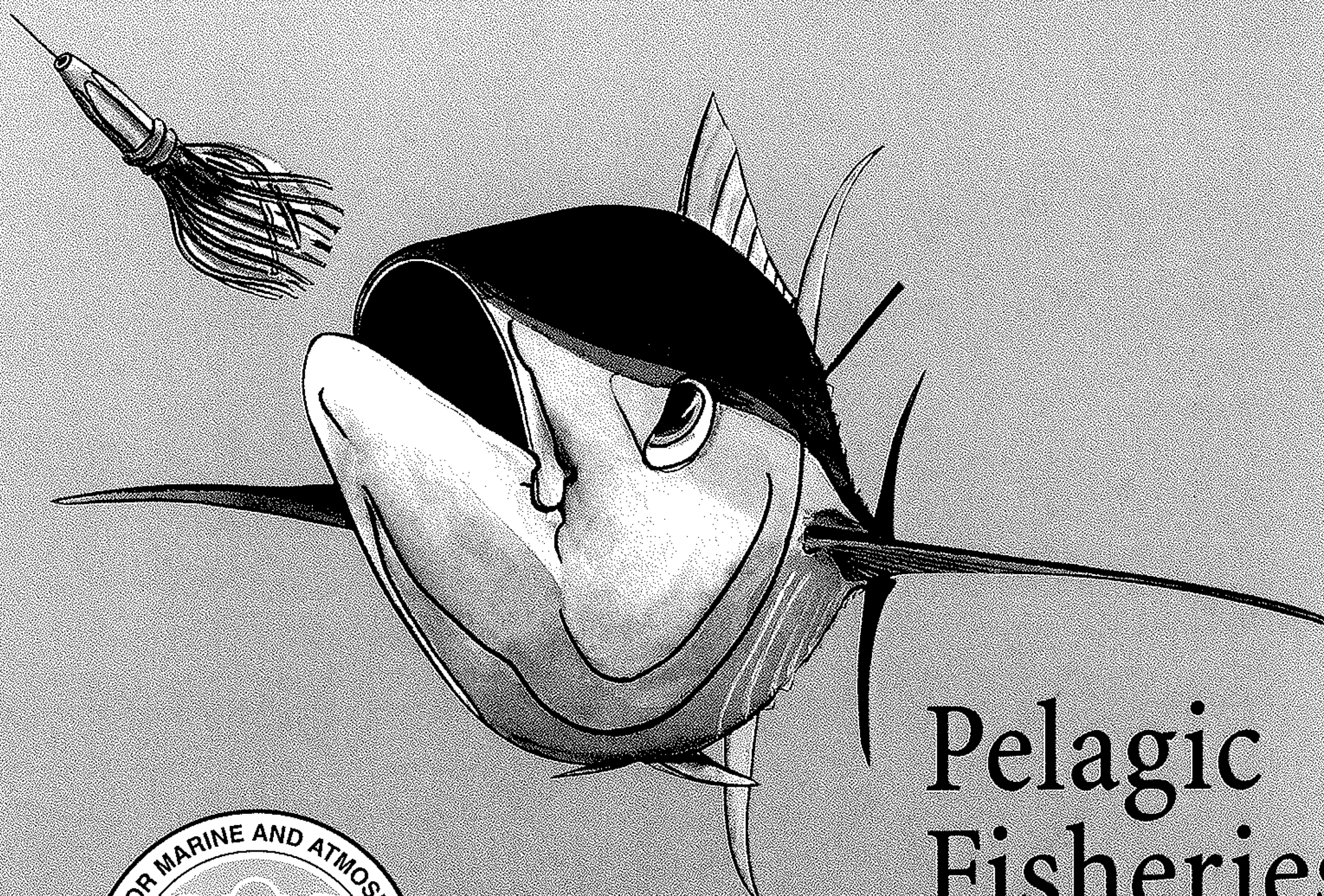
Externalities and Management Regimes in Fisheries Exploitation

Yoav Wachsman

SOEST 02-03
JIMAR Contribution 02-346



JOINT INSTITUTE FOR MARINE AND ATMOSPHERIC RESEARCH
~UH-NOAA~
JIMAR

Pelagic Fisheries Research Program

Externalities and Management Regimes in Fisheries Exploitation

Yoav Wachsman

Department of Economics
University of Hawaii, Manoa
2424 Maile Way, Room 542
Honolulu, Hawaii 96822

SOEST 02-03
JIMAR Contribution 02-346

ACKNOWLEDGMENTS

I would like to thank Sam Pooley for his many helpful comments. This paper was funded by project number 653536 through cooperative agreement #NA67RJ0154 between the Joint Institute for Marine and Atmospheric Research and the National Oceanic and Atmospheric Administration. The project's objectives were to use game theory in order to better understand fisheries exploitation and to determine the best management policies for national and international fisheries. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its subdivisions.

ABSTRACT

A large number of authors use game theory to model the strategic interaction amongst fishermen. This paper explains the different types of externalities that occur in fisheries exploitation and summarizes the game-theoretical models on each type. The paper also explains the different management regimes that fisheries fall under and how the management of fisheries has changed over time. Ultimately, the goal of the paper is to discuss the best management policy that should be adopted to deal with different types of externalities under different management regimes.

1. INTRODUCTION

1.1. The Use of Game Theory in Fisheries Economics

A large number of authors have used game theory to model the strategic interaction amongst fishermen (see Sumaila, 1999). A fishery is defined as a geographical area in which a specific species of fish (a target species) is harvested using a specific fishing technology (e.g., long liner, purse seine, etc.). The use of game theory is appropriate for analyzing situations in which economic agents either impose an external cost or bestow an external benefit on other agents. Fishermen usually generate external costs or benefits for other fishermen that operate in the same fishery or in interrelated fisheries. Unless these externalities are fully compensated for, they lead fishermen to behave in a way that is sub-optimal from a social perspective because the fishermen do not consider the social cost (or benefit) of their actions. According to Gordon (1954) sub-optimization in the exploitation of fisheries occurs when the set of actions that fishermen take does not maximize the net rent from the fishery.

Externalities are common in the exploitation of marine resources because property rights are seldom fully assigned. Even after the UN Convention on the Law of the Sea granted coastal nations economic control over the 200 miles adjacent to their shores, many of the world's fisheries remained outside the control of any single government (Munro, 1982). Furthermore, most national fisheries, which are under the jurisdiction of a coastal nation, are not partitioned amongst individual owners because of political considerations and the prevailing conviction that common, natural resources should not be allocated to private owners. Finally, even when ownership rights are fully assigned in one fishery, the stock of fish may straddle (migrate) between fisheries.

This paper has three goals. First, the paper explains all the possible types of externalities that fishermen may impose on one another and provides a summary of game-theoretical models on each type. Although other authors discuss various externalities, no author has provided a comprehensive list of externalities. Second, the paper analyzes the different fisheries management regimes that are commonly used and how recent changes in the management of marine fisheries are affecting the ways in which externalities are corrected. Finally, the paper discusses various policies that are used to manage fisheries and argues why an Individual Transferable Quotas system is the best policy to use.

