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A Multilateral Approach to Pelagic-Fishery Decimation

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This study chronicles pelagic-fishery decimation over the past two decades with special emphasis upon the plight of Bluefin Tuna (*Thunnus thynnus*). Environmental economics and game theory provide an apt framework for examining the implications of this phenomenon. Since pelagic fish continually roam the open ocean in search of prey, they cannot be confined to the jurisdiction of any one nation, thereby rendering them inter-national. My methodology incorporates both unilateral and multilateral aspects into a cohesive mathematical-model of resource sustainability. The unilateral element entails the theoretical application of research on externalities and optimal-yield functions, while the multilateral element delineates the emerging need for international agreements and self-enforcing contracts as long-term solutions to the problem.

I. General Overview

As a common-property resource, pelagic fisheries have proven themselves vulnerable to systematic depletion. By definition, pelagic fish live in the open sea (Allen 1953). A pelagic fishery constitutes an impure public-good insofar as it is rival but non-excludable. In "Analyzing Externalities: 'Direct Interaction' vs. 'Asset Utilization' Frameworks," Herbert Mohring & Hayden Boyd (1971) observe that "with quasi public-goods, [individuals] receive different amounts" (353). For a non-regulated fishery, discrepancies in resource appropriation engender allocative inefficiency.

In non-territorial waters, a pelagic fishery is an open-access resource, since it "lacks any system of rules governing its use" (Harris 2002, 77). Entry restrictions remedy some of the problems arising in an open-access fishery. Specifically, entry restrictions derive from administrative policy proscribing access to a particular fishery. In *The Economic Approach to Environmental and Natural Resources*, James Kahn (1995) asserts that "open-access exploitation….has driven many fish stocks to such low levels that they are threatened with extinction" (267). Under restricted-access policy, administrative agencies may auction licenses to those with the greatest incentive to fish, thereby fostering efficiency. However, this process fails to promote equity insofar as only the highest bidders garner fishing licenses.

A fish stock's geographic mobility is directly related to its inherent complexity (Townsend 1990). As oceanic wanderers, pelagic fish necessarily rate high in biological complexity. Incidentally, a negative correlation exists between fishery complexity and management success. This relationship illuminates resource managers' failure to prevent pelagic stocks' collapse over the past two decades. According to Ralph Townsend (1990), "Empirical evidence suggests that….limited entry is [merely] one component of an effective management-program" (372). Therefore, resource managers must implement a comprehensive agenda, in order to ensure long-term sustainability for pelagic fisheries.

II. Fishery Decimation as a Negative Consumption-Externality

The equilibrium of an ideal market-system yields an efficient allocation of the available economic resources (Bruce 2001, 40). The *Fundamental Theorem of Welfare Economics* sets forth the primary criterion for Pareto Optimality in a competitive market. Market failure occurs in the absence of allocative efficiency. In regard to pelagic fisheries, market failure stems from externalized social costs. These externalities lead to an inefficient distribution in the quantity of fish harvested and marketed vis-à-vis society as a whole. Over the past two decades, pelagic fisheries have suffered overexploitation as a result of intensive harvest by commercial fishermen. In this vein, destructive harvesting methods have severely depleted pelagic fisheries worldwide.

Figure 1: Negative Consumption-Externality (Pelagic Fisheries)[1]

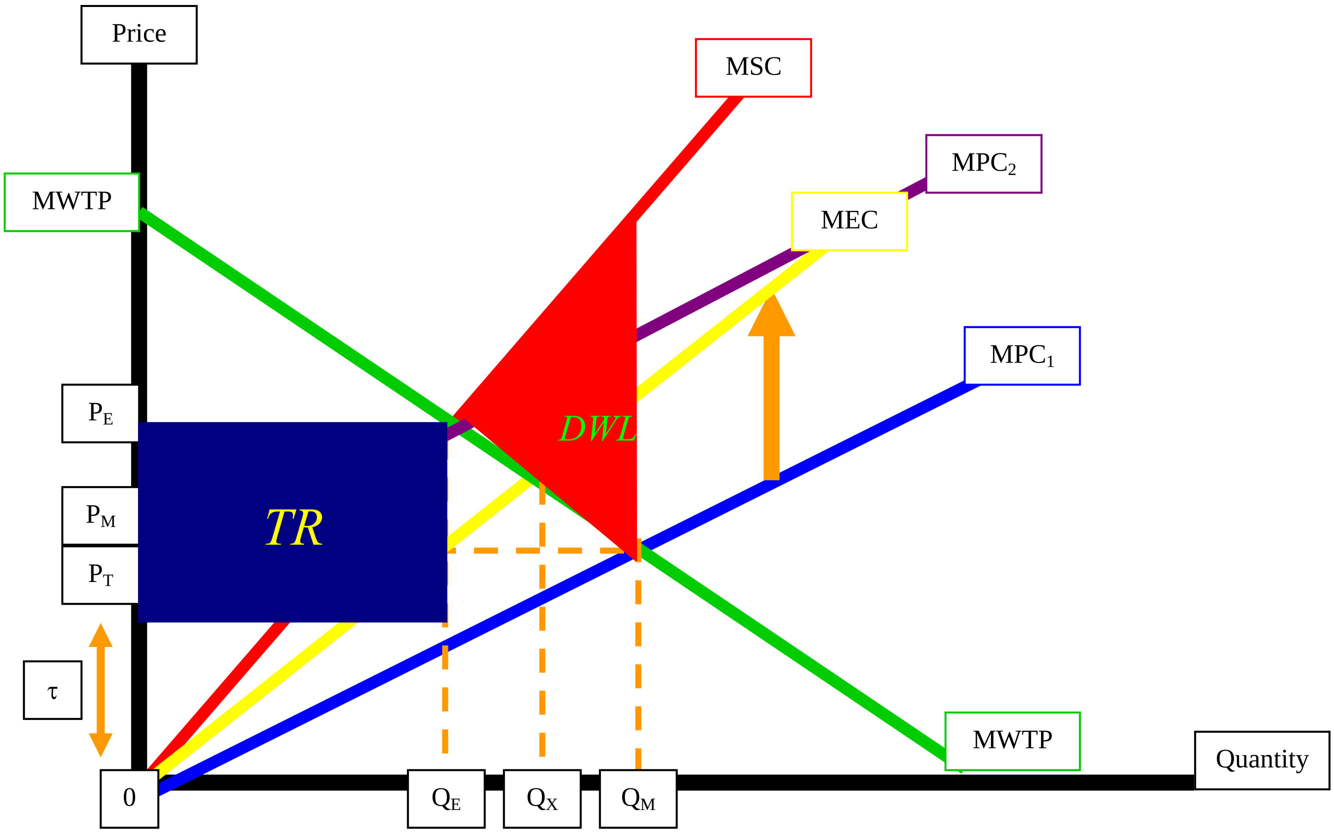


Figure 1 illustrates corrective policy in the form of a Pigouvian Tax.

