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OVEREXPLOITATION OF FISHERY RESOURCES: CAUSES AND PRESCRIPTIONS

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Abstract:

Regional Fishery Management Organizations (RFMOs) have a poor record of managing fish stocks on the high seas and promoting sustainable fishing practices. Under collectively managed fisheries, because fishers do not bear all of the costs associated with fishing activity, they overfish. Moreover, the costs of participating in RFMOs are high, the coalitions are difficult to sustain and free riding is prevalent. By internalizing the negative externality of overfishing associated with collectively managed fisheries, Individual Transferable Quota (ITQ) schemes more effectively manage fishery resources than RFMOs. Through the institution of a quota system that effectively accounts for the costs of fishing activity, ITQs change the incentives that fishers face and promote more sustainable fishing practices among members. Through improved enforcement from quota revenues, ITQs can modestly reduce non-member free riding.

Individual Transferable Quotas have proven successful only in the management of domestic fisheries, whereas RFMOs manage international fisheries. Although differences in scale and jurisdiction exist between ITQs and RFMOs, ITQ measures have the potential to be adapted to RFMOs, improving high seas fishery management. Another market-based system, a tax system, can avoid the issues of quota allocation and ecological uncertainty in ITQs by relying on price as a control rather than quantity. However, the tax-based system is unproven and requires further discussion.

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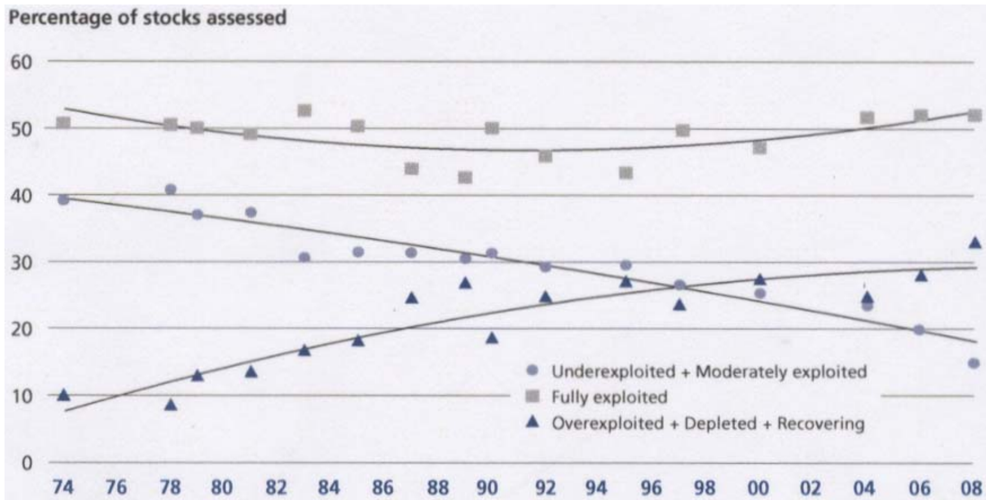
Introduction

Ocean resources had long been considered infinite, and industrialization of the fishing industry was met with optimism. In 1883, a leading English biologist, T. H. Huxley, proclaimed, "The cod fishery, the herring fishery… and probably all the great sea-fisheries, are inexhaustible (Clemmitt, 2005, 10)." With a similar mentality, in 1969, the congressional Stratton Commission predicted that the annual worldwide fishing catch—60 million tons—could be increased to 500 million tons (Clemmitt, 2005). During the remainder of the 20th century, the recognition of drastic declines in fishery populations altered that perception, leading to international fishing agreements and the proliferation of fishery management strategies (Nelson and Crothers, 2006; Clemmitt, 2005).

Today, global fisheries are in peril, with certain fish species being overexploited to the extent of depletion. Fish are being caught at an unsustainable rate that does not allow stocks to reproduce and maintain stable populations. In 1996, global marine fish capture levels peaked at 86.3 million tons. Over the next decade, catch levels varied but trended downward, declining to 79.5 million in 2008. The most recent (2010) UN FAO State of World Fisheries and Aquaculture (SOFIA) assessment reports that, despite the modest decrease in total catch, the number of fish stocks in danger has continued to rise. The amount of global marine fish stocks that are overexploited, depleted, or recovering from depletion increased from 10 percent in 1974 to 32 percent in 2008 (see Figure 1 below). Likewise, the amount underexploited or moderately exploited stocks declined from 40 percent in the mid-1970s to 15 percent in 2008 (see Figure 1). Fifty-three percent of fish stocks are fully exploited, limiting the capacity to sustainably expand fish production. If current worldwide fishing practices are not altered valuable fish species risk being damaged beyond repair (FAO, 2010).

Figure 1: Global Trends in the State of World Marine Fish Stocks



Source: (FAO, 2010) Years beginning at 1974

Along with the ecological importance of fishery habitats and fish stocks, the security of fisheries involves economic and health considerations. The fish industry is an integral part of the global economy, accounting for a large portion of international trade and GDP and serving as means of income for millions. In 2008, global capture fisheries production was valued at $93.9 billion, providing a livelihood for 540 million people, and accounting for 10 percent of total agricultural exports. Fish provide the global population with a valuable source of food, giving more than l.5 billion people 20 percent of their average level of protein. Fisheries are key to the health of the global environment, economy, and population (FAO, 2010).

In 2009, the total production from world fisheries was 145 million tons, of which inland production accounted for 45 million and marine production for 100 million. Of the portion of inland production, aquaculture represented the majority, at 35 million, while capture provided the remainder, at 10 million. Conversely, for marine production, capture fishing was dominant, with 79.9 million tons, while aquaculture produced only 20.1 million. Thus, aquaculture is becoming a more important source of fish (total aquaculture was 55.1 million in 2009) but still does not supply as much as capture fishing (total capture was 90 million in 2009). Moreover, aquaculture is more prevalent in inland fisheries while capture fishery dominates marine fisheries (FAO, 2010).

The focus of this thesis will be the management of marine capture fishery resources. The problems inherent in fishery management are compounded as scale increases, moving from inland fisheries to domestic marine fisheries (exclusive economic zones (EEZs)) to the high seas (international waters). Progress had been made in the management of domestic fisheries, but serious issues must be overcome in international fisheries. The high seas account for 60 percent of world's oceans, and represented 15 percent of the global marine catch in 2003, increasing from 9 percent in 1950. Improvements in technology and increasing demand for fish will continue to increase high seas production and the management of high seas fisheries will remain a significant problem until international efforts among fishing states can produce an effective management scheme (Pauly and Cullis-Suzuki, 2010).

International agreements currently assign this management role to Regional Fishery Management Organizations (RFMOs). As forms of collective management, eighteen RFMOs are tasked with managing nearly all of the high seas. Depending on geographic location, different coastal and inland nations participate in RFMOs. Within their jurisdictional zones, these organizations set fishery guidelines and manage the behavior of fishers to promote sustainable fishing practices. Plagued by high enforcement costs and free rider problems, RFMOs have performed poorly in their management role.

Two thirds of fish stocks under RFMO management are overexploited or depleted, substantially higher than the global average (Devaney, 2005; Pauly and Cullis-Suzuki, 2010).

Alternatively, Individual Transferable Quota (ITQs) management schemes are instituted within EEZs and have performed well, successfully promoting sustainable fishing practices. This thesis examines the role of RFMOs in international fishery management and proposes that they shift towards an ITQ system, arguing that ITQ schemes more efficiently manage fishery resources by internalizing the negative externality of overfishing that is associated with collectively managed fisheries, whether domestic or international. In RFMOs, free riding is prevalent among members and non-members. In ITQs, free riding is significantly reduced among members but still exists to some extent among non-members, depending on the quality of enforcement. While ITQs have the benefit of a sovereign state to govern the fishery and enforce rules, RFMOs must rely on international agreements and, largely, self-enforcement by participating states. Fundamental to the ITQ system is changing the incentives that participants face, which can be applied to collectively managed domestic or international fisheries.

Having presented the initial conclusion that ITQs are more effective management systems than RFMOs—due partially to differences in management practices and partially to differences in fishery scale and jurisdiction—this thesis argues that high seas management could be improved if RFMOs implemented aspects of ITQs, particularly tradable fishing quotas. Further discussion is then presented about a tax-based system, which could potentially overcome the allocation and ecological uncertainty issues inherent in ITQ systems. While ITQs are more efficient management strategies, problems exist in the allocation of quotas and the determination of the total allowable catch (TAC).

Section 1 examines the general nature of fisheries, outlining the management issue as a classic tragedy of the commons (TOC). After establishing that fisheries face TOC conditions and outcomes, Section 2 applies game theory to analyze the behavior of states in collective management systems. The central point established here is that effective management coalitions are difficult to sustain because members are prone to free riding behavior. Section 3 turns away from theory and describes the roles of RFMOs as fishery managers, highlighting why they fail. Section 4 presents ITQs as a market-based solution that produces preferable ecological and economic outcomes by changing the incentive structure of individual fishers, and outlines how RFMOs could adopt ITQ measures. In section 5, two market-based management schemes, a fee and a quota system, are compared, concluding that a fee-based system would overcome certain issues present in ITQ systems.

Fishery Overexploitation and the Tragedy of the Commons

Introduction

The tragedy of the commons is a type of collective goods problem that arises when actors consuming a common good fail to coordinate consumption habits and cooperate with established rules and norms. In the absence of coordination and cooperation, the common good can be overexploited in an unsustainable manner. Continuous overexploitation leads to the depletion of a resource and failure to provide the collective good (Hardin, 1968; Goldstein and Pevehouse, 2008).

Two aspects of collective resources, non-excludability and rivalry (see Matrix 1), create individual incentives that do not align with optimal social outcomes. As with public goods, individual users cannot be excluded from consuming a collective good. Unlike public goods (national defense), an individual user's consumption habits affect the quality and quantity of the collective good. In a collectively managed fishery, all actors are granted equal access to fish and the actions of each actor affect the total stock of fish. Because an individual does not bear the entire cost associated with his fishing activity, excessive fishing is incentivized.

Matrix 1
Excludability and Rivalry: Definition of Goods

	Excludable	Non-excludable
Rivalrous	Private goods	Common goods
Non-rivalrous	Club goods	Public goods

International actors and domestic actors give rise to the collective goods problem. In international fisheries, fish resources are shared collectively by states rather than owned individually. However, fishing gains are individual while costs are collective: A fishing catch benefits a single actor, but the environmental and economic costs arising from aggregate fishing activity affect all stakeholders of the fishery. While there are rules established to govern international waters, complete compliance is difficult or impossible to produce because enforcement mechanisms are typically weak or nonexistent. The actors of sovereign states can operate in international waters without being held accountable for fishing practices by a specific central government. Cooperation among states is ultimately voluntary and compliance with rules is often only realized through self-enforcement. (Nelson and Crothers, 2006; Rouba, 2009; Goldstein and Pevehouse, 2008).