1.2. Cooperative and Non-cooperative Game Theory

Game-theoretical models use either cooperative or non-cooperative analysis (see Gibbons, 1992 for lessons on game theory). Cooperative game theory assumes that agents (e.g., fishermen) are able to reach a mutually beneficial, contractual arrangement. Because fishermen usually inflict external costs on one another they can benefit from reaching a contractual arrangement that attempts to offset the negative consequence of these externalities. Such arrangements may specify a set of acceptable actions that each fisherman must adopt such as the weight of the catch or the fishing gear that each fisherman is allowed.

Munro (1979) suggests that in order to reach the optimal level of harvest, the more patient fisherman (the one who discounts future returns from the fishery less heavily) must purchase the ownership rights of the other fishermen. However, in many cases ownership rights are not fully defined. For example, a fisherman who operates in a certain fishery may not be able to prevent other fishermen from entering the area or may not be able to legally transfer his rights to fish in the area to others. Additionally, even when ownership rights are fully defined (as a coastal nation owning the water adjacent to its shores) the fishery owner may be reluctant to transfer ownership of the fishery to others out of political, environmental, or security concerns.

Sumaila (1997) and Houba, Koos and Vardy (2000) show that it is possible for two fishermen who compete over a fishery to reach an agreement over their harvest levels as long as the less patient fishermen, the one with the higher discount rate, receives a larger share of the surplus. However, just because two parties can reach a mutually beneficial agreement it does not mean that cooperation between the two parties is possible. For cooperation to exist not only do the parties involved have to reach an agreement but the agreement must be enforceable. Enforceability means that the parties must be able to monitor each other's behavior and punish players who violate the terms of the agreement. Without enforceability each fishermen has the incentive to deviate from the arrangement and behave in a self-serving way that hurts other members of the group.

Enforceability is difficult to achieve in fisheries exploitation for several reasons. First, as previously discussed, property rights over fisheries are seldom fully defined, which means that additional fishermen may enter the fishery. Furthermore, it is difficult and very costly for each fisherman to monitor the behavior of other fishermen. Harvesting takes place in the open seas where it is nearly impossible for fishermen to monitor each other's actions. Fishermen may be able to examine the catch that each of them harvests by inspecting each vessel as it returns to port. However, if the fishermen that utilize a given fishery operate out of different ports, monitoring everyone's catch can be quite costly. Uncertainties about the dynamics of the stock (size, concentration, and rate of growth) and the inability to observe the stock directly makes monitoring particularly difficult and creates pressure on the agreement to be altered (see Hannesson, 1984; Clark, 1985 about fishing under uncertainties).

Enforceability is particularly difficult to achieve in international fisheries, which are not under the jurisdiction of any individual nation. International fisheries are usually exploited by fishermen from several distant water fishing nations (DWFNs). National governments may be unwilling to permit monitors from other nations to inspect fishing vessels that carry their flag. Furthermore, each government has the incentive to allow, or even encourage, its fishermen to deviate from the agreement in order to increase their profit. Additionally, national governments may find it difficult to punish fishermen of other nationalities that deviate from the agreement without creating a political strife.

In many cases fishermen are unable to reach a cooperative solution because ownership rights are incompletely defined, as is the case with international fisheries, or because a cooperative contract is too difficult to monitor and enforce. This is why only a handful of papers on fisheries exploitation use cooperative game theory. When a contractual arrangement is unfeasible or too costly then non-cooperative game theory must be used to determine the strategy chosen by each fisherman.

Most of the other articles mentioned in this paper use non-cooperative game theory. In non-cooperative game theory all agents simultaneously select their best response from the set of strategies chosen by all other agents in equilibrium. This solution was first conceptualized by John Nash and is called Nash equilibrium. For example, suppose that two individuals draw water from the same well. The less water there is in the well the more expensive it is to draw an additional gallon of water from the well (because the water level drops). Therefore, if one of the individuals increases his extraction it becomes more expensive for the other individual to draw water from the well and he will reduce his extraction. The game reaches Nash equilibrium when the marginal cost of extracting another gallon of water equals the marginal benefit of extracting another gallon for both individuals (because neither individual will want to extract an additional gallon of water).

In fisheries exploitation, the solution to non-cooperative, game-theoretical models is often referred to as a bionomic equilibrium. The game reaches a bionomic equilibrium when the stock of fish reaches a biologically stable level or growth rate and none of the fishermen have an incentive to change their strategy (fishing effort or harvest) given the strategies chosen by other fishermen (the fishermen reach a Nash equilibrium)

2. EXTERNALITIES IN FISHERIES EXPLOITATION

2.1. A Brief Discussion on Externalities

The activity of one fisherman may impose externalities on other fishermen that either operate in the same fishery or operate in interrelated fisheries. Interrelation implies that actions that are taken in one fishery affect the welfare of fishermen in another fishery. For example, two target species in the same fishing ground (an aquatic area) may interact in some biological way. Fisheries in two different fishing grounds may become interrelated if species straddle between them. Two fisheries may also become interrelated if pollution that is created in one fishery travels to the other fishery.

A negative externality occurs when an agent inflicts a cost on another agent without compensating the other agent for it. A positive externality occurs when an agent bestows a benefit on another agent without being paid for it. When a stock of fish or a group of biologically related stocks is commercially exploited by more than one fisherman, five types of externalities may occur: dynamic, market, biological, spillover, and production externalities. This section explains the different types of externalities that may occur in fisheries exploitation and summarizes the articles that are written on each type. Also included are explanations on what types of management policies should be adopted to deal with each kind of externality. At the end of the section there is a brief discussion on the possible presence of multiple externalities.

2.2. Dynamic Externalities

Dynamic externalities occur when an increase in fishing effort or harvest by one fisherman reduces the number of fish that are available for other fishermen. Dynamic externalities occur both because the removal of fish decreases the amount of fish that is available for other fishermen at that point in time and because a decrease in the present size of the stock may negatively affect the future size of the stock. Clark (1980) analyzes a model with dynamic externalities when entry to the fishery is restricted to a fixed number of fishermen. He shows that fishermen will harvest more than is socially optimal because they do not take into account how their harvest diminishes the capability of other fishermen to harvest from the fishery.

The presence and extent of dynamic externalities depend on the species' behavior and the fishing technology utilized by the fishermen. Species can be categorized into school fisheries and search fisheries (Wilen, 1985). Species that are labeled as school fisheries travel in large schools (packs) and are usually harvested using capital-intensive technologies such as purse seine, which are large nets that are used to encircle the school, or trawler nets, which are dragged behind vessels. By contrast, species that are labeled as search fisheries are more or less distributed evenly in a given fishing ground and are usually harvested using traditional technologies such as pole-and-lines or long liners.

In school fisheries a successful harvest by one fisherman can substantially diminish the capacity of other fishermen to harvest the species by eliminating or significantly reducing the size of the school. On the other hand, in search fisheries an increase in the effort of one fisherman will only gradually decrease the capacity of other fishermen to harvest the species. Nearly all papers on fisheries economics use a production function that is continuous in effort thus implicitly assuming that the fishery is a search fishery. A noteworthy exception is Ruseski (1999) who examines the strategic interaction between a coastal nation and DWFNs that harvest the same species in a separate fishing ground under search fisheries and school fisheries.