Figure 1 frames pelagic-fishery decimation as a negative consumption-externality.[2] Negative externalities impose net costs upon society without adequate compensation. Two types of policies serve to alleviate the effects of negative externalities: corrective and internalization. Corrective policies penalize those responsible for generating an externality, and thereby attempt to establish a new equilibrium at which society's marginal willingness-to-pay (MWTP) equals the externality's marginal social-cost (MSC). Pigouvian Taxes are the most common form of corrective policy. Conversely, internalization policies strive to internalize the total external-cost (TEC) of an externality by assigning property rights such as individual transferable-quotas (ITQs) to a commonly owned resource.

In Figure 1, marginal private-cost (MPC) shifts inward ($MPC_1 \rightarrow MPC_2$) in response to a Pigouvian Tax (τ). The tax amount (τ) determines the size of the shift in MPC, and corresponds to the externality's marginal external-cost (MEC). This shift creates a new equilibrium-price (P_E) and quantity (Q_E) at which MPC_2 equals MSC—the optimal harvest of fish. At the original market-price (P_M) and quantity (Q_M), the DWL triangle represents the deadweight loss (DWL) associated with the externality. DWL measures the allocative inefficiency of a negative externality. Most importantly, the TR rectangle signifies the total revenue (TR) generated by the Pigouvian Tax (τ).

In reality, corrective policies have proven inadequate for reversing the trend in pelagic-fishery depletion. The current situation necessitates a more thorough analysis incorporating both unilateral and multilateral aspects. Since pelagic fish continually roam the open ocean in search of prey, they cannot be confined to the jurisdiction of any one nation, thereby rendering them inter-national. Jurisdictional spillover engenders international externalities as a result of over-fishing. Unilaterally, research concerning negative externalities and maximum sustainable-yield (MSY) provides a framework for pelagic-fishery management. Multilaterally, international agreements may foster the recovery of pelagic stocks worldwide, but these long-term solutions require both federal and international law-enforcement.

III. Unilateral Element

A. History of Overexploitation

The "Tragedy of the Commons" elucidates pelagic fisheries' long history of overexploitation. As a common-property resource, a fishery is both rival and non-excludable (Bruce 2001). Essentially, these two characteristics render a fishery an impure public-good. However, this status poses problems for fishery managers by creating a prisoners' dilemma for fishermen.

The prisoners' dilemma facing fishermen hinges upon an incentive to over-fish at the Nash-Equilibrium harvest level. This incentive fuels fierce competition among rivals competing for high catches. Non-excludability precludes entry restrictions in a fishery due to the high marginal-cost of exclusion. This scenario leads to indecision, indifference, and inefficiency among fishermen. Consequently, the U.S. government passed the Magnuson-Stevens Act in 1976, thereby establishing the National Marine Fisheries Service (NMFS).

B. Derby System

In 1976, the Magnuson-Stevens Act effectively created a derby system by privatizing American fisheries. Specifically, the act demarcated an exclusive economic-zone (EEZ) within 200 miles of the U.S. East and West Coasts. This EEZ restricts foreign fleets from fishing in "U.S. waters," and thereby appropriates the respective fisheries to the domestic fleet. Although these regulations have protected pelagic stocks from overexploitation by foreign fishermen, they have failed miserably on the domestic front.

NMFS currently manages key pelagic fisheries by implementing annual/seasonal quotas, which force fishermen to shut down once aggregate harvest-levels have been reached. This policy is inefficient insofar as it provides an incentive for fishermen to exhaust their quotas early in the season. According to Neil Bruce (2001), "The derby system causes an inefficient race among [fishermen] to catch….as many fish as possible" in the least amount of time (113). This system encourages fishermen to invest in large vessels capable of spending several days/weeks at a particular fishing spot. Over time, these marathon trips raise the total cost of fishing due to "wasted" time spent travelling long distances and burning high quantities of fuel. In this vein, the derby system devalues a firm's human and physical capital by distorting the incentive to fish.

Figure 2: Double-Prong Inefficiency of Derby System[3]

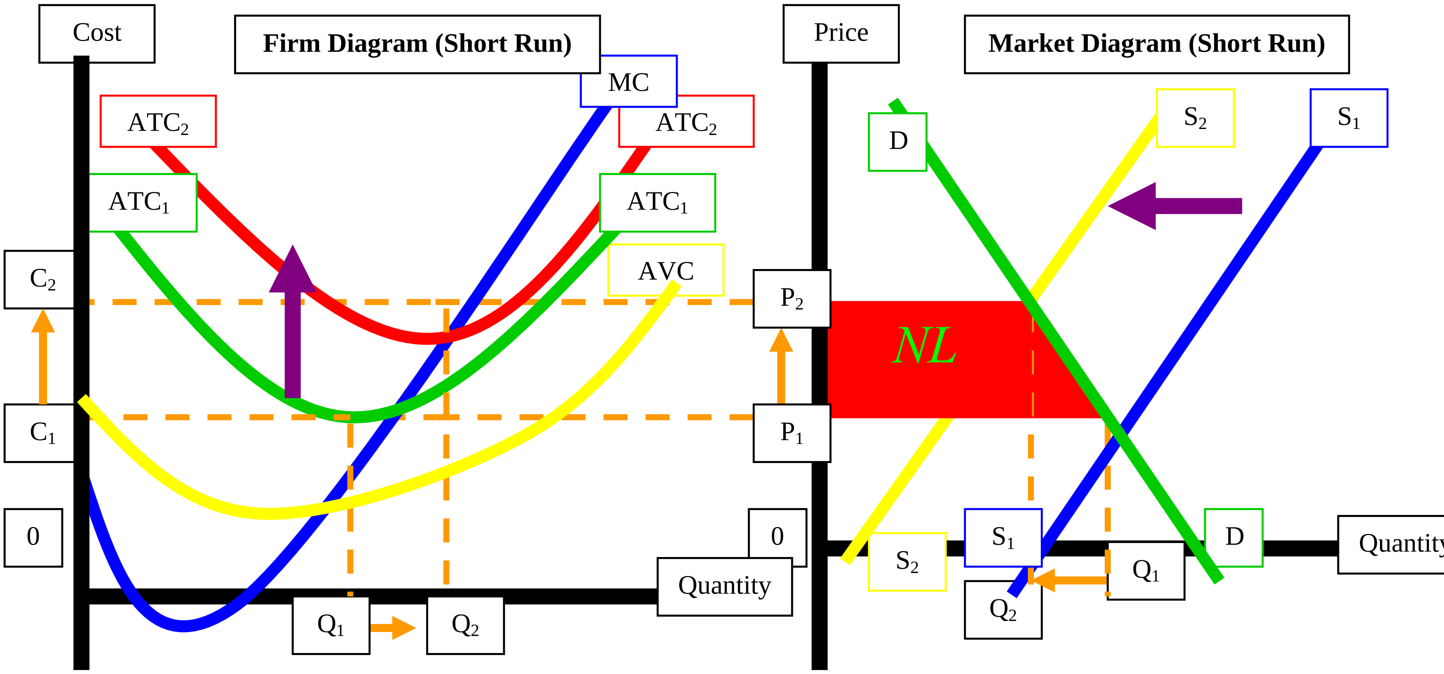


Figure 2 demonstrates that a cost/price hike engenders inefficiency in the fish market.