In domestic fisheries, although governments have clear jurisdiction over the common resource, the collective goods problem still arises. Within domestic fishing communities, the same cost and benefit aspects of international waters often prevail; while benefits are individual costs are collective—unless institutions and members succeed in internalizing the negative externality of resource depletion. While states hold mandate to govern fisheries within Exclusive Economic Zones (EEZs)—those areas extending 200 miles from their coastline—it is costly to patrol expansive waters and enforce rules. Thus, the conditions of open access and non-governance that lead to the tragedy of the commons at the international level can be prevalent in offshore domestic waters. However, unlike international waters, voluntary cooperation and compliance is more likely in local fishing communities because, among small community members and institutions, relationships are stronger and enforcement is more easily realized (Nelson and Crothers, 2006; Rouba, 2009).

The Tragedy of the Commons

In considering resource management, Hardin (1968) concludes that resources held in common by a sufficient population will be overexploited and tend towards degradation. The solution to this problem is not technical, one that can be solved through technological advancement, but rather behavioral (Hardin, 1968).

> Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all (Hardin, 1968, 1244).

According to Hardin, in order to prevent a common resource from being destroyed, the values and morals of the actors consuming the resource must be changed through coercive action. Where resources are common they should be managed by government, impelling adherence to rules through strict enforcement mechanisms. In most instances, unless the consuming population is particularly small—not representative of contemporary situations—resources as common goods are unjustifiable. Privatization leads to a more sustainable, equitable outcome by producing behavioral changes. Privatization more fully internalizes costs and promotes economically and ecologically favorable fishing practices (Hardin, 1968; Rouba, 2009).

Hardin's tragedy of the commons argument carries specific conditions and assumptions regarding the nature of common resources and the nature, motivations and behavior of actors. Rouba (2009) discusses crucial assumptions regarding "individual motivations, characteristics of individuals, the nature of existing institutional arrangements, interaction among users of the resource, the ability of the users to create new institutional arrangements, and the behavior of regulatory authorities" (Rouba, 2009, 539).

Basic conditions preface the operating assumptions. Common goods are rivalrous, one individual's consumption affects that of others, and non-excludable, no individual can be excluded from enjoying the resource. The use of common property is limited to a certain group of managing individuals, whereas open access is open to all without regulation (total absence of property rights). Individuals possessing property rights are sole users of the resource, accountable for costs and benefits. State property is regulated and controlled by a government, determining who can exploit the resource and the manner in which they can do so. In reality these property rights regimes overlap. State property can exhibit conditions of open access, as can communal property. Hardin adopts the condition of open access, producing rivalry and non-excludability. As will be explained, these conditions and the following assumptions apply to different fishing communities in different manners, more appropriately in some than others (Hardin, 1968; Rouba, 2009).

According to the tragedy of the commons, individuals seek to maximize their utility and are shortsighted. Because the short-term individual utility gained from consumption—extracting one fish—outweighs the collective disutility from consumption—one less available fish for all—individuals will consume as much as they can presently without regard for the long-term collective good (Hardin, 1968; Rouba, 2009).

All actors are homogenous. They behave in the same manner and have equal capabilities. Individuals adopt the same consumption patterns, consuming as much as possible, and possess the same ability to consume (Hardin, 1968; Rouba, 2009).

There are no institutional arrangements that regulate the resource (open access), actors do not interact, and agreements cannot be changed or created. Therefore, a lack of governing authority exists, and individuals do not coordinate their actions to produce management plans. If coordination is somehow reached, compliance cannot be maintained (Hardin, 1968; Rouba, 2009).

The outcome is that each profit-maximizing individual will excessively consume the resource in the present period. Individuals will not coordinate their consumption patterns to create long-term sustainability, and the resource will tend towards destruction—for fisheries, depletion of fish stocks (Hardin, 1968).

Solving the tragedy of the commons is not a technical matter. Technological advancement will not be able to reverse the trends of diminishing fish stocks. Rather, fishing advancements (satellite tracking) exacerbate the problem of fishery overexploitation. Instead, internalizing the costs of fishing, by enforcing fishery rules and exacting penalties for noncompliance or by privatizing fishery resources, will change individual behavior and mitigate the problem of overexploitation (Hardin, 1968).

Applicability of the Tragedy of the Commons to Fishery Resources

The conditions, assumptions, and outcomes of the tragedy of the commons more closely approximate the situation of international fisheries than domestic fisheries. However, actors in domestic fisheries sometimes exhibit similar behavior and the same outcome, overexploitation and degradation, can occur (Hardin, 1968; Rouba, 2009).

While other motivations exist—adventure, independence—the TOC assumption of shortsighted, profit maximizing individuals is representative of fishery exploitation at both levels, international and domestic. The “rule of capture”—property rights over fish are not established until the fish are caught—strengthens this assumption. Fishers invest in expensive equipment and fishing boats with the aim of turning a profit. However, at the local level, greater interaction among fishers may produce altruistic behavior that counters this assumption, decreasing free riding problems. Free riding occurs when an individual has entered into a group agreement (limiting fishing effort) but reneges, by shirking responsibilities because the benefit of doing so is greater than the cost. A profit-maximizing, shortsighted individual will shirk responsibility if the benefit outweighs the cost. Locally, closer ties among resource managers may serve to limit, but not eliminate, this type of behavior (Rouba, 2009).

Homogeneity of firms is a simplification of reality that is not necessarily accurate. Fishers with varying motives and capabilities exist. However, this assumption more closely approximates the situation of international fisheries where greater scale is required to conduct fishing activity, decreasing the amount of smaller or recreational boats (Rouba, 2009).

Hardin (1968) assumes open access or de facto open access under state property regimes. In the case of the latter, if the state cannot properly regulate its waters then the resource will be open access by practice, though not by law. Under open access free entry and exit exists. Catch limits, gear restrictions—limits on types of hooks, lines, or other equipment—permits, social norms, and capital costs weaken the open access assumption to varying degrees. Regulations only limit entry to the extent that they are established and enforced. The costs associated with investing in fishing equipment limit exit. The difficulty of enforcing rules strengthens the assumption of open access. Local enforcement mechanisms tend to be more successful than international ones. Locals face ostracism from community members for breaking agreements and implementing regulations on a smaller scale is more feasible (Rouba, 2009).

The assumption that individuals do not interact and cannot create or change institutions is not representative of local fisheries. Community members interact with each other over many periods (not a one-shot game) and take into account their actions and the actions of others with regard to future fishing prospects. Free riding behavior presently can be punished in the future if punitive institutions exist. Local fishing communities do show the potential to create effective institutions that limit free rider behavior by punishing scofflaws. Rouba (2009) shows that communal fisheries in Oregon were successful in fostering coordination among fishers, establishing strong institutions to limit catch, and enforcing rules to decrease free riding behavior, while similar efforts in California fisheries were significantly less successful. The California sardine fishery was an example of the tragedy of the commons, in part because of government mismanagement arising from political confrontation. Inaction by government officials to implement management plans, greater scale of the fishery, and the prevalence of TOC incentives and behavior among individuals led the fishery to be overexploited. Internationally, coordination exists to create institutions—the EU commons fisheries policy—but coherence of regulations at multiple levels and enforcement are more difficult to achieve. Relatively less interaction and weaker institutional arrangements at the international level more closely matches the assumptions of the tragedy of the commons (Rouba, 2009).

The TOC model does not specify a type of regulation regime (Rouba, 2009). The TOC outcome and the documented difficulty of establishing and maintaining strong regulatory institutions in domestic and international communities suggest that an alternative method of management would be more successful. This paper will study a market-based system, Individual Transferable Quotas, while comparing it to a communal system, Regional Fishing Management Organizations, arguing that RFMOs should adapt ITQ measures.

The tragedy of the commons can have predictive power for both international and domestic fishery outcomes, greater than optimal fish catch levels and resource degradation. However, its conditions and assumptions more closely approximate the situation of international fisheries. Despite the shortcomings of the TOC model at the domestic level—degree to which theoretical description fits reality—it remains a useful framework for studying the problem of fishery overexploitation. The sharpest distinction between international and domestic fisheries is scale. Internationally, multiple institutional levels are at work, international, national, and local, and a greater number of boats traffic waters (Rouba, 2009). The performance of collective management techniques at the international level has been poor, while domestically there have been mixed results. Individual Transferable Quota management schemes have proven effective in various countries, most prominently Iceland. The ITQ system is a form of privatization—establishing rights over fishing resources that can be bought and sold—and evaluating the success of ITQs can serve to validate the tragedy of the commons argument. However, the manner in which distinct ITQ management schemes are conducted will affect their success. Drawing comparisons with communal management schemes, RFMOs and local management cases, this thesis will argue that ITQs better serve to manage fishery resources by internalizing the negative externality associated with common pool resource exploitation, whether or not the common resource is successfully regulated. Further, my thesis will argue that ITQs produce favorable ecological and economic outcomes.

Game Theory and Fishery Resources

Prisoner's Dilemma and Nash Equilibrium

Given profit-maximizing actors and open access conditions, a game-theoretic approach can be a powerful way to model possible outcomes of fishing activity. Game theory provides insights into how fishers will behave under tragedy of the commons assumptions.

A simple point from which to start is consideration of the prisoner's dilemma game. According to a generalization of the game, two players (A and B) face two decisions that result in different payoffs. Players can either cooperate (C) or defect (D).

Matrix 2
Prisoner's Dilemma Payoff

		Player A: C	Player A: D
Player B	C	3,3	4,1
	D	1,4	2,2

Players make their decisions simultaneously, and thus can only conjecture what the other will do. However, given that the players are rational, they will choose the move that maximizes their utility, the payoff. If both cooperate, both accrue a payoff of three. If both defect, they only receive two. While the payoff under mutual cooperation is greater, the outcome of the game is mutual defection (Parkin, 2010).

In considering the moves of B, player A realizes that his best response is to choose D given either move by B. Thus, the dominant strategy for A is to defect[1]. If B chooses C and A chooses D, player A receives a payoff of four, which is greater than the payoff gained by choosing C. If B chooses D, A should choose D, again providing a greater payoff than C (Parkin, 2010).

Because player B is also rational, he has the same dominant strategy as A, and the outcome of the game is defection by both players. This outcome is the Nash equilibrium: Given the other's move, neither player can gain by changing strategy. From a position of Nash equilibrium, no player can improve their payoff by acting unilaterally. Thus, preventing the equilibrium of mutual defection requires coordination among players (Parkin, 2010).

While defection is the Nash equilibrium, it is Pareto-dominated by cooperation, a situation in which both players are made better off. Mutual defection is Pareto-dominated because there exists an alternative outcome that makes no player worse off and one player better off. In fact, if both players cooperate they achieve higher individual and joint payoffs than if both defect. Thus, the Pareto-dominant strategy is cooperation—a position from which no player can be made better off without making another worse off. Repetitions of the game can give rise to the Pareto-efficient solution in which the players coordinate their moves to maximize collective utility, both choosing C. Over multiple periods, by realizing the potential gains from coordination—rather than those of unilateral action—players can form coalitions in order to maximize the sum of their

[1] A dominant strategy is a strategy providing a player the best possible outcomes given any choice of the other player. The dominant strategy of A is defection. Given either choice by B, the choice of defection provides the largest payoff to A. Player B has the same dominant strategy.

individual utilities and collective utility. For fishers, choosing C can translate to reducing fishing effort, while the choice of D represents free riding. If fishers can construct credible institutions that limit effort and punish free riders, then an efficient, sustainable catch can be maintained. As the number of players (fishers) increases, it becomes more difficult to maintain a coalition because the gains from free riding increase.