Theoretical models on dynamic externalities in fisheries exploitation are either dynamic or static and assume either profit maximization or utility maximization. The standard static model was developed by Gordon (1954) and Schaefer (1957). Static models assume that the fishery reaches a steady-state stock size given the level of effort chosen by the fishermen. Effort is usually assumed to be a continuous and one-dimensional (such as time spent in the fishery). An increase in the effort by one fisherman reduces the steady-state stock and thus the marginal product for all the other fishermen (assuming that there is positive relationship between the size of the stock and harvest per unit of effort). Therefore, an increase in the effort of one fisherman induces all the other fishermen to reduce their effort by decreasing their marginal product of effort.

Static models are relatively simple in exposition and therefore allow researchers to investigate complex strategic interaction. Ruseski (1998) uses a static model to analyze the interaction between two national governments whose fleets exploit an international fishery. Ruseski shows that each government has the incentive to license more vessels than is socially optimal and to subsidize their fleet's effort. Wachsman (2002) uses a static model to analyze the interaction between a coastal nation and the foreign fishermen that it permits to operate in its fishery. Wachsman shows that the coastal nation will charge fishermen a higher fishing fee than is socially optimal because it can increase its revenue by increasing the fishing fee above the socially optimal level.

Dynamic models were first suggested by Scott (1955) and later developed by several other authors, most notably Clark (1976). Dynamic models utilize calculus of variation or optimal control theory to derive a path of actions (as effort levels or harvests) for each fisherman as a function of time. Although dynamic models are more realistic, since they assume that fishermen discount future returns, their complexity limits their applications.

Levhari and Mirman (1980) made the simplifying assumption that fishermen maximize a log-linear utility function instead of profit in order to explicitly solve a dynamic model of fisheries exploitation. They show that if the fishermen's utility is concave (which means that the marginal utility from harvest of fish diminishes) then the lower the level of stock in a given period the higher the opportunity cost of harvesting the stock. Therefore, when one fisherman increases its harvest, which decreases the future size of the stock, other fisherman will decrease their harvest in order to avoid decreasing their own utility by too much in the future.

Several management policies have been suggested to offset the effects of dynamic externalities. These policies include output taxes, input taxes, output quotas, input quotas and individual transferable quotas (ITQ) [see Hanley et al., 1997]. Arnason (1990) argues that although all these management policies could theoretically induce fishermen to harvest the optimal amount of fish under perfect information, the information gap that exists between the fishery manager (the agency that is responsible for managing the fishery) and the fishermen makes the use of taxes or input quotas impractical.

Fishermen maximize their profit by choosing the level of effort for which the marginal revenue of effort equals the marginal cost of effort. An input tax (i.e., a tax on effort or on fishing gear) induces fishermen to reduce their effort by increasing their marginal cost of effort. An output tax (i.e., a tax on the fishermen's harvest) induces fishermen to reduce their effort by lowering the price that the fishermen receive for the species and hence lowering the fishermen's marginal revenue of effort. (The fishermen's marginal revenue of effort equals their marginal product of effort times the price that they receive for the species.)

In order to correctly use input or output taxes the fishery manager must know the production and cost functions of each fisherman. Otherwise, the manager would not know how much tax to charge in order to induce the fisherman to harvest the optimal amount of fish (the amount that will maximize the net return from the fishery). However, fishermen have an incentive to misreport their true cost and production in order to get a lower tax levied on them. Furthermore, fishermen's cost and production constantly change as a result of changes in the price of inputs or the adoption of new fishing technologies. Finally, if each fisherman has a different cost function or production function the fishery manager may need to levy a different tax on each fisherman, which could be politically infeasible.

Inputs quotas (i.e., restrictions on the types and amount of gear that fishermen can use) are also unlikely to lead fishermen to harvest the optimal amount of fish. Just as with taxes, the fishery manager would need to know the production function and cost function of each fisherman in order to optimally administer input quotas. Additionally, because fishermen normally use multiple inputs (e.g., net, labor and boat), input quotas as well as input taxes may cause fishermen to substitute away from cost-efficient inputs to less efficient inputs in order to evade the quotas or taxes.

If the fishery manager does not have perfect information about the fishermen's cost and production functions, it is better off issuing an output quota such as a total allowable catch (TAC). A TAC states the maximum quantity of fish that can be harvested from the fishery in a given season. A TAC is a more direct policy tool than taxes or input quotas because it directly determines the amount of harvest that can be removed from the fishery instead of attempting to induce fishermen to choose the optimal harvest by altering their economic incentives. However, the imposition of a TAC alone is likely to lead fishermen to race for the fish before the quota is met and use expensive technology to do so. Additionally, the fishery manager may find it difficult to enforce a TAC if it does not regulate which fishermen can operate in the fishery.

Arnason (1990) claims that an ITQ system is the only practical management policy under imperfect information when dynamic externalities exist. ITQs control dynamic externalities by appropriating what share of the TAC each fisherman is permitted to harvest. Furthermore, economic theory predicts that because ITQs are transferable they will end up in the hands of the most efficient fishermen because these fishermen would be willing to pay the most for them.

The aforementioned models examine simple dynamic externalities in which several fishermen compete over an identical catch (same species, in the same stage of development and in the same fishing ground). However, dynamics externalities are often more complex. For instance, Sumaila (1997) explores a model with a cohort externality in which two fishermen, using different fishing technologies, harvest the same species at different stages of its growth. Sumaila examines the fish war between Russia, which uses trawlers to harvest young cod, and Norway, which uses pole-and-line technology to fish mature cod, in the Barents Sea. He shows that a cooperative solution can be reached if the Norwegian fishermen bribe the Russian fishermen (by giving them a larger share of the surplus) in order to induce the Russians to allow more cod to mature.

Another type of dynamic externality that is largely ignored in economic literature is the so-called bycatch externality. Bycatch externalities occur when a group of fishermen who target one species incidentally harvest another species, called a bycatch species. Bycatch externalities are likely to occur when fishermen use mass-production methods as purse seine vessels or trawlers. When the bycatch species has an existence value but no commercial value (as is the case with dolphins that are sometimes accidentally caught by tuna boats) the bycatch externality leads to social loss. When the bycatch species has commercial value the bycatch externality can lead to an inefficient harvest even if the fishermen are permitted to sell their bycatch (Boyce, 1996). Boyce concludes that the introduction of ITQs can eliminate the problems created by bycatch externalities as long as both the target species and the bycatch species are harvested under an ITQ system and the bycatch species does not have existence value.

Economic research indicates that the best way to deal with dynamic externalities, whether they are simple, cohort, or bycatch externalities is by issuing ITQs. If administered properly ITQs lead to a socially optimal outcome for the following reasons. (1) The total catch cannot exceed the TAC and therefore is optimal as long as the TAC is optimally set. (2) Fishermen with high operating costs will sell their ITQs to fishermen with lower operating costs. Nonetheless, when the bycatch species has an existence value other input constraints are needed in order to reduce the harvest of the bycatch. For example, the use of turtle-safe fishing nets has all but eliminated accidental killing of sea turtles (Boyce, 1996).