In Figure 2, the short-run firm diagram illustrates an average-cost ($C_1 \rightarrow C_2$) increase for a commercial fisherman in the derby system. Specifically, average total-cost (ATC) shifts upward ($ATC_1 \rightarrow ATC_2$) in response to the increased costs of maintaining a larger vessel. This shift establishes a new equilibrium (C_2, Q_2) at which ATC_2 equals marginal cost (MC). In the short-run market diagram, the firm's cost hike raises the price of fresh fish ($P_1 \rightarrow P_2$), and thereby shrinks the equilibrium quantity ($Q_1 \rightarrow$Q2). The NL trapezoid represents the net loss (NL) of consumer surplus in the market for fresh fish.

Figure 3: Market Diagram (Long Run)

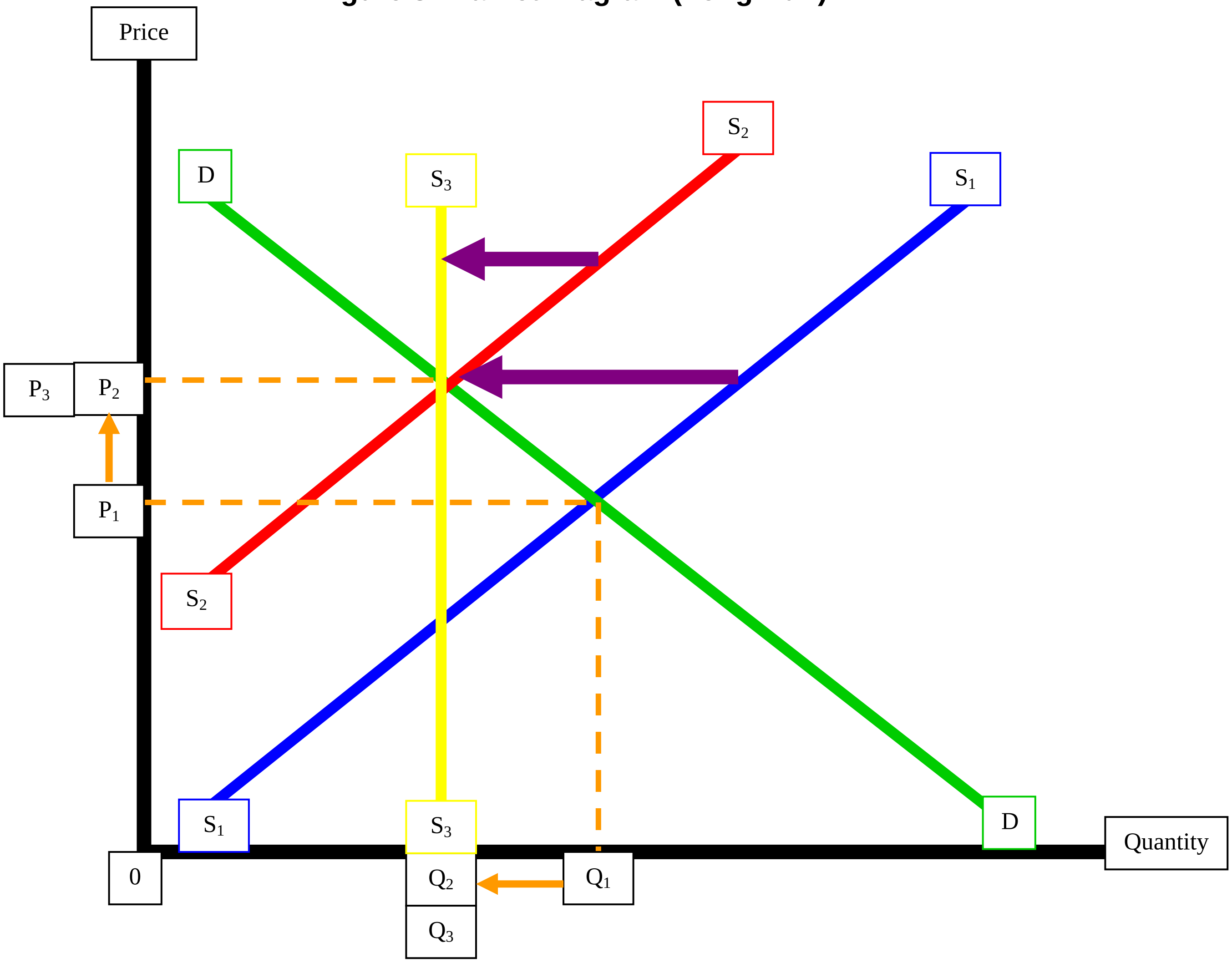


Figure 3 portrays Derby System's in-season and off-season equilibria in the market for fresh fish.

In Figure 3, high costs induce inefficient vessels to exit the fishery, thereby shifting supply inward ($S_1 \rightarrow S_2$). As the number of vessels stabilizes, the equilibrium price ($P_1 \rightarrow P_2$) increases and equilibrium quantity ($Q_1 \rightarrow Q_2$) decreases in the market for fresh fish. At the *in-season equilibrium* (P_2, Q_2), firms earn normal economic-profit (π). Once fishermen have exhausted their annual/seasonal quota, supply becomes inelastic and rotates inward ($S_2 \rightarrow S_3$). Supply inelasticity establishes the off-season equilibrium (P_3, Q_3) at which fresh fish remains unavailable until the season reopens. During the off-season, the scarcity of locally caught fish evinces the derby system's inherent inefficiency.

C. Coase Theorem

A property right is a legal rule of entitlement granting its owner the right to enjoy its benefits, to command payment if it is used for others' benefit, and to prevent trespass (Bruce

2001). Individual property-rights may remedy most problems associated with the derby system, but efficiency mandates transferable appropriation in a fishery. A transferable property-right permits its owner to sell it at market value. According to the Coase Theorem, "The assignment of transferable property-rights to a resource will lead to an efficient outcome" if individuals act rationally, and if their bargaining costs are sufficiently low (Bruce 2001, 99). For fishermen, bargaining costs remain nominal so long as political gridlock and bureaucratic red-tape do not thwart the negotiation process. In this vein, rational expectations may breakdown if collusion persists among a group of commercial fishermen.

D. Individual Transferable-Quotas (ITQs)

The Coase Theorem spawned ITQs as a viable internalization-policy for fishery externalities. In *Public Finance and the American Economy*, Neil Bruce (2001) defines an ITQ as "the right to catch a given fraction" of a fishery's annual allotment (113). ITQs privatize a fishery by affording individual fishermen the right to catch a percentage of the current annual-harvest, as well as those of the future. This continuity enables ITQs to ensure the future vitality of a fishery. In "Efficiency of ITQs in the Presence of Production Externalities," Asgeir Danielsson (2000) asserts that "ITQs generate a Pareto-Optimal market solution in a fishery" (37). In other words, ITQs appear adequate for internalizing the social costs of a negative externality.

In "The Economic Theory of a Common-Property Resource: The Fishery," Scott Gordon (1954) notes that "common-property resources are free for the individual [but] scarce for society" (135). ITQs circumvent this dilemma through privatization of common-property resources, thereby rendering them both rival and excludable. In a private fishery, individual owners do not over-fish because they must absorb the full costs of stock depletion and ecosystem damage. In this vein, ITQs provide an incentive for individual fishermen to advocate MSY harvesting techniques, as opposed to those rooted in maximum economic-yield (MEY)[4]. Bruce (2001) delineates MSY as the strategy, which "maintains a fish stock, so that a constant harvest is possible from year to year" (112). Constant harvest-levels may protect fisheries from overexploitation, while ensuring a stable equilibrium in the market for fresh fish.