Cournot Duopoly

The Cournot duopoly model is another manner of studying the behavior of competing actors. According to this model, two competing firms (firms A and B) seek to maximize their profits, while holding the belief that each other's output is constant.

The market begins as a monopoly. As a monopolist, firm A produces at the quantity (Q_{a1}) where marginal revenue (MR_{a1}) intersects marginal cost (C), and charges the price where quantity intersects demand (P_a) (see Figure 5 in the Appendix). The box (P_a d e C) represents the profits for firm A under monopoly. Firm B sees that there are profits and decides to enter the market. Believing that firm A's output will remain unchanged, firm B assumes that it will have access to the additional demand, producing at the quantity (Q_{b1}) where MC equals MR (MR_b) (see Figure 6 in the Appendix). By entering the market and increasing total output, firm B lowers the initial market price. At the new market price, with firm B producing at Q_{b1}, firm A assumes additional demand with the belief that firm B's output will remain unchanged. Again, the increased output decreases the market price (Rosenman, 1998).

The process repeats itself until both firms are producing at a profit-maximizing level of output (Q_a^*, Q_b^*), equilibrium (see Figure 7 in the Appendix). The firms' responses to one another are described by their best response functions, showing the level of output that will maximize a firm's profit given the other firm's output. Firm A's output—according to the best response function—is a function of firm B's, and vice-versa. In a fishery, the level of output translates to the size of the fish catch by each actor. Fishers determine their own catch level as a function of others' catch, which is taken as given (Rosenman, 1998).

Cournot-Nash Solution and the Fishery

A Cournot-Nash solution can be used to describe the behavior of fishing actors and the resulting effect on fish population. Mirman and Levhari (1980) construct a Cournot-Nash model in which two states compete for a changing fish population, deriving cooperative and non-cooperative solutions. In a non-cooperative solution, countries are concerned with their own intertemporal welfare, disregarding that of others. In a cooperative solution, a central authority controls each country's level of catch. First, each country seeks to maximize the sum of discounted utilities—present consumption is preferred to future consumption. As Cournot duopolists, the countries maximize utility subject to each other's level of consumption, taken as given. Then, the countries maximize their utility jointly through coordination. The model is dynamic in that the underlying fish population changes in response to the actions of the two countries. The decisions of countries 1 and 2 produce a Cournot-Nash equilibrium that does not necessarily correspond to the steady-state (zero growth) equilibrium of the fish population (Mirman and Levhari, 1980; Kwon, 2006).

Countries 1 and 2 seek to maximize utility in the present period but cannot exhaust the fish population because doing so would produce zero utility in all subsequent periods. The natural population of fish is determined by the biological growth rule,

$$X_{t+1} = X_t^{\alpha}, \qquad 0 < \alpha < 1. \qquad \text{(see Figure 8 in the Appendix)}$$

where alpha is the rate of growth. The fish population is normalized at a steady state of one, and populations greater than or less than one tend towards this equilibrium level over time. For one period, after fish have been consumed by countries 1 and 2, the remaining fish population in the next period is represented by $(X- c_1 - c_2)^{\alpha}$, where c_1 is the level of consumption for country 1 and c_2 the level of consumption for country 2. The discount factor for countries 1 and 2 are β_1 and β_2, respectively, and the countries' best response functions are,

$$(1 + \alpha\beta_1)c_1 + c_2 = x \qquad \text{country 1 response function}$$
$$c_1 + (1 + \alpha\beta_2)c_2 = x \qquad \text{country 2 response function}$$

The response function curves intersect at the Cournot-Nash equilibrium point, (c_1^{-}, c_2^{-}) (see Figure 9 in the Appendix), yielding a fish population of $(x - c_1 - c_2)^{\alpha}$ in the next period. Extending the model across infinite periods produces similar response functions, while accounting for future discount and fish growth rates. The result is that the long-term Cournot-Nash equilibrium produces a steady state of fish,

$$x^{-} = (\alpha\beta/(2- \alpha\beta))^{\alpha/(1-\alpha)},$$

where β represents the discount factors of both countries, assuming that the countries have the same discount factor. In reality, differing discount factors may lead to variation in fishing behavior. The steady state of fish under the Cournot-Nash equilibrium is less than the natural steady state, and, as will be shown, less than the cooperative steady state (see Figure 10 in the Appendix) (Mirman and Levhari, 1980).

If the countries coordinate their fishing activities and maximize their joint utility, they are left with a larger steady state of fish than if they do not coordinate. The joint optimal policy is,

$$x - 2c = \alpha\beta x.$$

In this situation the entire catch is 2c and each country has an individual catch of c. Mirman and Levhari (1980) assume countries of equal size and catch level—states of different sizes and catch will be explored later. The steady-state quantity of fish is $X^{\wedge} > x^{-}$

$$X^{\wedge} = (\alpha\beta)^{\alpha/(1-\alpha)} > (\alpha\beta/2-\alpha\beta)^{\alpha/(1-\alpha)} = x^{-}$$

A cooperative solution in which the countries jointly maximize the sum of their discounted utilities produces a larger equilibrium steady state of fish than a non-cooperative solution in which the countries maximize their individual utilities. Mirman and Levhari (1980) conclude that, while the Cournot-Nash equilibrium leads to greater consumption of fish and a resulting smaller fish population, tending towards extinction, the cooperative solution decreases consumption and produces a larger population, tending towards infinity (Mirman and Levhari, 1980).

Although the model is a simplification of reality, it suggests that fishery members can mitigate the problem of decreasing fish stocks if they can coordinate their fishing activities. If coordination can be achieved, successful collective management schemes are possible.

Building on the work of Mirman and Levhari (1980), Denisova and Garnaev (2008) extend the model to include *n* number of states, and conclude, similarly, that the cooperative approach yields a larger steady-state level of fish than the non-cooperative approach. While the cooperative approach will result in a relatively larger fish population, full coordination is difficult to achieve. Coalitions of more than two member states tend to break down. Kwon (2006) considers a situation of multiple fishing states achieving partial coordination—a portion of the states engage in some form of coordination. Although the partial coordination solution produces a larger steady-state fish population than no coordination, the coordinating coalition members, who internalize a significant share of the externality amongst themselves, can only sustain the coalition "in limited cases" (Kwon, 2006). All of the aforementioned Cournot-Nash equilibria studies show that no-coordination is Pareto-dominated by full coordination (Kwon, 2006). Yet coordination is the exception, not the norm, illustrating the difficulty of sustaining coalitions.

Numerical Example of the Mirman-Levhari Model

Using the Mirman and Levhari model I developed numerical examples of fishing activity among two states, illustrating the fish stock and fish catch outcomes under both cooperative and non-cooperative solutions. To create this model I applied the Mirman and Levhari equations to hypothetical parameters. The outcomes of these numerical examples follow the behavior and predictions of the original model.

The steady state level of fish is set at 1,000,000 and the initial level of fish at 200,000 (see Figures 11-13 in the Appendix). These numbers are arbitrary, but the manner in which they change given different conditions is significant. The fish population changes according to the aforementioned equation $(X_t - c_1 - c_2)^{\alpha}$, where the fish stock in the next period (X_{t+1}) is determined by the fish stock in the present period (X_t) minus the consumption of state 1 and state 2 (c_1, c_2), and raised to the rate of growth (α)—loose approximation of the reproduction rate. Because the population is normalized at 1 and alpha is between zero and one, smaller alphas represent faster growth rates and larger alphas represent slower growth rates. The growth rate alpha from Mirman and Levhari (1980) is a simplification, where rates below .5 represent incredibly quick reproduction—perhaps microbes. My examples use three different rates of growth, .6, .7 and .9, where .6 could represent fish that reproduce much faster and .9 could represent fish that reproduce much slower (see Figures 11-13 in the Appendix).

Under the non-cooperative solution the levels of consumption for each state are determined by the best response functions (see Figure 9 in the Appendix) and given by the equations,

$c_1 = \alpha\beta_2(1 - \alpha\beta_1)x / 1 - (1 - \alpha\beta_1)(1 - \alpha\beta_2)$ and $c_2 = \alpha\beta_1(1 - \alpha\beta_2)x / 1 - (1 - \alpha\beta_1)(1 - \alpha\beta_2)$

where the discount rates represented by β_1 and β_2 are assumed to be equal. Under the cooperative solution the states jointly maximize their utility, which is represented by the equation $c_j = x(1 - \alpha\beta_1) / 2$, where c_j is the level of consumption by each state. In Figures 11-13 in the Appendix, the joint catch is listed as the combined catch of both states under the cooperative solution, and, under the non-cooperative solution, the catch of each state is listed. The states are identical and thus consume equal amounts in each case.

As predicted by Mirman and Levhari (1980), the eventual steady states under the cooperative solutions are greater than those of the non-cooperative solutions. With the fastest growth rate, .6, the fish population actually increases for both cases, but the cooperative solution results in a larger steady state fish stock and catch level for each state than the non-cooperative solution. When alpha equals .7 or .8 (only .7 is depicted in Appendix), the steady state catch and stock levels decrease for the non-cooperative case but increase for the cooperative case. When alpha equals .9, the catch and stock levels decrease for both cases, but the fish decline under the non-cooperative solution is much greater, nearing zero.

Across all levels of fish growth, in the earlier periods, the states consume more fish when they do not cooperate. This shortsighted behavior diminishes the population earlier producing lower eventual steady state populations. Thus, by not overexploiting the fish populations, the cooperating states exhibit behavior that results in greater fish populations and greater fish harvests. Under cooperation, the fish population only declines with the slowest growth rate, while under non-cooperation, the fish population only increases with the fastest growth rate.

The results suggest that gains from cooperation are greatest when the underlying fish stock does not reproduce at a fast rate. In these situations, overexploitation will quickly diminish the resource and lead to depletion. These results are reflected in international agreements that protect slow growing species—international law has more sensitive provisions for whales in part because their population takes a long time to regenerate itself if it has been diminished by an exogenous force, whaling. In my examples, for simplicity, the discount rate is constant. At greater discount rates, there will be greater catch levels, as present consumption is preferred to future consumption. The implications for fishing agreements are that states that do not have a stake in the long-term health of the fishery will exhibit shortsighted behavior, overexploiting the resource because they greatly prefer present consumption (see RFMO member opting out on page 27).

Having presented theoretical examples of fishing consumption activities and the effect on fish population, the thesis turns next to an empirical study of different management schemes. RFMOs will be studied to see which cooperative approach more closely approximates the situation of collective management schemes. After concluding that RFMOs suffer from free riding problems and overexploitation of fishery resources, another scheme, ITQs, will be evaluated.