2.2. Market Externalities

Market externalities are pecuniary externalities. The presence of market externalities affects fishermen's behavior by altering their financial state (the demand that they face).

Market externalities occur when the quantity harvested by one fisherman affects the compensation (price) that other fishermen receive. Therefore, in order for market externalities to exist fishermen must have some market power (an ability to influence market price).

The market power of each fisherman depends on the size of the fisherman's harvest relative to the market supply and on how integrated the market for the species is. The larger the fisherman's harvest relative to the market supply the more market power he has. Therefore, a small group of fishermen who operate in a fishery that produces a large share of the world market supply could have considerable market power. This may be the case, for instance, with the Western Central Pacific Ocean, which is exploited by a few DWFNs and according to Lodge (1998) provides over 40% of the world's tuna. As the number of fishermen increases the competition amongst them intensifies and the market power of each fishermen decreases. Under open access the number of fishermen may become so large that none of the fishermen has any market power.

Fishermen may also have considerable market power if the market for the species is not well integrated even if they do not supply a large share of the total market. Markets for certain species may not be well integrated because the species cannot be transported over long distances or because there are considerable barriers to trading the species. If the market for the species becomes more integrated then the market power of each fisherman will fall. Similarly, if the agents that purchase the fish from the fishermen (i.e., processors and final consumers) have significant market power they may be able to bid down the price of the species and therefore weaken the market power of the fishermen. Campbell (1996) shows that processors may have considerable market power in the tuna industry.

When fishermen have market power harvesting by one fisherman creates a market externality for other fishermen. Fishermen play a Cournot-Nash game similar to the game envisioned by Cournot (1838) to analyze the strategic interaction between two duopolies. When one fisherman increases his harvest, he increases the market supply of the species and thus decreases the market price. The decrease in market price decreases the marginal revenue of other fishermen and induces them to reduce their harvest.

Datta and Mirman (1999) conclude that the presence of market externalities will exacerbate the over-harvesting that results from dynamic externalities. This is the case because when market externalities exist each fisherman has the incentive to increase his effort (above the level of effort that he would choose if market externalities did not exist) in order to reduce the market price and induce other fishermen to reduce their effort. Datta and Mirman note that free trade will improve welfare by reducing the fishermen's market power, thus weakening the market externalities between them. Hence, policies that encourage market integration, such as lowering trade barriers, can help offset the negative effects of market externalities.

Dockner et al. (1989) show that when one of the fishermen acts as a Stackelberg leader by committing to a level of effort first, the resulting outcome will be worse than when no leader exists. Because the leader can force other fishermen to reduce their fishing effort it would choose a level of effort that is higher than the level it would have chosen if it made its decision at the same time as other fishermen. Therefore, having one of the fishermen act as a Stackelberg leader results in more over-fishing than if no leader exists. Dockner et al. also add that the leader obtains more profit than the follower unless the follower manages to develop a superior fishing technology.

A more complex type of market externalities that has not been carefully considered in the literature occurs when a change in the price of one species affects the demand for other species. Two species that are used for human consumption are likely to be net substitutes. If two species are net substitutes an increase (decrease) in the price of one species will increase (decrease) market demand for the other species. An increase in the harvest of one species would drive down its market price and would, therefore, decrease demand for substitute species. Fishermen that harvest substitute species will respond to the fall in demand by decreasing their harvest. (They will reduce their harvest regardless of whether or not they have any market power.) Consequently, substitutability between species can offset some of the over-harvesting that may occur because of dynamic externalities and simple market externalities.

One should bear in mind that market externalities do not create inefficiencies but simply aggravate (or in the case of two substitutes, possibly offset) inefficiencies that result from the existence of dynamic externalities or other types of externalities. The use of ITQs can control the negative effects of dynamic externalities and therefore eliminate any additional deleterious effects that occur because of market externalities.

Anderson (1991) shows that when market externalities exist the sale of the ITQs may be inefficient. In other words, quotas may not be allocated to the fishermen with the lowest cost. Nonetheless, ITQs can be fairly effective if markets are well integrated, which implies that fishermen have little market power. Market externalities will not exist if fishermen have no market power (i.e., are price takers). Therefore, governments should pursue policies that encourage integration in the market for fish (such as free trade) and eliminate policies that create economic or technological advantages for some fishermen (such as subsidies) and thus increases their market power.

2.4. Biological Externalities

Fishermen may inflict externalities on one another even if they harvest different species. Biological externalities, first discussed in the economic literature by Fischer and Mirman (1992), occur when the species that one fisherman harvests interacts in some way with species that another fisherman harvest. Fischer and Mirman identify three types of interspecies interactions. Two species may have a symbiotic relationship, in which case an increase in the stock of one species positively affects the reproduction rate of the other species. Two species can be competing for the same resources (as food and space), in which case a reduction in the stock of one species increases the reproductive rate of the other species. Finally, two species can have a predator-prey relationship.

Fischer and Mirman conclude that when fishermen harvest two species that have a symbiotic relationship both species will be over-fished since the fishermen do not account for the positive effect that their target species has on the other species. (The fact that two target species have a positive interaction implies that harvesting one species has a negative externality on the fishermen that target the other species.) When fishermen harvest two species that have a competitive relationship then both species will be under-fished because the fishermen do not account for the negative effect that their target species has on the other species. Finally, when two species have a predator-prey relationship then the prey will be over-fished and the predator will be under-fished.

Unlike exploitation with dynamic externalities, which are characterized by stable equilibrium strategies (perturbations away from the equilibrium will cause fishermen to return to their equilibrium strategies), the presence of biological externalities may lead to unstable equilibria. For instance, when two fishermen harvest species that have a competitive relationship an increase in the harvest by one fisherman above the equilibrium harvest will induce the other fisherman to increase his harvest as well; thus, moving the fishery away from equilibrium. Instability makes exploitation in the presence of biological externalities harder to predict but sometimes easier to correct since fishermen may easily move away from a sub-optimal equilibrium.

Boyce (1992) asserts that biological externalities can be eliminated through the establishment of an ITQ system as long as the fishery manager issues transferable quotas for all the interacting species. The use of any other management policy is even more difficult when biological externalities exist. In order to optimally administer taxes or input quotas the fishery manager not only has to know the cost function and other information about the fishermen but they must also fully understand how the different species that are harvested (including bycatch species) interact.

Even with ITQs, however, the fishery manager needs to carefully consider the interaction between the species in order to determine the TAC that should be established for each species. The recognition of biological externalities should lead the fishery manager to issue a higher TAC for predators and competing species and a lower TAC for preys and symbiotic species than it otherwise would. With ITQs the TAC can be periodically adjusted if one of the species seems to be over-harvested or under-harvested to assure that the entire ecosystem is healthy.