In order to achieve MSY consistently, management agencies must strive for equity in ITQ allocations. In many fisheries, inequitable distribution of ITQs pits individual fishermen against each other, thereby fueling conflicts and inefficiency. For instance, legal battles ensue when discrepancies in ITQ allocations arise between commercial and recreational fishermen. Court injunctions exact a hefty toll on society as a means of conflict resolution. Therefore, equitable ITQ-allocation is a prerequisite for Pareto Optimality in pelagic-fishery management.

E. Resource Sustainability

New growth in [a fish] population depends upon the harvest rate relative to natural recruitment [in] the stock. If the harvest rate exceeds the recruitment rate, the stock declines, and vice-versa (Smith 1969, 181). Bionomic equilibrium occurs when a fish stock's harvest rate equals its recruitment rate. In "Mathematical Models in the Economics of Renewable Resources," Colin Clark (1979) notes that "slow-growing renewable resources are particularly [susceptible] to overexploitation by profit-maximizing agents" (85). MSY has eluded species such as White Marlin (*Tetrapturus albidus*) and Swordfish (*Xiphias gladius*), which require many years to reach sexual maturity. According to R. Hilborn, C. J. Walters, & D. Ludwig (1995), "Sustainable exploitation of renewable resources depends [upon] the existence of a reproductive surplus" (45). Since bionomic equilibrium (BE) provides no reproductive surplus, it fails to sustain a fishery in the long run. In an open-access pelagic fishery, MEY exploitation fosters BE, while MSY exploitation promotes resource sustainability.

F. Pareto Optimality (Pelagic Fishery)

Figure 4: Indifference-Curve Analysis (MEY vs. MSY)[5]

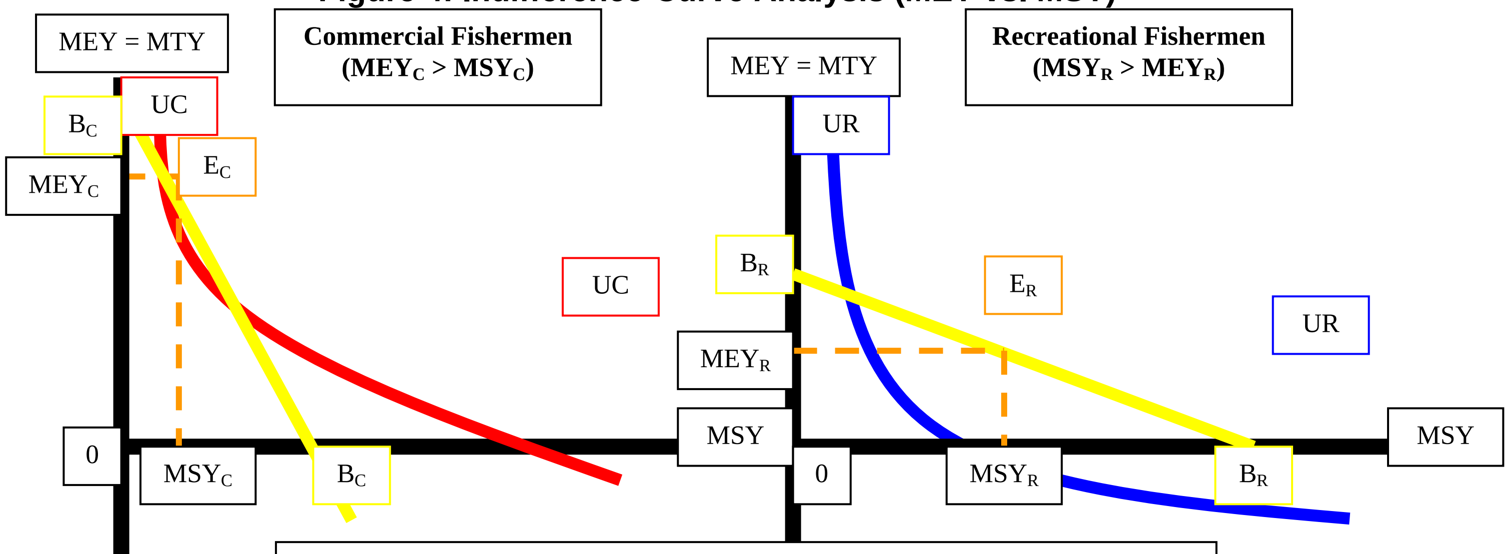


Figure 4 reveals the strategic tension between commercial and recreational anglers.

In Figure 4, indifference-curve analysis illustrates the respective preferences of commercial and recreational fishermen vis-à-vis MEY and MSY for an open-access pelagic fishery. The commercial fishermen's indifference curve (UC) indicates that they collectively prefer MEY_C to MSY_C because MEY portends profit maximization. For the commercial sector, the equilibrium exploitation-level (E_C) occurs at the intersection of UC and the budget constraint (B_C)[6]. Conversely, the recreational fishermen's indifference curve (UR) suggests that they collectively prefer MSY_R to MEY_R, since MSY facilitates resource sustainability through conservation. For the recreational sector, the equilibrium exploitation-level (E_R) occurs at the intersection of UR and the budget constraint (B_R)[7]. These diametrical preferences spark continual strife between the two groups of anglers.

Figure 5: Edgeworth's Box (Utility Maximization)[8]