Regional Fishery Management Organizations

As a method of collective resource management, RFMOs seek to set fishing guidelines that ensure sustainable fishing practices and conserve fish populations. Though RFMOs are independent organizations and many predate the 1982 United Nations Convention on the Law of the Sea (UNCLOS), they largely operate within the framework provided by UNCLOS. Considered the most broad international agreement relating to the management of oceans, the purpose of UNCLOS is to "delineate jurisdictional zones within the ocean, set rules for navigation, provide guidelines to conserve and manage living marine resources and the marine environment, clarify rules for deep seabed mining, and establish mechanisms for resolving disputes among parties" (Devaney, 2005, 2). Among other measures, the original agreement established Exclusive Economic Zones (EEZs), giving coastal nations the sole right to govern waters within 200 miles of their shore. While providing an outline for ocean management within those zones, it did not address the issue of the high seas, international waters beyond 200 miles of the coast. An extension of UNCLOS, the 1995 UN Fish Stocks Agreement, addresses high seas issues and defines a role for Regional Fishing Bodies (RFBs)—a broad term for organizations that manage and study oceans, one of which is an RFMO. Of the three main types of RFBs, including advisory boards and scientific bodies, RFMOs hold the most power to actively engage in resource management. However, their effectiveness is often hindered by their general structure and the nature of the resource they seek to manage (Devaney, 2005; Pauly and Cullis-Suzuki, 2010).

Since the mid-twentieth century, improved technology has allowed greater exploitation of the high seas. In 2003, high seas fisheries accounted for 15 percent of the global marine catch, increasing from 9 percent in 1950. More than ten million tons of fish were harvested from the high seas in 2006, while, in 1950, less than 2 million were harvested. Because 60 percent of ocean territory lies outside EEZs, RFMOs are expected to play a big role in governing the high seas. Common duties of RFMOs are providing fishery statistics and evaluations, setting total allowable catch (TAC) limits and vessel entry limits, determining gear restrictions and seasonal closure times, conducting general scientific research, and monitoring and enforcing compliance with rules. Within their jurisdictional zones (see Figures 14-16 in the Appendix), RFMOs are tasked with carrying out those duties to varying degrees. There are 44 RFBs, 18 of which are RFMOs. Each body maintains independence, setting own guidelines, yet some have overlapping territory (see Figures 14-16 in the Appendix). In some instances, different organizations are performing the same role in a given fishery, managing the same group of fish. Inconsistency, complexity, and lack of centralization are some of the issues that plague the RFBs generally and RFMOs in particular (Devaney, 2005; Pauly and Cullis-Suzuki, 2010; Willock and Lack, 2006).

Problems with Regional Fishery Management Organizations

Along with structural problems, there are various problems inherent in the current collective fishery management system that affect RFMOs in their ability to effectively promote sustainable fishing practices. As the tragedy of the commons argument predicts, free riding is rampant in many collectively managed fisheries. Countries can enter or exit an RFMO freely. If a fishery is depleted, countries may not join initially. After the fishery has been rebuilt through effort restriction by RFMO participants, new countries can begin to participate in the RFMO and reap the benefits of the recovered fishery without bearing any of the costs. Often distant water fishing nations (DWFN)—landlocked countries without direct access to oceans—will not be willing engage in collective management schemes until the cost of doing so is low. They have no incentive to behave otherwise. The problem of new entrants is prevalent and RFMOs struggle to accommodate current participants and countries seeking to participate. Moreover, among participating nations, there can be free riding when some are adhering to rules and others are not. When the benefits of non-compliance are high relative to costs, free riding among participants increases and it is more difficult to enforce the rules of the fishery (Devaney, 2005).

Another issue with free entry and exit to the fishery is opting out. Regional Fishery Management Organizations are non-binding agreements and countries can choose to leave if they are dissatisfied. For a country that does not wish to bear the associated costs, the benefits of leaving are high because only signatory countries are responsible for adhering to the RFMOs rules: countries can leave the organization and continue fishing, often in a destructive, unsustainable manner. Regional Fisheries Management Organizations can only manage those countries that voluntarily agree to operate within their guidelines. When countries opt out a greater burden is placed on the remaining participants and the RFMO cannot manage the fishery as effectively, as more countries are not engaging in sustainable fishing practices. Moreover, if a country plans to opt out in the future, it will have no incentive to restrict effort presently. The ease with which countries can opt out of an RMFO agreement reflects the difficulty of sustaining meaningful coalitions (Devaney, 2005).

An extension of free riding and opting out, one of the most serious issues in international fisheries, is illegal, unreported, and unregulated (IUU) fishing. IUU fishing can be defined as “any fishing that takes place within the jurisdiction of the RFMO, but does not comply with the regulations put forth by the organization” (Devaney, 2005, 6). The most recent (2010) UN FAO SOFIA report described IUU fishing as one of the most dangerous practices threatening high seas fisheries. Two primary types of IUU fishing are “non-participatory states” and “flags of convenience.” The benefits of not bearing the costs of RFMO participation—not purchasing a license or complying with general rules—but continuing fishing activity are large. Thus, many states fish unregulated, remaining noncompliant. Fishers of participating states engage in IUU fishing when they fly the flag of a non-member to avoid RFMO rules. As of 2005, more than 1000 large-scale fishing vessels were flying flags of convenience, despite an international effort to curb this practice. As with the non-participatory example, there are large benefits to flags of convenience IUU fishing, and these two types of free riding pose serious problems for collective management organizations (Devaney, 2005; FAO, 2010; Gianni and Simpson, 2005).

Ultimately, the effectiveness of RFMOs depends on the sacrifices that member states are willing to make by bearing the costs of restricting effort and enforcing rules. Members of more advanced RFMOs install vehicle monitoring systems, pay on-board observers and establish catch documentation schemes (CDS). While these make illegal fishing among signatory states more difficult, they also increase the costs of participation. Greater participation costs make free riding more beneficial, which fundamentally undermines the goal of RFMOs. To be successful, RFMOs would have to provide IUU fishers the incentive to join the RFMO or otherwise adhere to its regulations, and disincentivize shirking among current members.

Evaluation of Regional Fishery Management Organizations

Evaluating the performance of RFMOs, Pauly and Cullis-Suzuki (2010) take a "two-tiered approach" measuring how well the organizations are expected to perform in theory and how well they actually manage fisheries in practice. The former examines the standards RFMOs impose and the latter studies biomass figures of managed fish stocks over time. The organizations score poorly in both evaluations, averaging a 57 percent theory score and a 49 percent practice score—zero being the worst performance and 100 being perfect (Pauly and Cullis-Suzuki, 2010).

The theory evaluation analyzes the structure and practices of RFMOs and compares them against the "Recommended Best Practices for Regional Fisheries Management Organizations" report. The report identifies 26 components of a successful RFMO—including monitoring and enforcement penalties for non-compliance, access control, catch limits, and research programs. Organizations were scored for each component and then given an overall score combining the 26 parts. Eighteen RFMOs were studied, the lowest scoring 43 percent (Pacific Salmon Commission (PCS)) and the highest at 74 percent (Western and Central Pacific Fisheries Commission (WCPFC)). While the average score for all RFMOs is low, they did score high in the "General Information and Organization" category, averaging 70 percent, representing efficient documentation and gathering of statistics. Although this is an important role, it does not address more critical issues or translate to accomplishment of the primary goal, to promote sustainable fishing practices. The lowest average category was "Allocation," at 43 percent, reflecting the problems posed by new entrants. Regional Fisheries Management Organizations lack a definitive system for accepting or rejecting new members and for ensuring that members contribute equitably. Under these circumstances, RFMOs struggle in accommodating new and current members. The score with highest variation was "preventing IUU fishing." Across RFMOs there is no consistent set of preventative measures to combat this practice. The theory evaluation represents how RFMOs should perform based on their guidelines and mandates (Lodge et al., 2007; Pauly and Cullis-Suzuki, 2010).

The practice evaluation assesses 48 fish stocks of 14 RFMOs. In determining scores, two ratios were analyzed, F/F_{MSY} and B/B_{MSY}, where F and B represent the fish mortality rate and current biomass, respectively, and where F_{MSY} and B_{MSY} are the mortality rate and biomass level that achieve the maximum sustainable yield (MSY). The MSY represents the largest catch that can be withdrawn from the fishery while allowing the fish to sustainably reproduce so that their population does not become depleted. An optimally managed fishery will yield ratio values near 1. If $F/F_{MSY} > 1$, the fishery is overfished. If $B/B_{MSY} < 1$, the fishery is depleted. The lowest scores are ratios representing overfished, depleted fisheries, and the highest are underfished, healthy fisheries. Middling scores were overfished but not depleted, or vice versa, fisheries—a fishery could be depleted but under good management and nearing recovery or not depleted but overfished with diminishing stocks. Along with the two ratios, a time series of the abundance (biomass) of the primary RFMO fish stocks was gathered. The primary stocks are those with the largest catch. For most RFMOs, fish stock abundance fluctuated annually but trended downward over time. The mortality ratio, biomass ratio, and abundance time series data were computed to yield a final score, represented by a percentage, with 100 percent being the highest (Pauly and Cullis-Suzuki, 2010).

All RFMOs averaged low scores, with CCSBT scoring the lowest, 0 percent, and CCAMLR the highest, 67 percent. Thirty-two of the 48 stocks studied were either depleted or being overfished. Over time, the general trend of RFMO managed fish stocks was decline. While the theory scores are low, the lower practice scores highlight the difficulty RFMOs have in implementing their management plans and enforcing rules. These figures indicate that RFMOs are not promoting sustainable fishing practices.

Of the two evaluations, the most significant is the state of fish stocks: Two thirds of fish stocks under RFMO management are either depleted or overexploited. The 2010 SOFIA report estimates that 32 percent of global marine fish stocks are either depleted or overexploited. The significantly higher value for those stocks under RFMO management may in part reflect their role in seeking to protect endangered stocks, but, nonetheless, represents a failure in accomplishing that goal.

Individual Transferable Quotas

The key issue undermining the success of RFMOs is free riding. For these organizations to be successful in managing fish stocks members must be willing to make sacrifices and non-members must be excluded or enticed to join. However, rather than bear the costs of participation, states—particularly developing countries—choose to engage in IUU fishing, or, if current members are dissatisfied, they can freely leave because most agreements are non-binding. Among participants, free riding occurs in the form of flags of convenience. In collectively managed fisheries fishers are prone to free riding behavior that produces a negative externality of overfished or depleted fish stocks. By changing fisher behavior through incentive structure, ITQ schemes effectively address the issue of free riding among members. This leads to a substantial internalization of the negative externality and promotes more sustainable fishing practices. Enforcement issues for non-members can still exist under ITQ schemes, but, due to smaller scale and well defined jurisdiction in EEZs and due to quota fees that help pay for enforcement, the issue of enforcement in ITQs is reduced. Disregarding scale and jurisdiction, by assessing fees for quotas ITQs partially alleviate free riding among non-members by improving enforcement. Thus, adapting ITQ measures to RFMOs could likely improve fishery management by significantly decreasing participant free riding (flags of convenience) and, potentially, modestly decreasing non-participant free riding (non-participatory states).