2.5. Spillover and Production Externalities

A fourth class of externalities discussed by Copeland (1990) is spillover externalities. Spillover externalities occur when the activity that takes place in one fishery affects the capacity of fishermen to harvest fish in another fishery. Hence, the externality "spills over" to another fishery. Spillover externalities can be either negative, as is the case with pollution, or positive, as in the case with enhancement (an improvement of existing environmental conditions). Pollution or enhancement in one fishery can affect the health and growth rates of species in other fisheries.

Fishing vessels may pollute fishing grounds by discarding oil and waste into the water and by damaging coral reefs with their gear (especially their nets and anchors). Thus, harvesting for one species can damage the aquatic environment and harm other species in the same fishing ground. The effects of pollution can spill over to other fishing grounds if the pollution is non-stationary or if species migrate from one fishing ground to another (so-called straddling species). For example, some fish (i.e., sturgeon) hatch their eggs in coastal water while other fish (i.e., salmon) travel up streams to hatch their eggs. Polluting the hatchery may compromise the health of the species and reduce the number of species that mature and return to the open seas where they are harvested by other fishermen. Copeland (1990) notes that if the spillover effect on other fishermen is substantially greater than the direct effect on the fisherman who owns the hatchery, the hatchery owner may have the incentive to damage the hatchery (either actively or passively by allowing pollution to occur) in order to decrease the harvest of other fishermen and increase the market price of the species.

The movement of fish from one fishing ground to another also creates a direct spillover externality, which is sometimes called a straddling externality. Some fish, such as salmon and sturgeon, hatch new generations in coastal fisheries and then return to the open seas. Other species, like tuna, travel great distances in the open sea. When a stock is highly migratory harvesting the stock in one fishery will affect its size in other fisheries not only by physically removing some of its members but also by reducing its reproductive capacity (Kaitala and Munro, 1993). When straddling is ignored the species may be over-fished in one or all fisheries.

Straddling is a particularly perplexing problem because a species may straddle between fisheries that are under the jurisdiction of different governments or between a national fishery and an unregulated international fishery. Kaitala and Lindroos (1998) suggest that the most effective way to manage a straddling stock is through the formation of regional agreements among the coastal nations that harvest the stock. However, when a stock straddles between a national fishery and an international fishery the resulting spillover externality is more difficult to solve. McKelvey et al. (2002) shows that DWFNs operating in an international fishery will intensify their fishing when the stock straddles between the international fishery and a national fishery.

Production externalities are similar in many respects to spillover externalities. Production externalities occur when the production of one fisherman directly affects the production capabilities of other fishermen. For example, congestion in the open seas or at the port may interfere with the ability of fishermen to operate. Also, the presence of fishing vessels can scare away a potential catch. Production externalities can affect other fisheries (e.g., a different target species in the same fishing ground) and thus become spillover externalities.

Boyce (1992) shows that despite their relative effectiveness ITQs will not offset the effects of production externalities. Production externalities in fisheries exploitation, however, have not been studied empirically. It is quite likely that their impact (when they exist) is quite small. In particular, if a fishery is so crowded that it suffers from production externalities the resulting dynamic externalities amongst the fishermen is a substantially more serious problem than the production externalities. In most cases, production externalities can be eliminated by limiting the number of fishermen that use the fishery and by establishing some coordination among them (such as who harvests where).

2.6. Multiple Externalities

Strategic interactions between fishermen can be quite complex. Actions taken by one fisherman may impose a multiplicity of externalities not only on other fishermen in the same fishery but also on fishermen in interrelated fisheries. The potential presence of multiple externalities makes the work of fishery manager an intricate task.

Although no author has incorporated all the aforementioned externalities into a single model several authors have examined models with multiple externalities. Dockner et al. (1989) and Datta and Mirman (1999) examine models with both market and dynamic externalities. As discussed earlier, market externalities are only a problem insofar that they aggravate the undesirably high level of effort (or harvest, depending on the model used) that results from the existence of dynamic externalities. Therefore, by controlling for the negative effects of dynamic externalities, ITQs also eliminate the problems created by market externalities.

Fischer and Mirman (1996) examine a model with both dynamic externalities and biological externalities by considering the case in which two fishermen harvest both interacting species. They find that the dynamic externality dominates the biological externality. Even if the biological interaction is negative (which means the fishermen will under-fish the species in the absence of a dynamic externality) fishermen will still end up over-fishing both species if they simultaneously harvest them. Fischer and Mirman argue that the presence of a positive biological externality (as mutual consumption of the same prey by the two target species) reduces but never eliminates the over-fishing caused by a dynamic externality. By contrast, the presence of a negative biological externality (e.g., symbiosis between the two target species) aggravates the over-fishing that is caused by a dynamic externality.

Spillover and production externalities are both negative externalities. The existence of such externalities implies that harvest by one fisherman (or merely the presence of the fisherman) hurts other fishermen in the same or in interrelated fisheries. Therefore, spillover and production externalities aggravate the over-fishing that results from the presence of dynamic externalities.

Simple intuition can help us understand the strategic interaction amongst fishermen in the presence of multiple externalities. When a stock of fish is harvested by several fishermen (either in the same fishery or in different fisheries if the species is highly migratory) and their behavior is unregulated then the fishermen will always exert more effort than is socially optimal. The presence of additional market, spillover, production or negative biological externalities will further aggravate the over-fishing that is caused by the dynamic or straddling externality. On the other hand, the presence of positive biological externalities and possibly substitutability in consumption between species will partially offset the negative effects of other externalities but will never completely eliminate over-fishing (Datta and Mirman, 1999).

The possibility of multiple externalities lends strong support for the use of ITQs because the more externalities there are the more information the fishery manager needs to know in order to administer other types of management policies. In order to optimally use input taxes, output taxes or input quotas the fishery manager has to know the cost and production functions of each fisherman and the dynamics of stock. The manager may also have to understand the effects of any market, biological, spillover and production externalities amongst the fishermen (possibly in multiple fisheries). On the other hand, if an ITQ system is used, all the fishery manager needs is the optimal amount of harvest. In order to determine the optimal harvest the manager needs to understand the dynamics of the stock, however, it does need to know the fishermen's cost and production functions or about any production externalities that may exist.

The use of ITQs may not completely offset the negative effects of production or spillover externalities. Danielsson (2000) argues that ITQs do offset the effects of production and spillover externalities but his conclusions are sensitive to the model used. ITQs minimize the extent of spillover and production externalities by preventing a race for the fish. Coordination between fishermen and some input regulations (as requiring cleaner engines or limiting the size of fishing nets) can further control these externalities.

The introduction of ITQs can also offset the negative effects of biological and bycatch externalities as long as the harvest of all the interrelated species is regulated through an ITQ system and the species do not have an existence value. Additional gear requirements may eliminate bycatch with existence value. Therefore, game theory generally supports the use of a universal ITQ system with some modifications.

3. MANAGEMENT REGIMES

3.1. A Brief Typology of Fisheries Management

Fisheries can fall under one of several management regimes. The type of regime used influences how various externalities affect the fishermen's behavior. International fisheries are fisheries that are located entirely outside the Exclusive Economic Zone (EEZ) of any nation. International fisheries are generally not regulated and are therefore referred to as open-access fisheries. However, in some cases the DWFNs that exploit them reach cooperative agreements regarding their management. National fisheries fall under the jurisdiction of a coastal nation.