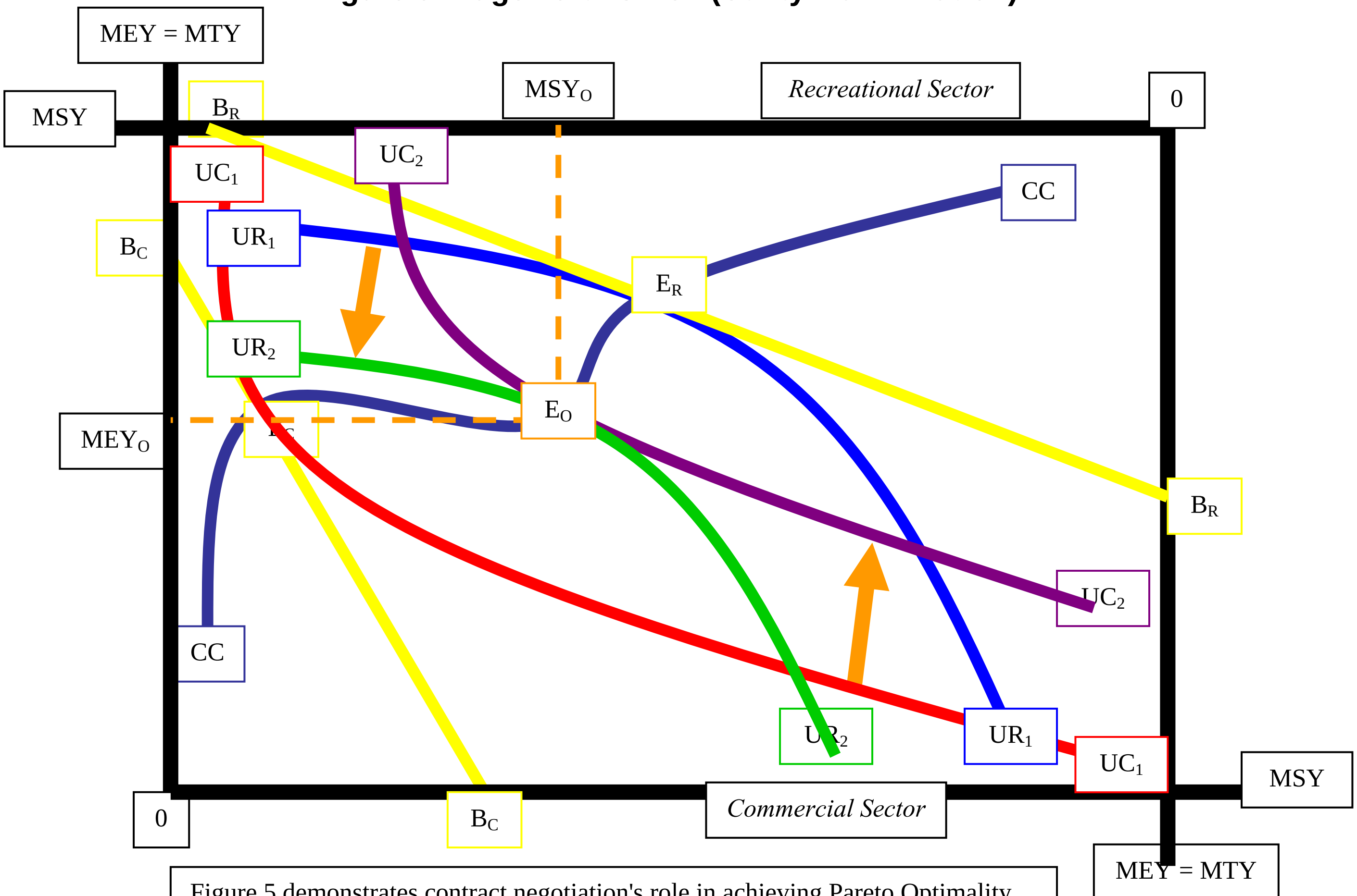


Figure 5 demonstrates contract negotiation's role in achieving Pareto Optimality. Utility transfers provide an incentive for both commercial and recreational anglers to establish an efficient exploitation-level (E_O).

Figure 5 depicts Pareto Optimality in an unregulated pelagic-fishery. Edgeworth's Box facilitates utility maximization for commercial and recreational fishermen through the contract curve (CC). CC essentially demarcates the set of all efficient preference-combinations for both sectors by connecting E_C and E_R. Through utility transfers, both groups of fishermen negotiate ($UC_1 \rightarrow UC_2$ & $UR_1 \rightarrow UR_2$) until they arrive at the optimal exploitation-level (E_O). By fostering resource sustainability ($MSY_O > MEY_O$), E_O ($UC_2 = UR_2$) ensures efficient exploitation for both sectors operating in an open-access pelagic fishery.

IV. Multilateral Element

A. Jurisdictional Spillover

From a multilateral standpoint, pelagic-fishery decimation generates international externalities. An international externality impacts society as a global negative-externality. In “Strategic Enhancement & Destruction of the Environment in the Presence of International Externalities,” Brian Copeland (1990) observes that a free-rider problem ensues with international externalities insofar as resource “enhancements may benefit more than one country" (213). In other words, the positive effects of a nation's internalization policy may overlap into its neighbors' jurisdictions, thereby reducing the joint incentive for fishery enhancement. Jurisdictional spillover occasions a free-rider problem because some nations may choose to "free-ride" if they receive the benefits of others' enhancement efforts without incurring any of the concomitant costs. This scenario has continually doomed strategies aimed at facilitating the long-term recovery of pelagic stocks.

B. Free-Rider Problem

Figure 6: Strategic Tension[9]

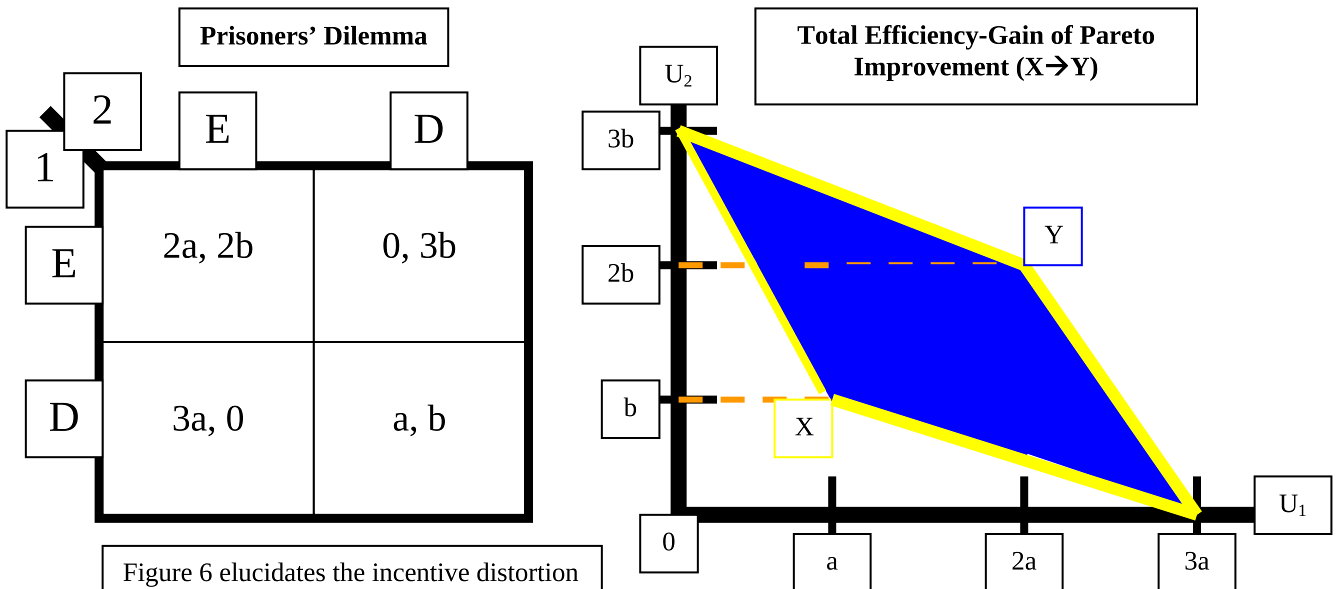


Figure 6 elucidates the incentive distortion inherent to jurisdictional spillover.

Figure 6 illustrates a prisoners' dilemma occasioned by the free-rider problem. In the matrix, a domestic country (player #1) and foreign country (player #2) simultaneously and independently choose either to enhance (E) or destroy (D) a pelagic fishery subject to joint exploitation. Iterative dominance results in bilateral destruction, and thereby reveals an incentive to over-fish at the Nash Equilibrium (D, D). Both nations remain at (D, D) insofar as neither one unilaterally deviates from the dominant strategy.