Individual Transferable Quotas in Iceland

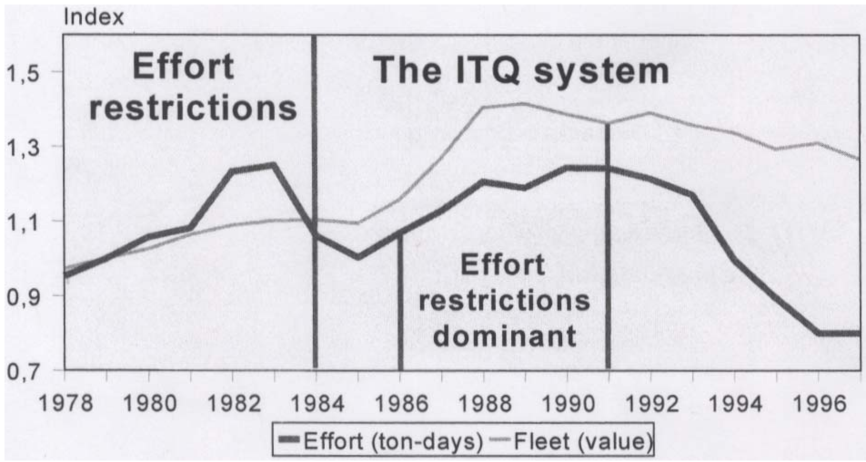
Iceland was one of the first countries to institute an ITQ management scheme and has an extensive history of fishery management, providing a comprehensive view and understanding of the ITQ system. In the mid-1970s the first ITQ systems were established for certain fish species in Icelandic territorial waters. While these first programs had success, they were separate entities providing only for individual species. In 1990, comprehensive legislation was passed establishing a consistent ITQ system for all fish. Today Iceland operates one of the most sophisticated ITQ management schemes. Under this system a national total allowable catch (TAC) is determined by the Marine Research Institute based on scientific advice and instituted by the Ministry of Fisheries. The TAC represents the amount of fish that can be caught within Iceland in a given year. This amount cannot be exceeded, serving to control the annual fish catch level. Shares of the TAC are allocated to individual fishing vessels for each species of fish, and the shares can be divided and traded. Finally, access to the fishery is restricted to vessels with valid fishing licenses, and, to help pay for monitoring and enforcement, there are fees associated with quota ownership (Arnason, 1993; Ministry of Fisheries and Agriculture, 2011).

The TAC and tradeable quotas reduce uncertainty and set limits, which allow fishers to plan ahead and fish sustainably. A fisher may expend their allocated quota within the first three months of the fishing year. If that fisher decides it is beneficial to continue fishing he can purchase additional shares at their market price. Likewise, fishers not exhausting their quotas can sell the remainder. Allowing quota trading helps to allocate resources efficiently—those who have the capacity to catch more fish and greater demand for quotas can purchase them from others. Information about species stock levels and catch levels are posted on a regular basis. This helps fishers plan their outings, reducing the number of more dangerous voyages and preventing overfishing. Central to the ITQ system, the establishment of property rights helps avoid rule of capture mentality—striving to capture more fish than competitors in the short term because ownership does not exist until fish are caught—and allows fishers to plan how and when to utilize their quotas, through personal use or compensation for non-use. The price of the quotas represents the market value of fishing and internalizes among individual users the costs of fishing activity. This changes the incentives that fishers face and leads to more sustainable fishing practices. As the tragedy of the commons argues, the key to preventing destruction of a common resource is changing the behavior of users (Arnason, 1993; The Economist, 2008; Ministry of Fisheries and Agriculture, 2011).

Along with the catch limit, other measures help support sustainable fishing and the health of the fishery. Bycatch—other fish that the fisher does not intend to catch and are often of little value—cannot be discarded but must be counted as part of the vessel's quota. If the Ministry of Fisheries believes that overfishing is occurring in a certain area it can shut down the fishery, suspending further activity until it is deemed safe to fish again. Deep sea trawling is limited—the trawl limit is set at 12 miles—and during spawning season certain sections of the fishery are closed. Certain measures are in place to protect particularly high value and fragile fish stocks: the TAC for cod is only 20 percent of fishable biomass. Additionally, the catch of cod fish, and some other fish species, is limited by size. To avoid fishing a high proportion of the younger fish, only 10 percent of the cod catch can be less than 50 cm. Many of these measures are instituted in RFMOs. Rather than entirely replace the management guidelines that predated the Icelandic ITQ scheme, the old rules were integrated into the new system. These measures complement the general quota system and promote fishery sustainability. It is worth pointing out that while both RFMO and ITQ systems have the same intent, the fundamental difference between the two lies in the incentives for individual fishers. Changing individual incentives through property rights establishment reduces member free riding and assessing fees for quotas can improve enforcement for non-members (Arnason, 1993; The Economist, 2008; Ministry of Fisheries and Agriculture, 2011).

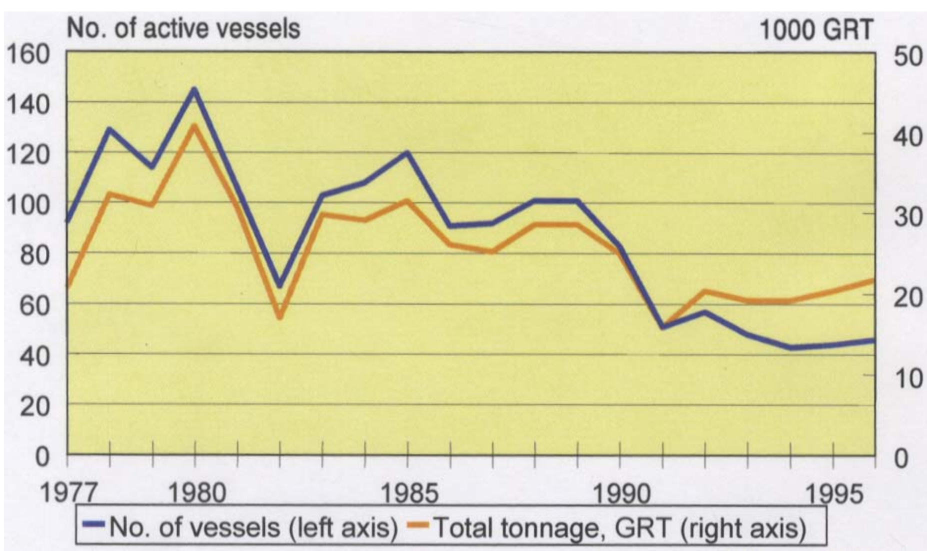
In a descriptive account of Iceland's ITQ system, Arnason (1993) documents the system and evaluates its efficiency between 1983 and 1992. The conclusions are that during that time period the ITQ system was largely efficient, aside from periods in which it was managed unsuccessfully. Introduction of the ITQ system brought large efficiency increases in the herring and capelin industries, reducing fleet and catch levels. In 1984, the introduction of the system in Demersal fishery brought about a decrease in fishing capital and effort, reducing catch. Between 1986 and 1990 effort and capital levels temporarily rebounded before decreasing again when the system was improved upon in 1990 (see Figure 2 below). The results of the Demersal fishery reflects the broad usage of the ITQ system between 1985 and 1990 when the "managing system was only partially an individual quota system" (Arnason, 218, 1993). Improvements to the system with the passage of the Fisheries Management Act are reflected in reduced catch levels. In a later study, Arnason (2002) shows that these improvements continue through 1995. Moreover, under the ITQ system, while reducing the fleet and catch level, the unit catch per fishing fleet increased (see Figure 3 and Figure 4 below) (Arnason, 1993; Arnason, 2002).

Figure 2: Icelandic Fishery 1
Evolution of Demersal Fishing Fleet and Effort



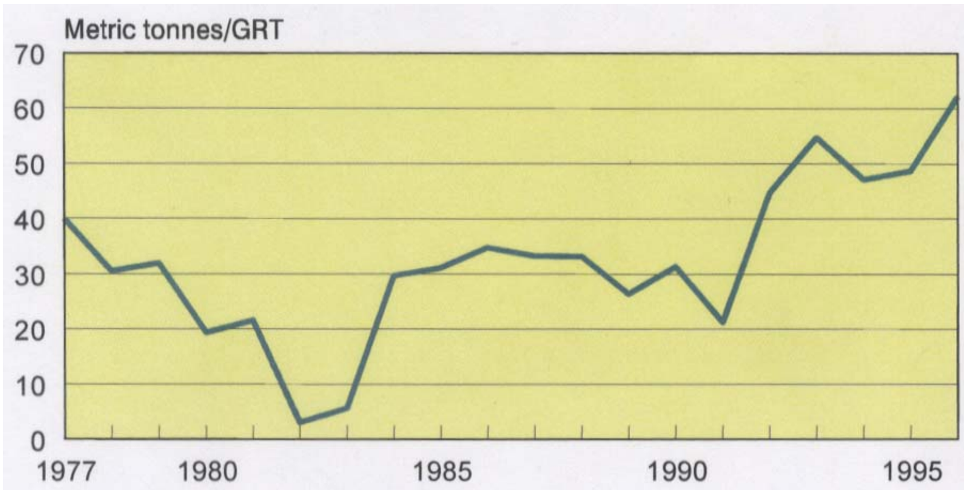
Source: (Arnason, 2002)

Figure 3: Icelandic Fishery 2
Maximum Number of Active Vessels in Pelagic Fishery in Any Month



Source: (Arnason, 2002) GRT=Gross Registered tonne

Figure 4: Icelandic Fishery 3
Catch Per Unit of Fishing Fleet



Source: (Arnason, 2002) GRT=Gross Registered tonne

The initial conclusion of this thesis is that ITQ schemes more effectively manage fishery resources than RFMOs by internalizing the negative externality of overfishing associated with collectively managed fisheries. Individual Transferable Quotas effectively address member free riding and modestly improve enforcement against non-members. By instituting a quota system that effectively accounts for the costs of fishing activity, ITQs change the incentives that fishers face and promote sustainable fishing practices among members that are more ecologically and economically efficient. However, ITQ systems are currently only being instituted domestically, and, while free riding by members of ITQs is reduced, free riding among non-members can still exist. Individual Transferable Quotas have only been in EEZs, but they have the potential to be adapted to the RFMO structure. Allowing quotas to be traded among RFMO participants would be one way to adapt an ITQ scheme to a multi-state framework. While this would reduce member free riding, enforcing compliance among non-members could still pose a problem. These issues will be explored in the consideration of the North East Atlantic Fisheries Commission.

Adapting ITQs to RFMOs: The North East Atlantic Fisheries Commission

Adapting Individual Transferable Quota schemes to RFMOs could improve high seas fishery management. A central role of RFMOs is determining a TAC, and, in the case of more progressive RFMOs, allocating shares of the TAC to participating nations. Unlike ITQs, the portions of the TAC are not a designation of property rights. They are not divisible and cannot be traded. Rather, they serve as a TAC for each participating state, as part of the total RFMO TAC. Within the RFMO framework, establishing tradable quotas could improve fishery management by producing the favorable aspects of ITQ schemes, altered participant incentives and potential revenue for greater enforcement.