Governments generally attempt to regulate the behavior of fishermen in national fisheries in order to maximize the national welfare from the fishery. Fisheries that are regulated by the coastal state's government and are only exploited by domestic fishermen are referred to as government-regulated fisheries. In some cases, governments assign control of the fishery to local cooperatives (groups of fishermen that jointly exploit and manage the fishery). Fisheries that are jointly managed by a group of fishermen, such as a local cooperative, are referred to as common-pool fisheries. Finally, in some cases national governments allow foreign fishermen to operate within their EEZ. Governments may allow foreign exploitation for political motives or because domestic fishermen do not have the necessary technology to optimally explore the fishery. Fisheries that are under the control of a national government but are exploited by foreign fishermen are referred to as foreign fisheries.

The way fisheries are managed has substantially changed in the latter half of this century (see Ishimine, 1978 for summary). Until the latter half of this century open-access fisheries were freely exploited by DWFNs. This freedom of exploitation benefited developed countries, who possess fishing technology superior to that of less developed countries (LDC). In 1970 the United Nations General Assembly declared international waters to be the common resource of mankind and called for any benefits that accrue from their exploitation to be shared amongst all nations. Although this declaration was hailed by LDCs, conflicts over how the benefits from the exploitation of fisheries should be shared rendered this proposition unrealistic.

In the 1970s representatives to the UN negotiated the extension of countries' economic control over the sea and its resources. The negotiation culminated in the United Nations Third Convention on the Law of the Sea, which adopted the Extended Fisheries Jurisdiction (EFJ). The EFJ granted coastal nations exclusive economic control over the 200 nautical miles adjacent to their shores and bought many of the world fisheries under governmental control. Most nations began phasing out exploitation by foreign fishermen.

However, many LDCs found it profitable to permit DWFNs to continue exploiting their fisheries in exchange for a fishing fee, a licensing fee or both. As LDCs develop their fishing technology it is not clear how many of these fisheries will remain open to foreign fisheries and how many of them will be fully nationalized.

3.2. International Fisheries

It is well known that when no restrictions are placed on the extraction or consumption of a common resource, as is the case with most international fisheries, the resource is overexploited and in some cases completely depleted. Gordon (1954) claims that when there is open access to a fishery fishermen would continue to enter the fishery until all the rent from the fishery is dissipated. As long as an additional vessels can make economic profit, new fishermen have the incentive to enter the fishery and the fishermen who are already exploiting the fishery have the incentive to increase the size of their fleet. (See Ostrom, 1990, for a detailed discussion on rent dissipation).

Theoretically any open access fishery will reach a zero profit condition. Under open access the effects of any negative externalities as dynamic, market and spillover externalities will be very severe. Fishermen will exert as much effort as they can without incurring a loss. In fact, since capital is non-malleable (investment in fishing equipment is either irreversible or can only be sold for scrap value) fishermen may continue to harvest fish even when they are incurring an economic loss in order to recover some of their fixed cost (Munro, 1998).

However, even in international fisheries there may be economic or political barriers that prevent fishermen from entering the fishery. High capitalization and travel cost to the fishery may limit the number of fishermen that operate in the fishery. International fisheries that are geographically isolated and are harvested using capital-intensive methods may have particularly stringent barriers to entry. Finally, as shown by Ruseski (1998), the governments of the DWFNs that exploit an international fishery have the incentive to limit the number of vessels that travel to fishery to ensure that their national fleets earn a positive return from exploiting the fishery.

The management of international fisheries has been the subject of much debate and has been studied extensively using game theory (see McKelvey, 1997 for summary). Levhari and Mirman (1980), Dockner et al. (1989), Fischer and Mirman (1996) and Ruseski (1998) conclude that because of the existence of dynamic externalities each DWFN will exert more effort than is socially optimal. Specifically, the total effort that the DWFNs exert will be higher than the effort that maximizes the net return from the fishery. Ruseski also asserts that each nation will build a fishing fleet that is larger than optimal. Dockner et al. show that the presence of market externalities aggravates the over-fishing that results from existing dynamic externalities between the DWFNs. Fischer and Mirman (1996) note that when both biological and dynamic externalities are present fishermen will always harvest more fish than is socially optimal.

All the papers above implicitly assume that the number of DWFNs (and thus fishermen) in the fishery is finite and fixed. Theoretically, when access to the fishery is limited each fisherman will earn a positive profit (Karpoff, 1989). However, Dupont (1990) finds that even under restricted access rent from the fishery is largely dissipated via input substitution. Fishermen switch to higher-production, higher-cost technologies in order to compete with other fishermen, which decrease the fishermen's profit in the long run. Therefore, regardless of whether access to fishery is constrained (due to a political agreements or barriers to entry) or unconstrained, international fisheries will suffer from rent dissipation due to the presence of dynamic externalities and possibly other negative externalities (discussed in section 2).

3.3. Government-regulated and Common-Pool Fisheries

The EFJ has placed many international fisheries under the jurisdiction of coastal nations. Theoretically, the act should increase social welfare because, as previously discussed, when a fishery is unregulated the presence of dynamic externalities and other negative externalities leads to rent dissipation. National governments can use various policies to optimally regulate fishermen's behavior. However, the fact that a fishery is brought under regulation does not necessarily mean that the fishery manager will regulate the fishery in a socially optimal way.

Arnason (1990) recognizes that the fishery manager may not have sufficient information to optimally use most types of management policies. Because of imperfect information and the unpredictable ways in which fishermen may respond to new regulations the use of taxes or input quotas may lead to a reduction rather than an increase in welfare. The establishment of an ITQ system can help overcome the problem of incomplete information by allocating ownership rights over the fishery and permitting the market to find the optimal allocation and prices for the quotas. Nonetheless, the fishery manager must still determine what the TAC should be.

Evidence exists that fishery managers often allocate TACs to groups in a way that contradicts economic intuition (e.g., Armstrong and Sumaila, 2001). Additionally, ITQs will not lead to an optimal response when the target species or bycatch species have an existence value (Boyce, 1996). Furthermore, the allocation of ITQs may prove politically difficult because of resistance by fishermen that wish to enter the fishery and by processors who may end up losing profit because of the system (Matulich et al., 1996).

Establishing a market-based solution such as an ITQ system may be difficult because fishery managers may be more interested in improving their own welfare rather than social welfare. For example, a manager may support certain interest groups in exchange for political backing (Anderson, 1984). For example, the manager may institute policies that induce a higher level of harvest than optimal in order to help processors obtain a lower price. The manager may also try to maximize bureaucratic cost in order to increase the earnings of its staff.

The shortcomings of ITQs (despite their superiority over other management policies) have promoted some governments to consider more cooperative solutions to fisheries management. For example, the American Fisheries Act enables fishermen to form cooperative bargaining units that jointly manage a fixed share of the TAC for the North Pacific pollock fishery. Matulich et al. (2001) use a game-theoretical model to show that such an arrangement is an improvement but will not lead to the win-win solution that the government is hoping for and will create additional market failures. The potential for beneficial cooperation amongst fishermen exists in smaller communities where fishermen can monitor each other's actions and can apply social pressure on one another. However, in most cases common-pool fisheries need some external supervision.