Jurisdictional spillover precludes bilateral enhancement as a rational strategy for the two countries, since neither one has an incentive to conserve the pelagic fishery if its counterpart becomes a free rider. In Figure 6, progression from the Nash Equilibrium (D, D) to the efficient strategy (E, E) denotes a Pareto Improvement. The graph depicts the effect of this potential improvement by jointly maximizing the domestic country's utility (U_1) and the foreign country's utility (U_2). The polygon represents the total efficiency-gain of bilateral fishery-enhancement, and the movement from the equilibrium level of over-fishing (X) to the efficient level of resource sustainability (Y) ensures utility maximization for both nations. However, an agency such as the International Commission for North Atlantic Fisheries (ICNAF) must induce utility-transfers between the two countries, in order to remedy incentive distortion in the prisoners' dilemma.

In response to the free-rider problem plaguing pelagic-fishery management, ICNAF has enacted legislation governing ITQs on both sides of the Atlantic Ocean. However, no agency currently exists to enforce these laws, thereby rendering them ineffective. This power vacuum in both federal and international law-enforcement has exacerbated the decline of pelagic stocks over the past two decades. For instance, Atlantic Swordfish (*Xiphias gladius*) face extinction in the 21st Century, unless drastic measures foster high recruitment among current brood-stock. Law enforcement provides vestigial hope for this species insofar as it may internalize the social costs associated with international externalities.

In "New Directions in Law and Economics," Alan Sykes (2002) argues that "international law must be self-enforcing," in order to achieve full compliance (15). By altering unilateral incentives, self-enforcing contracts may effectively solve the free-rider problem. However, self-enforcement mandates multilateral coordination among domestic and foreign nations, in order to ensure optimal enhancement. According to Copeland (1990), "Countries [may] attempt to influence the outcome of bargaining over harvest levels by strategically investing in [resource] enhancement" (222). ICNAF must consider the strategic implications of fishery enhancement when inducing utility-transfers among contracting nations. By implementing these multilateral agreements, ICNAF may facilitate international law-enforcement, and thereby foster the gradual recovery of Atlantic pelagic-fisheries.

V. Methodology

A. Mathematical Model (Gordon)[10]

(1) $$L = cE \times (a - bL)$$
(2) $$\lambda L = L(C,E,P)$$
(3) $$\lambda C = qE$$
(4) $$\lambda P = a\text{-}bL$$

The above equations underpin Gordon's basic fishery-model. Functional analysis of equation 1 demonstrates the sustainability condition (Max L = MSY) insofar as maximizing landings (L) promotes MSY given the model's constraints: equation 2, equation 3, and equation 4.[11] For Gordon, C corresponds to fishing costs; E denotes fishing effort; and P refers to fish population. In the fishery model, a signifies natural population-level; b serves as the depletion coefficient—an indicator of L's influence upon P; c acts as the production coefficient; and q couches fishing effort in terms of real dollars. As the model's primary constraint, equation 2 defines L as a function of C, E, and P. Equation 3 and equation 4 yield the model's total-cost and total-revenue functions respectively, thereby establishing the criterion ($L = C$) for bionomic equilibrium (BE).

Figure 7: MSY Fishery-Model (Gordon)[12]

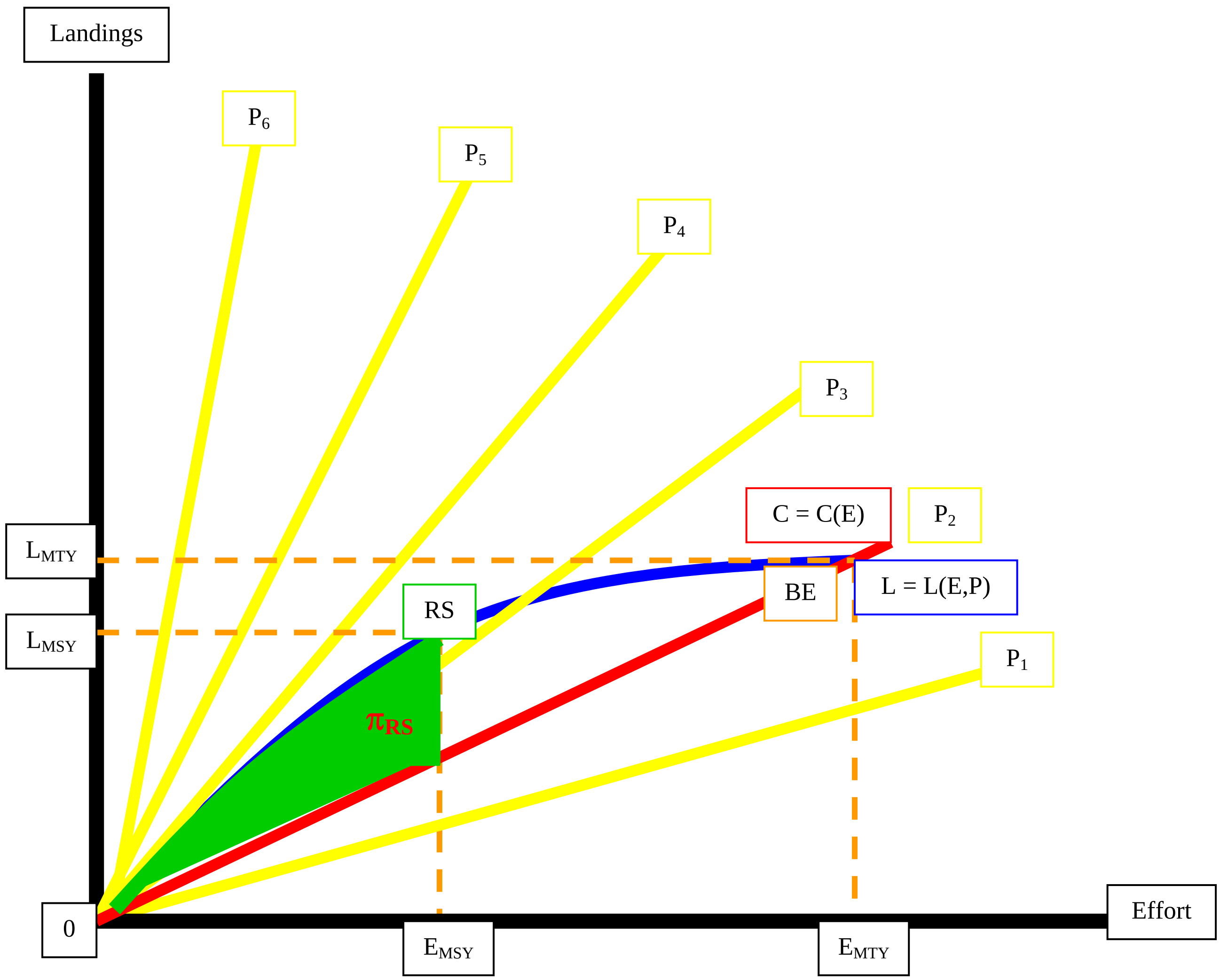


Figure 7 presents sole ownership as the optimal means of ensuring resource sustainability (RS). At the RS condition ($E_{MSY} = L_{MSY}$), sole owners necessarily maintain MSY.