The North East Atlantic Fisheries Commission (NEAFC) is one of the most successful RFMOs, described as "best practice" fishery management. Pauly and Cullis-Suzuki (2010) gave the NEAFC a 63 percent theory score and a 73 percent practice score, which were fifth and fourth best respectively. These scores are particularly high considering the amount of fish the NEAFC manages and the number of boats that frequent its jurisdiction. Fishing is a fundamental, historic industry for most of the NEAFC participating nations. While the NEAFC represents one of the more effective RFMOs, problems with fish stock management persist. The four primary fish stocks are pelagic redfish, Atlanto-Scandian herring, blue whiting, and the Northeast Atlantic mackerel, of which three have been overexploited at different periods since the 1990s. The blue whiting has been overexploited to the greatest extent, with actual fish landings far above TAC levels every year between 1997 and 2004 (Bjørndal, 2008; Pauly and Cullis-Suzuki, 2010).

Members of the NEAFC are Iceland, Norway, the Faroe Islands, Denmark, Russia, the EU and, informally, the United Kingdom. For certain fish species the NEAFC allocates shares of the TAC to each state. Iceland, the Faroe Islands, and Denmark operate ITQs within their EEZs. Norway and the United Kingdom operate Individual non-transferable Quotas that essentially function as quota systems—vessels must be traded to transfer the quotas. Russia does not operate an ITQ system, but, under a bilateral agreement with Norway, purchases quota shares of the Norwegian EEZ TAC. NEAFC (2010) suggests that increased international cooperation by further allowing EEZ quotas to be tradable among nations would increase efficiency and "socio-economic return" (Bjørndal, 2008, NEAFC, 2010).

Given that the NEAFC states are allocated shares of the high seas' TAC and that most participants operate ITQs within their EEZs, the NEAFC could adopt ITQ measures by allowing states to reallocate portions of the high seas' TAC, creating divisible, tradable quotas. For each state, quotas could be allocated to vessels that participate in the EZZ fishery, which would extend ITQ management techniques to the RFMO jurisdiction. While maintaining and building upon the current management procedures, implementing a quota system in international waters could reduce free riding among participants. Reducing barriers in how the quotas were traded would further improve efficiency. As in domestic ITQ systems, assessing quotas fees could generate revenue for enforcement, but free riding among non-participants would still pose an issue considering the larger scale.

Market-Based Management Schemes: Quota or Tax

While ITQs prove to be effective domestically and have the potential to be adapted to certain RFMOs—those relatively successful at establishing TAC levels and allocating portions—another similar market-based management scheme may avoid some of the issues that can arise in the ITQ systems. Theoretically, a tax and a quota management system operate identically in correcting the externality associated with fishing activity. However, the implementation of ITQs has highlighted certain issues that possibly would not exist under a purely fee-based system.

Under an ITQ system, the initial allocation of quotas can be problematic. In Iceland, when the system was broadly introduced in 1983, established fishing vessels were granted primary rights to the quotas without charge, and those vessels retained their quotas each year. Although legislation in 1990 made the quotas tradable, their value had increased substantially, favoring those vessels to which quotas were initially granted. Quotas could potentially be allocated by lottery, auction or granted (Iceland), and each method of allocation benefits a particular constituency. Palsson and Helgason (1995) argue that there is inequitable distribution of quotas in the Icelandic ITQ system, favoring large commercial interests and the initial grantees. The NEAFC also has issues with allocation, as member states have difficulty in compromising and determining portions for each state. A tax-based management scheme could avoid the allocation problem inherent in ITQ systems. Rather than control fish catch through the allocation of quotas, a tax-based system would assess a fee to the fish catch of each vessel, thereby using price as the controlling factor. The fish catch would be monitored through port controls—port authorities that inspect incoming boats—and on-board monitoring personnel, both of which have partially been established in the NEAFC. If the fee assessed for fishing was set correctly, it would operate in the same manner as a quota (Palsson and Helgason, 1995).

Determination of the TAC is another issue with the ITQ system and RFMOs. Fish stocks are highly uncertain from year to year, and, because the TAC is based on fishery population, this uncertainty can undermine the quota market and disrupt fishing activity. Weitzman (2002) assumes that ITQ managers determine their TAC limit based on imperfect information, and that, after the TAC has been set, quotas have been allocated, and the fishing year has commenced, the true fish population is subject to change. Due to the uncertainty of fish stocks, this is a realistic assumption. If the TAC is set too high—the managers misjudge the nature of fishery population and there are less fish than expected—then overfishing can occur within the ITQ system. A miscalculated TAC would worsen the situation of RFMOs. Because of the "ecological uncertainty" inherent in fisheries, Weitzman (2002) argues that a tax is preferable to a quota.

The quota system manages the fishery by directly controlling the quantity of fish that can be extracted, but, as the TAC is set prior to knowledge of the true fish population, it is an "informationally inflexible" system that does not account for differences between the estimated fish population and realized fish population. On the other hand, the price system is informationally flexible but cannot directly control the amount of fish that will be extracted in a given period. Rather, the fee assessed per unit catch would control marginal fisher effort. Because the fee can change subject to fishery population developments, increasing if the population is smaller, it can effectively manage the fishery while avoiding the uncertainty issue inherent in the ITQ system. However, no purely fee-based systems have been implemented in EEZs.

Conclusion

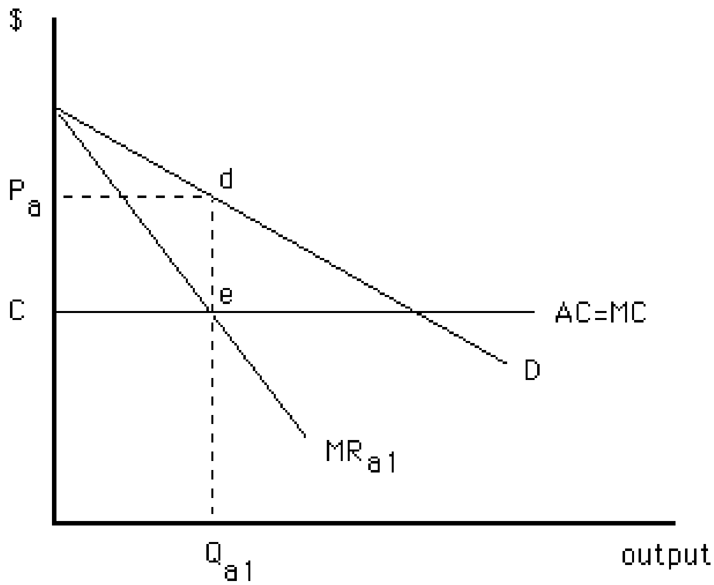
Regional Fishery Management Organizations have a poor record of managing fish stocks on the high seas and promoting sustainable fishing practices. Under collectively managed fisheries, because fishers do not bear all of the costs associated with fishing activity, they overfish. Moreover, the costs of participating in RFMOs are high, the coalitions are difficult to sustain and free riding is prevalent. By internalizing the negative externality of overfishing associated with collectively managed fisheries, ITQ schemes more effectively manage fishery resources than RFMOs. Through the institution of a quota system that effectively accounts for the costs of fishing activity, ITQs change the incentives that fishers face and promote sustainable fishing practices among members that are more ecologically and economically efficient. By improving enforcement with quota revenues, ITQs can lead to modest reductions in non-member free riding.

Differences in scale and jurisdiction exist between ITQs and RFMOs. Individual Transferable Quotas govern EEZs and RFMOs are used to manage international waters. Despite differences, adapting ITQ measures to RFMOs by establishing tradable quotas could improve fishery management by altering the incentives RFMO members face. While the adoption of ITQ measures could effectively reduce member free riding, it would only minimally reduce free riding among non-members, if at all, because enforcement issues are still present in domestic ITQs and would be exacerbated at a greater scale. Nonetheless, by creating more well-defined property rights the shift towards ITQ management by RFMOs would help promote more sustainable fishing practices. As fish production on the high seas continues to grow, international fishery management will become a more pressing issue. The success of the NEAFC and its coordinating members suggests that ITQ measures can improve upon, and possibly supplant, RFMOs as managing bodies for international waters.

Issues requiring further discussion are quota allocation, ecological uncertainty, and the potential role of landing fees in fishery management. A tax system could avoid allocation and TAC determination issues in ITQs by relying on price as a control rather than quantity. Perhaps policy could be implemented that combined quota and tax controls. Ultimately, the manner in which various programs are constructed and implemented will, in part, determine their level of success. The more successful RFMOs can be improved upon by implementing quotas within their TAC. Tax-based fishery management schemes could potentially overcome issues in ITQs, but this form of management lacks the history and empirical data to be effectively compared to either ITQs or RFMOs.

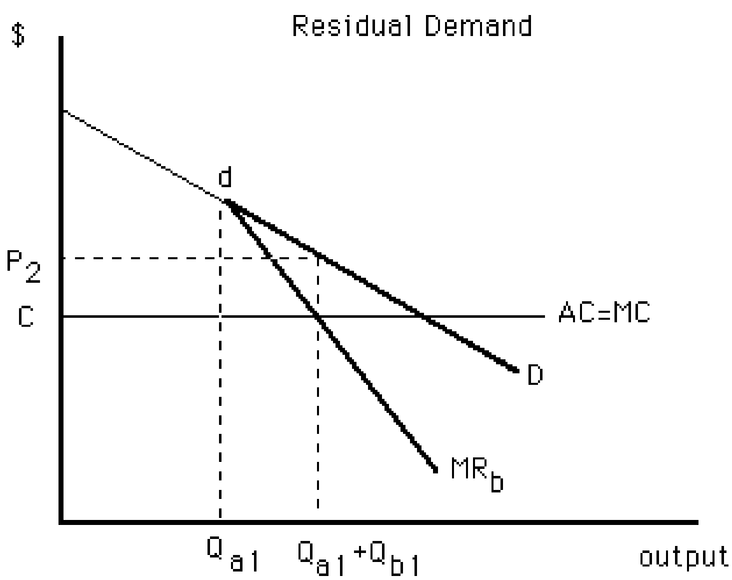
Appendix:

Figure 5: Firm A as a Monopolist



Source: (Rosenman, 1998)