3.4. Foreign Fisheries

There are circumstances in which it makes economic sense for a coastal nation to allow foreign fishermen to exploit its fisheries. The coastal nation can benefit from foreign exploitation by charging foreign fishermen a licensing fee to operate in the fishery and/or a fishing fee on the harvest that they remove from the fishery. Charles (1986) develops a model in which a costal nation decides how to allocate a fixed TAC between a domestic fleet and a foreign fleet. He shows that there are four possible patterns of development depending on the fishing fee, which is assumed exogenous, and the critical domestic resource rent (the minimum rent that would make it profitable for domestic fishermen to exploit the fishery). The coastal nation may allow both fleets to operate indefinitely, only allow one of the fleets to operate or slowly phase out foreign exploitation and replace it with domestic exploitation.

Clarke and Munro (1987, 1991) determine that a coastal nation will benefit from using a dual tax system, taxing the DWFN's harvest and taxing or subsidizing its fishing effort instead of only using a fishing fee. However, the coastal state will still not be able to simultaneously maximize the net return from the fishery and its share of the return. Raissi (2001) uses a similar model to Clarke and Munro but includes domestic exploitation. He assumes that the domestic fleet uses inferior fishing technology. Raissi shows that without government intervention the foreign fleet will eliminate domestic competition by exerting the maximum effort. However, the coastal state will induce the two fleets to converge to a common equilibrium by using a system of taxes.

Wachsman (2002) shows that when a coastal nation can determine the number of fishermen that operate in its fishery it has the incentive not restrict entry to the fishery and to charge a fishing fee that would induce fishermen to select the socially optimal level of effort. Although dynamic externalities would still exist, the fishing fee would internalize the costs of these externalities and the net return from the fishery will be maximized. Therefore, theoretically foreign fisheries would reach a socially optimal outcome if the coastal nation can determine the number of fishermen.

4. SUMMARY

Fishermen impose external costs (and sometimes benefits) on other fishermen that operate either in the same fishery or in interrelated fisheries. Fishermen always impose a dynamic externality on other fishermen that harvest from the same fishery by removing members of the stock. Although theoretically dynamic externalities can be controlled using a variety of management policies, imperfect information and uncertainties about the fishermen's reactions makes the use of most policies (such as taxes and gear specifications) impractical.

It is more practical to set a TAC for each fishery and periodically adjust it in order to assure the sustainability of the entire ecosystem. There is some consensus amongst economists that it is better to divide the TAC amongst fishermen using an ITQ system. If the TAC is not partitioned, fishermen have the incentive to invest in more powerful but expensive equipment in order to race for the catch. The lack of private ownership also makes it more difficult for the fishery manager to enforce the TAC.

ITQ systems can also internalize biological and bycatch externalities as long as the harvest of all interrelated species (interacting and bycatch) is allocated through ITQs and the bycatch species does not have an existence value. The possible presence of multiple externalities underscores the need to issue ITQs for all species in order to allow the prices of ITQs for all species to optimally adjust. The other advantage of using ITQs is that it is a market-based solution that limits the role of the fishery manager. If the power of the fishery manager is left unchecked then it may behave in ways that are self-serving rather than socially beneficial.

ITQs, however, have several shortcomings. ITQs cannot internalize the existence value of any species and may not fully offset the negative effects of spillover and production externalities. Additionally, fishermen sometimes find ways to exceed their quotas (Armstrong and Sumaila, 2001). If a bycatch species has an existence level then the fishery manager should impose additional inputs requirements to minimize harm to the bycatch species. When production or spillover externalities exist further coordination and input specifications (such as cleaner engines) may be needed. Straddling externalities also require the formation of regional cooperatives to try to coordinate the strategies of the coastal nation(s) and possibly DWFN(s) involved. These regional cooperatives may be achieved through political negotiations.

When fishermen market power they may also impose market externalities on one another. Market externalities aggravate the effects of existing dynamic externalities and other negative externalities. Policies that help market integration, such as the removal of trade barriers, can help weaken market externalities by divesting fishermen of their market power.

Management policies can only be applied in fisheries that are under the control of a government or a regional cooperative. Studies have shown that when fisheries are not regulated, as in the case of international fisheries, then the rent from the fishery will be dissipated. The EFJ has placed many of the world fisheries under the jurisdiction of coastal nations.

National government can now potentially offset the negative effects of externalities in many of these fisheries by optimally administrating them. Governments have used a variety of management policies to try to offset the effect of negative externalities in government-regulated fisheries (fisheries that are only exploited by domestic fishermen). This paper argues that ITQs is superior to other management policies. However, despite their apparent superiority to other management policies ITQs have been objected to on several grounds including the fact that they create private ownership over common natural resources.

Recently, the US and other countries have experimented with cooperative solutions for fisheries management such as assigning shares of a TAC to groups of fishermen, so-called local cooperatives. Game theory indicates that such cooperative solutions are unlikely to lead to a socially optimal outcome unless members of each cooperative can carefully monitor each other and punish defectors. Furthermore, there is little guarantee that the TAC will be divided optimally amongst the groups. Only time will reveal whether these cooperative solutions can be successfully administered.

Many LDCs, lacking the necessary technology to efficiently exploit their fisheries, have opted to permit foreign fishermen to exploit their fisheries in exchange for paying license and fishing fees. Although this phenomenon has been studied using theoretical models, more empirical evidence is needed to determine whether these arrangements are optimal from a social perspective.

REFERENCES

Anderson, Lee G. (1984). "Uncertainty in the Fisheries Management Process." *Marine Resource Economics*, 1(1): 77-87.

Anderson, Lee G. (1991). "A Note on Market Power in ITQ Fisheries." *Journal of Environmental Economics and Management*, 21(3): 291-96.

Armstrong, Claire W. and Ussif R. Sumaila (2001). "Optimal Allocation of TAC and the Implications of Implementing an ITQ Management System for the North-East Arctic Cod." *Land Economics*, 77(3): 350-59.

Arnason, Ragnar (1990). "Minimum Information Management in Fisheries." *Canadian Journal of Economics*, 23(3): 630-53.

Boyce, John R. (1992). "Individual Transferable Quotas and Production Externalities in a Fishery." *Natural Resource Modeling*, 6(4): 385-408.

Boyce, John R. (1996). "An Economic Analysis of the Fisheries Bycatch Problem." *Journal of Environmental Economics and Management*, 31(3): 314-36.

Campbell, H. F. (1996). "Prospects for an International Tuna Resource Cartel." *Marine Policy*, 50(5): 419-27.

Charles, Anthony T. (1986). "Coastal State Fishery Development: Foreign Fleets and Optimal Investment Dynamics." *Journal of Development Economics*, 24(2): 331-58.

Clark, Colin W. (1976). *Mathematical Bionomics: The Optimal Management of Renewable Resources*. Wiley, New York.