$$(5)\quad \pi_{RS} = \int_0^{L_{MSY}} L(E,P) - \int_0^{E_{MSY}} C(E)$$

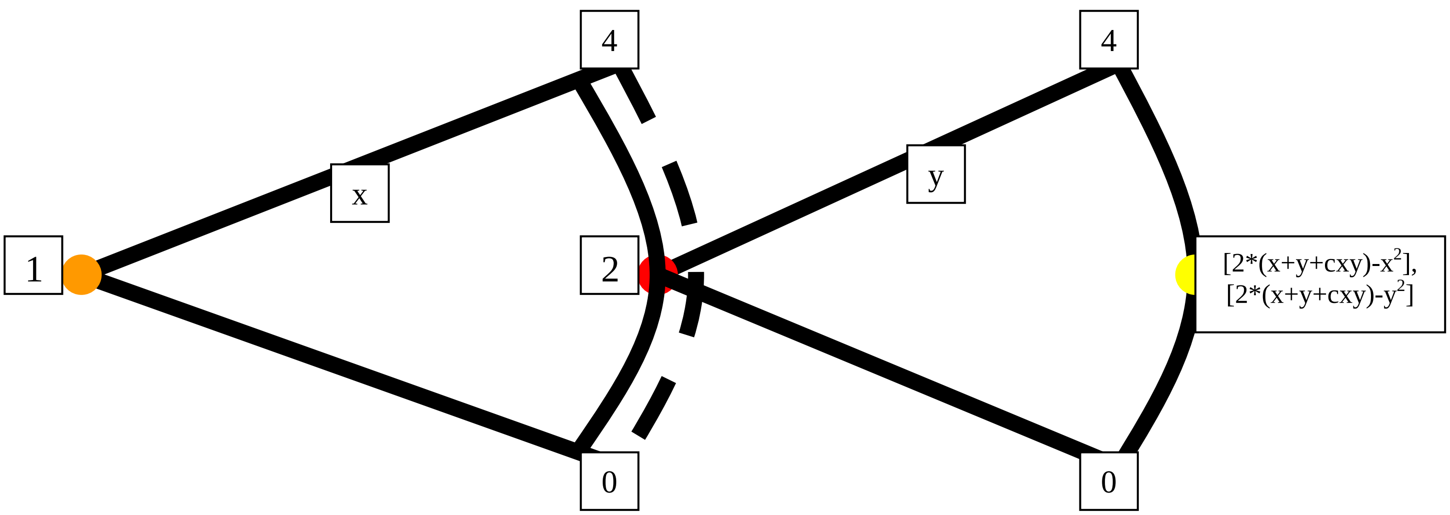
Figure 7 illustrates Gordon's fishery model. Under sole ownership, the MSY landings-level (L_{MSY}) and effort-level (E_{MSY}) confer positive economic-profits to fishermen. Equation 5 quantifies the total economic-profit (π_{RS}) generated under resource sustainability (RS) at which E_{MSY} equals the maximized difference between L & C (Max $[L - C]$). In a fishery, sole ownership generates a discrepancy between bionomic equilibrium (BE) and MSY (RS) because resource owners prefer short-run sustainability to long-run overexploitation. Consequently, MSY enables fishermen to earn positive economic-profits in the short run, while BE ensures normal economic-profits in the long run at the risk of overexploitation. Thus, *rational* sole-owners of a fishery necessarily operate at RS, in order to maximize profits.

In Figure 7, the dark polygon represents the total economic-profit (π_{RS}) generated at RS. The maximum total-yield (MTY)[13] effort level (E_{MTY}) occurs at the intersection of C and L (*L* = *C*), thereby indicating fishermen's break-even point under sole ownership. At BE, sole owners realize zero economic-profit by experiencing constant returns to scale. However, since $E_{MTY} > E_{MSY}$ and $L_{MTY} > L_{MSY}$, BE provides no reproductive surplus, and thereby precipitates over-fishing in the long run.

Gordon's model derives from the sole-ownership principle because competitive exploitation of a common-property resource decreases its overall value (Karpoff 1987). Figure 7 demonstrates that a fishery's value dissipates as L and C approach BE insofar as overexploitation engenders normal economic π for anglers. Most importantly, over-fishing hinders resource sustainability, and thereby causes stock collapses. The basic fishery-model supports ITQs as a weapon against stock depletion, since they effectively ensure sole ownership through transferable quotas. As resource stewards, commercial and recreational fishermen play a key role in pelagic-fishery management.

B. Game-Theoretic Analysis

Figure 8: Partnership Game[14]



(6) $$TR = 4 \times (x + y + cxy)$$

(7) $$TC = x^2 + y^2$$

(8) $$\pi = TR - TC \rightarrow \pi = 4 \times (x + y + cxy) - x^2 - y^2$$

In Figure 8, commercial fishermen (player #1) and recreational fishermen (player #2) simultaneously and independently select conservation effort-levels. In the payoff vectors, the commercial sector's effort level (*x*) corresponds to the recreational sector's effort level (*y*), and *c* serves as the complementarity coefficient (*c* = [0,4]). Each player experiences diminishing marginal returns to effort expended on fishery conservation as a result of asymmetric information. Both players value effort as "an amalgam of labor, capital, and energy" (Kahn 1995, 280). Equation 6 and equation 7 display the players' total-revenue (*TR*) and total-cost (*TC*) functions respectively, while equation 8 delineates the players' profit function (π). This functional analysis elucidates the game's strategic tension insofar as both players must coordinate their conservation efforts, in order to maximize joint profit.

Figure 9: Best-Response Functions (Partnership Game)[15]