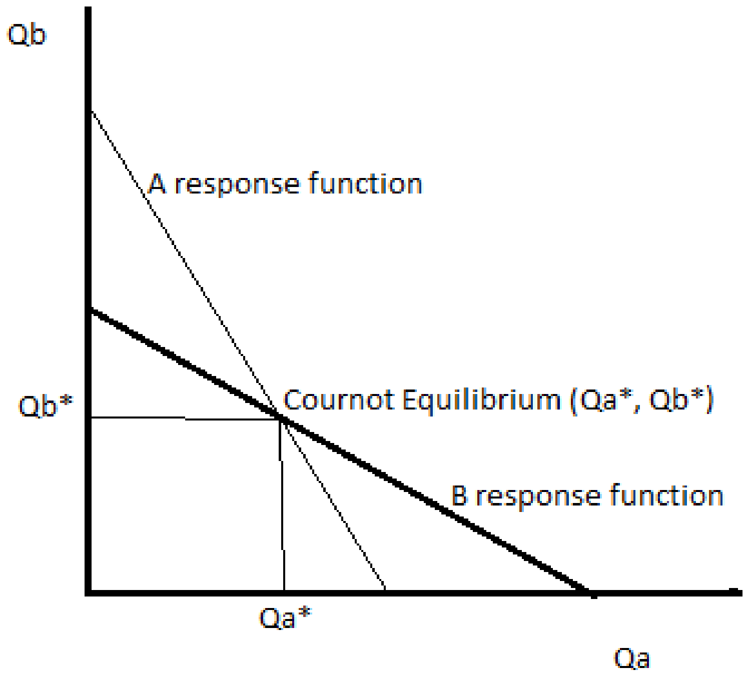
Figure 6: Firm B Enters the Market



I—Q_{b1}—I

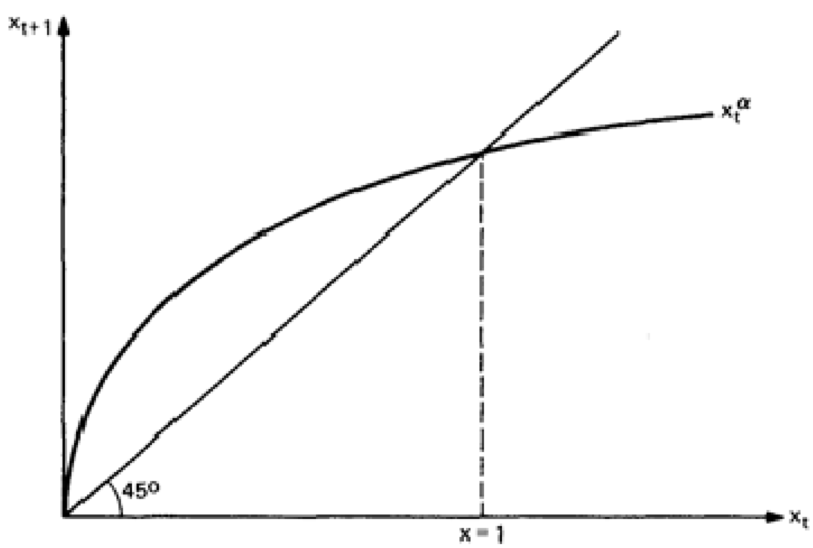
Source: (Rosenman, 1998)

Figure 7: Cournot Equilibrium



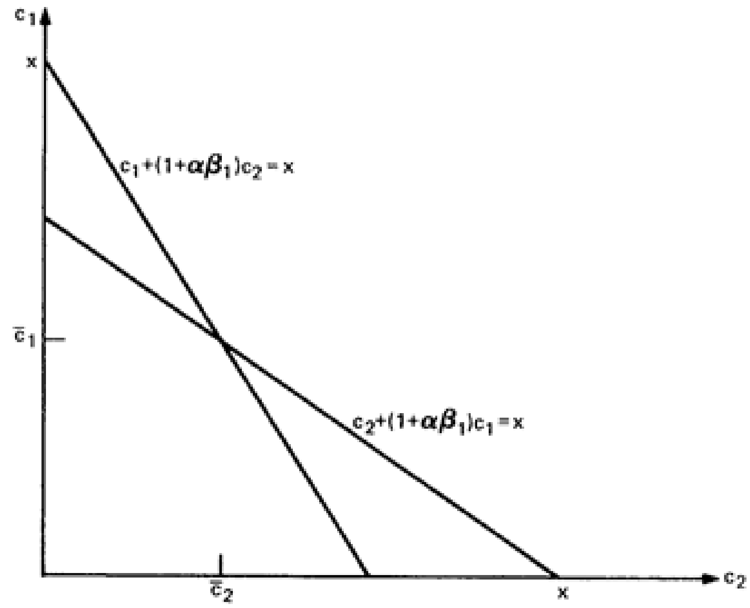
Source: (Rosenman, 1998)

Figure 8: Natural Law of Growth for Fish



X_t=present fish population, X_{t+1}=fish population in next period
Source: (Mirman and Levhari, 1980)

Figure 9: Cournot-Nash Equilibrium



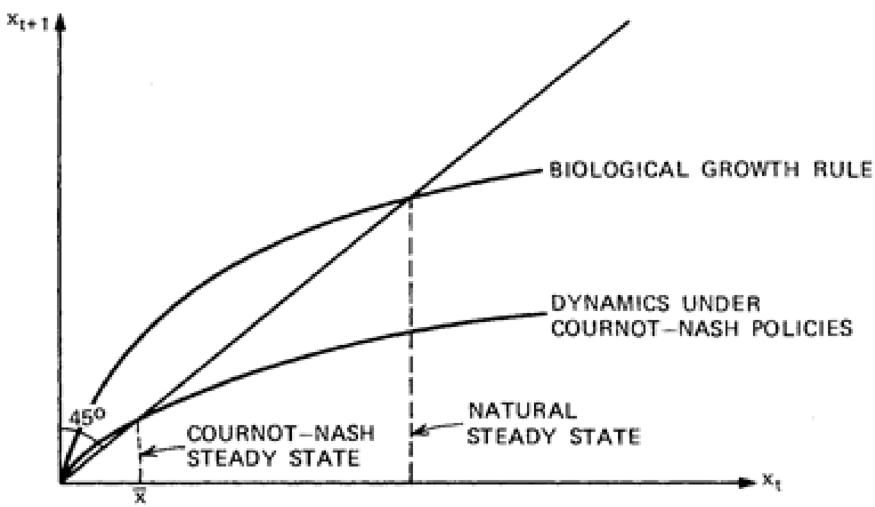
C1 and C2 are consumption for countries 1 and 2

$(1 + \alpha\beta_1)c_1 + c_2 = x$ country 1 response function

$c_1 + (1 + \alpha\beta_2)c_2 = x$ country 2 response function

Source: (Mirman and Levhari, 1980)

Figure 10: Cournot-Nash Dynamics



Source: (Mirman and Levhari, 1980)

Figure 11: Numerical Example for Two State Non-Cooperative and Cooperative Fish Catch and Fish Stock Levels Using Mirman-Levhari Model (a)

Steady State Level	Alpha (Fish Growth Rate)	Initial Fish Stock			Beta State 1, 2		
1000000	0.6	200000			0.9		
Period	Fish Stock Non-Coop		State 1 Catch	State 2 Catch		Fish Stock Coop	Joint Catch State 1 and 2
1	200000		63014	63014		200000	92000
2	209625		66046	66046		263060	121007
3	215621		67935	67935		310076	142635
4	219300		69095	69095		342230	157426
5	221538		69800	69800		363100	167026
6	222891		70226	70226		376229	173065
7	223707		70483	70483		384333	176793
8	224199		70638	70638		389279	179068
9	224494		70731	70731		392277	180447
10	224671		70787	70787		394087	181280
11	224777		70820	70820		395177	181781
12	224841		70840	70840		395832	182083
13	224880		70853	70853		396226	182264
14	224903		70860	70860		396462	182373
15	224917		70864	70864		396604	182438
16	224925		70867	70867		396690	182477
17	224930		70868	70868		396741	182501
18	224933		70869	70869		396771	182515
19	224935		70870	70870		396790	182523
20	224936		70870	70870		396801	182528
21	224936		70870	70870		396807	182531
22	224937		70870	70870		396811	182533
23	224937		70871	70871		396814	182534
24	224937		70871	70871		396815	182535
25	224937		70871	70871		396816	182535
26	224937		70871	70871		396817	182536
27	224937		70871	70871		396817	182536
28	224937		70871	70871		396817	182536
29	224937		70871	70871		396817	182536
30	224937		70871	70871		396817	182536

Source: (Mirman and Levhari, 1980) Beta=1/1+discount rate

Figure 12: Numerical Example for Two State Non-Cooperative and Cooperative Fish Catch and Fish Stock Levels Using Mirman-Levhari Model (b)

Steady State Level	Alpha (Fish Growth Rate)	Initial Fish Stock			Beta State 1, 2		
1000000	0.7	200000			0.9		
Period	Fish Stock Non-Coop		State 1 Catch	State 2 Catch		Fish Stock Coop	Joint Catch for State 1 and 2
1	200000		54015	54015		200000	74000
2	188172		50820	50820		234563	86788
3	180311		48697	48697		262253	97033
4	175005		47264	47264		283558	104917
5	171383		46286	46286		299494	110813
6	168893		45613	45613		311179	115136
7	167172		45149	45149		319628	118263
8	165977		44826	44826		325679	120501
9	165146		44601	44601		329983	122094
10	164566		44445	44445		333029	123221
11	164162		44336	44336		335178	124016
12	163880		44259	44259		336691	124576
13	163682		44206	44206		337754	124969
14	163544		44169	44169		338500	125245
15	163448		44143	44143		339023	125439
16	163380		44125	44125		339390	125574
17	163333		44112	44112		339647	125669
18	163300		44103	44103		339827	125736
19	163276		44097	44097		339953	125783
20	163260		44092	44092		340041	125815
21	163249		44089	44089		340103	125838
22	163241		44087	44087		340146	125854
23	163235		44085	44085		340177	125865
24	163232		44084	44084		340198	125873
25	163229		44084	44084		340213	125879
26	163227		44083	44083		340223	125883
27	163226		44083	44083		340230	125885
28	163225		44083	44083		340235	125887
29	163224		44082	44082		340239	125888
30	163224		44082	44082		340241	125889
31	163223		44082	44082		340243	125890
…	…		…	…		…	…
44	163222		44082	44082		340247	125891
45	163222		44082	44082		340247	125891
46	163222		44082	44082		340247	125891

Source: (Mirman and Levhari, 1980) Beta=1/1+discount rate

Figure 13: Numerical Example for Two State Non-Cooperative and Cooperative Fish Catch and Fish Stock Levels Using Mirman-Levhari Model (c)

Steady State Level	Alpha (Fish Growth Rate)	Initial Fish Stock			Beta State 1, 2		
1000000	0.9	200000			0.9		
Period	Fish Stock Non-Coop		State 1 Catch	State 2 Catch		Fish Stock Coop	Joint Catch for State 1 and 2
1	200000		31933	31933		200000	38000
2	166177		26532	26532		194341	36925
3	140656		22458	22458		189384	35983
4	121056		19328	19328		185032	35156
5	105763		16886	16886		181200	34428
6	93658		14954	14954		177819	33786
7	83952		13404	13404		174830	33218
8	76081		12147	12147		172184	32715
9	69629		11117	11117		169836	32269
10	64292		10265	10265		167750	31873
11	59839		9554	9554		165895	31520
12	56096		8956	8956		164243	31206
13	52928		8451	8451		162770	30926
14	50229		8020	8020		161456	30677
15	47919		7651	7651		160282	30454
16	45930		7333	7333		159233	30254
17	44211		7059	7059		158294	30076
18	42719		6821	6821		157455	29916
19	41420		6613	6613		156703	29774
20	40284		6432	6432		156029	29646
21	39288		6273	6273		155425	29531
22	38413		6133	6133		154884	29428
23	37642		6010	6010		154398	29336
24	36962		5901	5901		153962	29253
25	36360		5805	5805		153571	29178
26	35826		5720	5720		153220	29112
27	35353		5645	5645		152904	29052
28	34932		5577	5577		152621	28998
29	34558		5518	5518		152366	28950
30	34225		5464	5464		152138	28906
…	…		…	…		…	…
110	31365		5008	5008		150095	28518