Clark, Colin W. (1980). "Restricted Access to Common-Property Fishery Resources: A Game Theoretical Analysis." In *Dynamic Optimization and Mathematical Economics*, ed. P. Liu, Plenum Press, New York.

Clark, Colin W. (1985). *Bioeconomic Modeling and Fisheries Management.* Wiley Interscience, New York.

Clarke, Francis H. and Gordon R. Munro (1987). "Coastal States, Distant-water Fishing Nations and Extended Jurisdiction: Principal-agent Analysis." *Natural Resource Modeling*, 2(1): 81-107.

Clarke, Francis H. and Gordon R. Munro (1991). "Coastal States and Distant-water Fishing Nations: Conflicting Views of the Future." *Natural Resource Modeling*, 5(3): 345-69.

Copeland, Brian (1990). "Strategic Enhancement and Destruction of Fisheries and the Environment in the Presence of International Externalities." *Journal of Environmental Economics and Management*, 19(3): 212-26.

Cournot, Agustin A. (1838). Researches into the Mathematical Principles of the Theory of Wealth. *Published manuscripts*.

Danielsson, Asgeir (2000). "Efficiency of ITQs in the Presence of Production Externalities." *Marine Resource Economics,* 15(1): 37-43.

Datta, Manjira and Mirman, Leonard J. (1999). "Externalities, Market Power, and Resource Extraction." *Journal of Environmental Economics and Management*, 37(3): 233-55.

Dockner, Engelbert, Gustav Feichtinger and Alexander Mehlmann (1989). "Non-cooperative Solutions for a Differential Game Model of Fishery." *Journal of Economic Dynamics and Control*, 13: 1-20.

Dupont, Diane P. (1990). "Rent Dissipation in Restricted Access Fisheries." *Journal of Environmental Economics and Management*, 19(1), 26-44.

Fischer, Ronald D. and Leonard J. Mirman (1992). "Strategic Dynamic Interaction." *Journal of Economic Dynamics and Control*,16(2): 267-87.

Fischer, Ronald D. and Leonard J. Mirman (1996). "The Compleat Fish Wars: Biological and Dynamic Interactions." *Journal of Environmental Economics and Management*, 30(1): 34-42.

Gibbons, Robert (1992). *Game Theory for Applied Economists*. Princeton University Press, Princeton, NJ.

Gordon, Scott H. (1954). "The Economic Theory of Common Property Resources: The Fishery." *Journal of Political Economy*, 62: 124-42.

Hanley, Nick, Jason F. Shogren and Ben White (1997). *Environmental Economics: In Theory and in Practice*. Oxford University Press, New York.

Hannesson, Rognvaldur (1984). "Fisheries Management and Uncertainty." *Marine Resource Economics*, 1 (1): 89-96.

Houba, Harold, Sneek Koos, and Felix Vardy (2000). "Can Negotiations Prevent Fish Wars?" *Journal of Economic Dynamics and Control*, 24(8): 1265-80.

Ishimine, Tomotaka (1978). "The Law of the Sea and Ocean Resources." *American Journal of Economics and Sociology*, 37(2): 129-44.

Kaitala, Veijo and Gordon R. Munro (1993). "The Management of High Seas Fisheries." *Marine Resource Economics*, 8(4): 313-29.

Kaitala, Veijo and Marko Lindroos (1998). "Sharing the Benefits of Cooperation in High Seas Fisheries: A Characteristic Function Game Approach." *Natural Resource Modeling*, 11(4): 275-99.

Karpoff, Jonathan M. (1989). "Characteristics of Limited Entry Fisheries and the Option Component of Entry Licenses." *Land Economics*, 65(4): 386-93.

Levhari, David and Leonard J. Mirman (1980). "The Great Fish War: An Example Using a Dynamic Cournot-Nash Solution." *Bell Journal of Economics*, 11(1): 322-34.

Lodge, Michael (1998). "The Development of the Palau Arrangement for the Management of the Western Pacific Purse Seine Fishery." *Marine Policy*, 22(1): 1-28.

Matulich, Scott C., Ron C. Mittelhammer and Carlos Reberte (1996). "Toward a More Complete Model of Individual Transferable Fishing Quotas: Implications of Incorporating the Processing Sector" *Journal of Environmental Economics and Management*, 31(1): 112-28.

Matulich, Scott, C., Murat Sever and Fred Inaba (2001). "Fishery Cooperatives as an Alternative to ITQs: Implications of the American Fisheries Act." *Marine Resource Economics*, 16(1): 1-16.

McKelvey, Robert W. (1997). "Game-Theoretic Insights into the International Management of Fisheries." *Natural Resource Modeling*, 10(2): 129-71.

McKelvey, Robert W., Leif K. Sandal and Stein I. Steinshamn (2002). "Fish Wars on the High Seas: A Straddling Stock Competition Model." *International Game Theory Review*, 4(1): 53-69.

Munro, Gordon R. (1979). "The Optimal Management of Transboundary Renewable Resources." *Canadian Journal of Economics*, 12(3): 355-76.

Munro, Gordon R. (1982). "Fisheries, Extended Jurisdiction and the Economics of Common Property Resources." *Canadian Journal of Economics*,15(3): 405-25.

Munro, Gordon R. (1998). "The Economics of Overcapitalization and Fishery Resource Management: A Review." University of British Columbia, Department of Economics Discussion Paper: 98/21.

Ostrom, Elinor (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Political Economy of Institutions and Decisions series, Cambridge University Press, New York and Melbourne.

Raissi, N. (2001). "Features of Bioeconomics Models for the Optimal Management of a Fishery Exploited by Two Different Fleets." *Natural Resource Modeling*, 14(2): 287-310.

Ruseski, Goradz (1998). "International Fish Wars: The Strategic Roles for Fleet Licensing and Effort Subsidies." *Journal of Environmental Economics and Management*, 36(1): 70-88.

Ruseski, Goradz (1999). "Market Power, Management Regimes, and Strategic Conservation of Fisheries." *Marine Resource Economics*, 14(2): 111-27.

Schaefer, Milner B. (1957). "Some Considerations of Population Dynamics and Economics in Relation to the Management of Marine Fisheries." *Journal of Fisheries Research Board of Canada*, 14: 669-81.

Scott, Anthony (1955). "The Fishery: the Objective of Sole Ownership." *Journal of Political Economy*, 63: 116-24.

Sumaila, Rashid Ussif (1997). "Cooperative and Non-cooperative Exploitation of the Arcto-Norwegian Cod Stock." *Environmental and Resource Economics*, 10(2): 147-65.

Sumaila, Rashid Ussif (1999). "A Review of Game-Theoretic Models of Fishing." *Marine Policy*, 23(1): 1-10.

Wachsman, Yoav (2002). "A Model of Fishing Conflicts in Foreign Fisheries." University of Hawaii Economics, Department of Economics Working Paper: 2-16.

Wilen, James E. (1985). "Modelling Fishermen and Regulator Behaviour in Schooling and Search Fisheries." In *Progress in Natural Resource Economics: Essays in Resource Analysis by Members of the Programme in Natural Resource Economics (PNRE) at the University of British Columbia*: 153-70.