Source: (Mirman and Levhari, 1980) Beta=1/1+discount rate

Figure 14: Jurisdictional Map of Regional Fishery Management Organizations 1

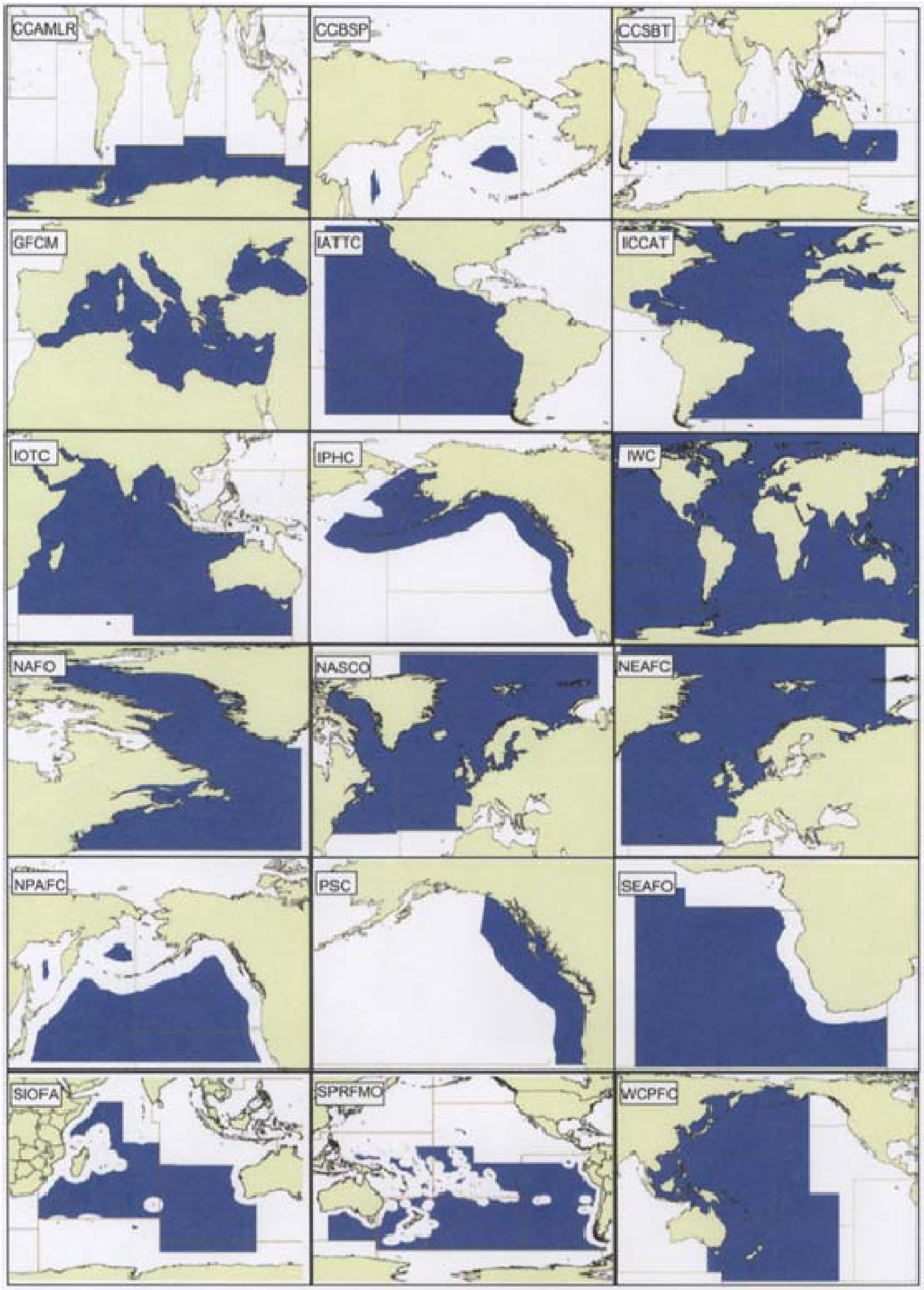
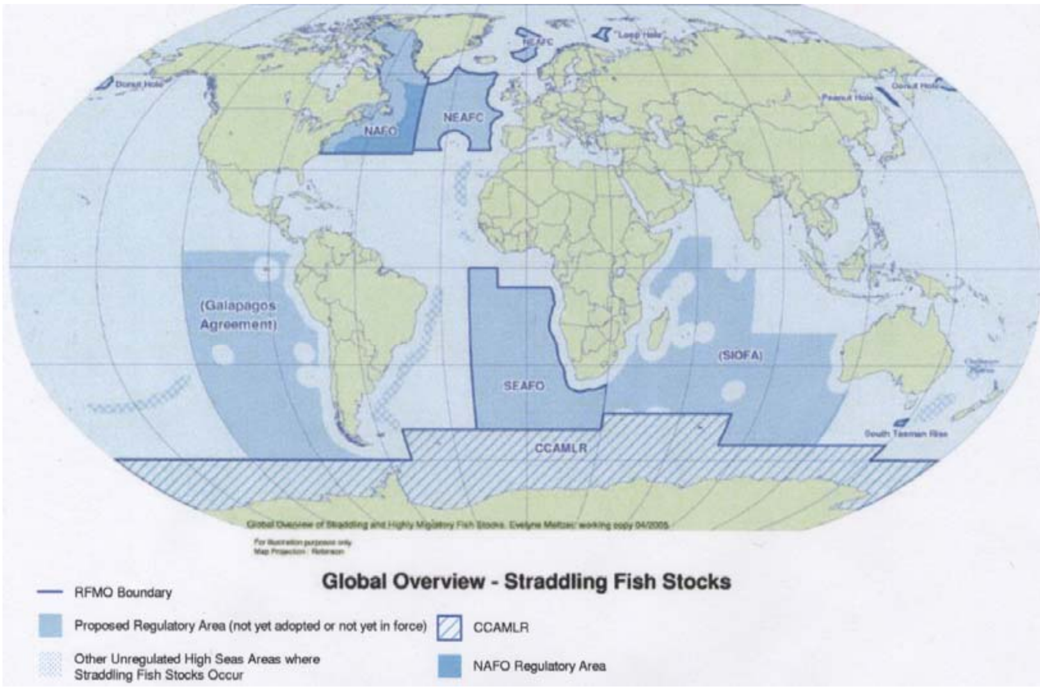


Fig. 1. Global coverage of RFMOs: each box represents the area under management of one of the 18 current RFMOs.

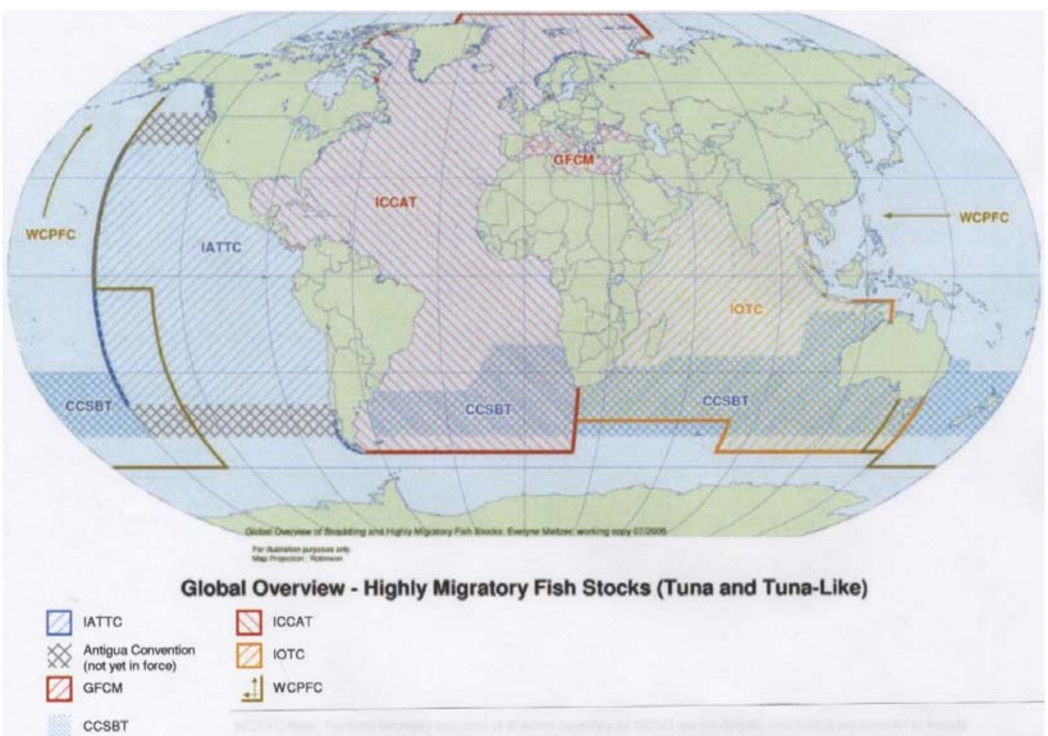
Source: (Pauly and Cullis-Suzuki, 2010)

Figure 15: Jurisdictional Map of Regional Fishery Management Organizations 2



Source: (Lodge et al., 2007)

Figure 16: Jurisdictional Map of Regional Fishery Management Organizations 3



Source: (Lodge et al., 2007)

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EDUCATION

PENNSYLVANIA STATE UNIVERSITY August 2007-May 2011

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- Schreyer Honors College
- Participated in PNC Leadership Assessment Center

Universidad Compultense de Madrid Spring Semester 2010

- Studied in Spain as part of Spanish Minor Program

EXPERIENCE

OFFICE OF UNITED STATES SENATOR JEFF BINGAMAN Summer 2009

Washington, DC

Staff Assistant: *Served as Staff Assistant for six weeks between July and August of 2009*

- Project: To improve efficiency, overhauled previous casework management system by creating a new federal agency hierarchy that was compatible with the new casework management software
- In telephone conversations and letter correspondence, addressed constituent's policy concerns by articulating the Senator's stance in relevant issue areas
- Managed the front office, by greeting and assisting guests and receiving incoming calls

Intern: *Served as one of ten Interns for five weeks between May and June of 2009*

- Researched GDP data of least developed countries, summarized findings using Microsoft Excel, and discussed information with a Legislative Assistant as part of an overarching effort to study the effectiveness of trade preference programs
- Worked as part of a team with other Interns to meet the daily needs of office staff
- Attended staff meetings and committee hearings

SIERRA STUDENT COALITION Fall 2008

State College, PA

Power Vote (*non-profit organization advocating for clean energy solutions)*

Intern: Prior to the 2008 General Election, served as one of seven interns who, in conjunction with and under the guidance of Sierra Club employees, organized a grassroots campaign to mobilize thousands of young voters at Penn State University focusing on the issue of climate change

Outreach:

- Recruited and trained over 200 volunteers
- Planned and managed various events in order to communicate Power Vote message and develop awareness
- As part of a Get-Out-The-Vote campaign, registered over 4,200 voters
- Coordinated efforts with the campus organizations, "Eco-Action" and "Environmental Society"