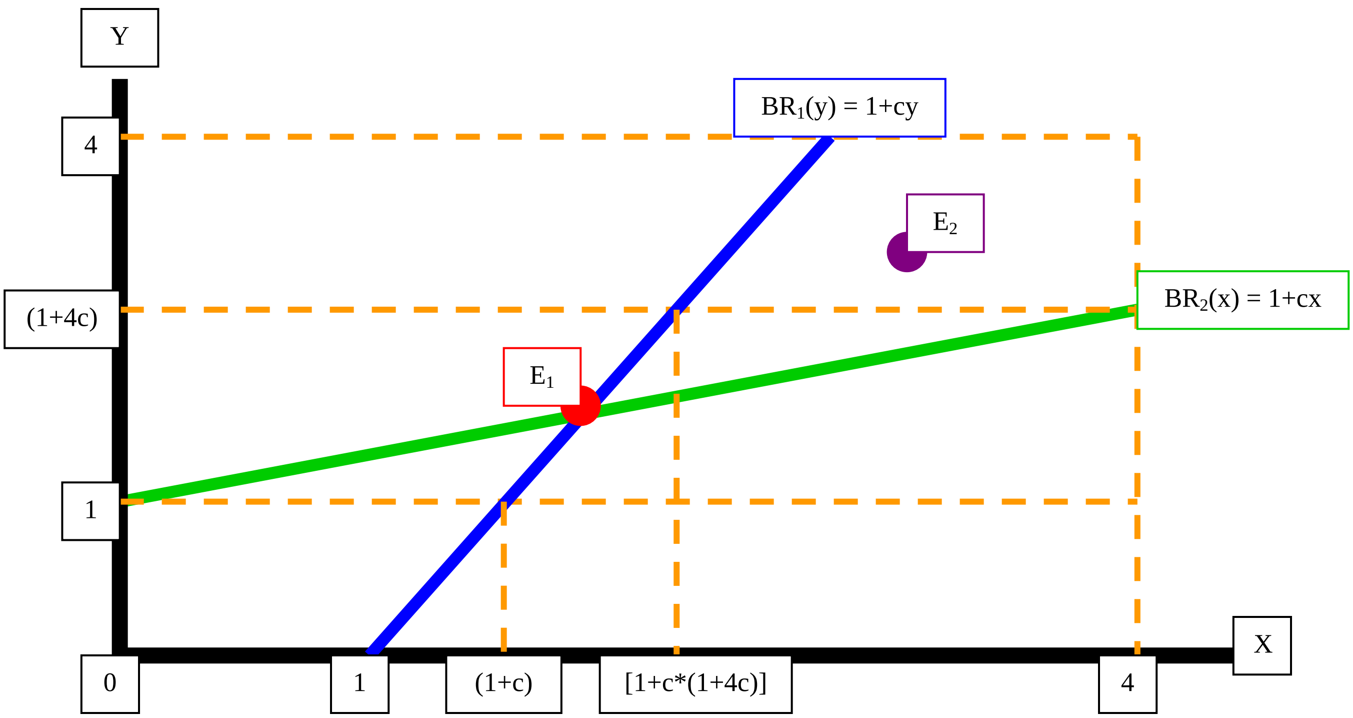


Figure 9 couches the optimal effort-level (E_2) as a non-rationalizable strategy in light of the players' best-response functions.

Figure 9 maps the players' best-response functions over their counterpart's behavioral expectations, in order to determine the game's effort-level equilibria (E_1 & E_2). In Figure 9, the inefficient Nash-Equilibrium (E_1) occurs at the intersection of the two best-response functions (BR_1 & BR_2), while the efficient strategy (E_2) lies outside the domain of BR_1 and BR_2. Since $E_2 > E_1$, E_2 denotes the optimal effort-level for each player. According to Joel Watson (2002), "A tension between individual and joint [incentives] exists when a player's private costs/benefits are not equal to joint costs/benefits" (201). In the partnership game, E_1 results from strategic tension insofar as progression from E_1 to E_2 evinces a Pareto Improvement. Each player's rational preference for Pareto Optimality necessitates *contract negotiation* between commercial and recreational fishermen.

Figure 10: Contract Negotiation (Stage I)[16]

Prisoners' Dilemma

1 \ 2	JA	IA
JA	4c, 4d	-3c, 5d
IA	5c, -3d	c, d

Figure 11 traces the negotiation process through which utility transfers facilitate efficient coordination.

(9) $\alpha = 3c$

(10) $\beta = 3d$

(11) $4c \geq (5c - \alpha)$

(12) $4d \geq (5d - \beta)$

Figure 10 portrays the 1st stage of contract negotiation between commercial and recreational fishermen. As a prisoners' dilemma, the players independently and simultaneously select either a joint agenda (JA) or an individual agenda (IA). Iterative dominance results in an inefficient Nash-Equilibrium (IA, IA) due to asymmetric information. In *Strategy*, Watson (2002) asserts that "deliberate contracting [provides] a way of avoiding inefficient coordination" (115). Thus, a self-enforcing contract may alter the players' incentives, so that they coordinate by selecting an efficient strategy (JA, JA).

Figure 11: Contract Negotiation (Stage II)[17]

Induced Transfers

1 \ 2	JA	IA
JA	4c, 4d	-3c+α, 5d-β
IA	5c-α, -3d+β	c, d

Figure 11 depicts the 2nd stage of contract negotiation between commercial and recreational fishermen. As an induced game, NMFS ensures bilateral agenda-coordination for fishery management through utility transfers (α & β) between the players. Equation 11 and equation 12 reveal the Nash-Equilibrium conditions for efficient coordination under the auspices of a self-enforced contract. According to Watson (2002), “A contract is an agreement about behavior, which is intended to be enforced” (115). To the extent that new circumstances alter strategies, “contracting [may] mitigate conflicts between joint and individual incentives” (Watson 2002, 115). NMFS oversees the negotiation process, induces the utility transfers, and implements the final contract.

Figure 12: Contract Negotiation (Stage III)[18]

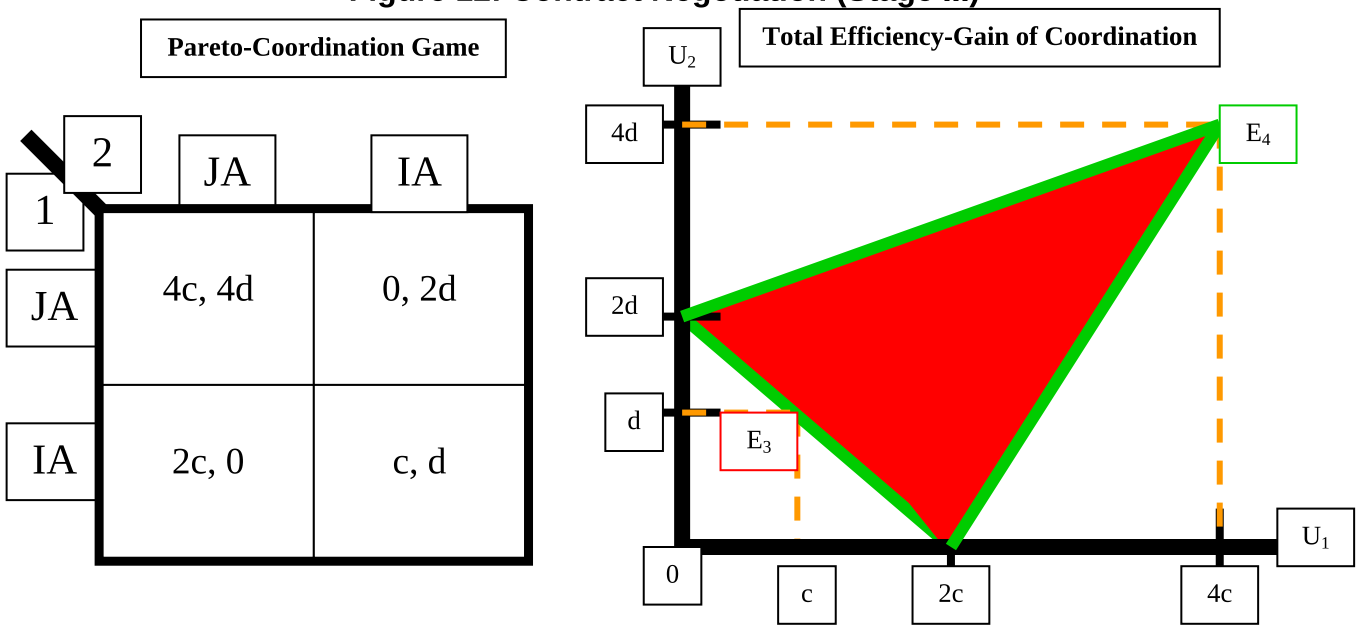


Figure 12 illustrates Pareto Optimality through a self-enforced contract between rational partners.

Figure 12 illustrates the 3rd stage of contract negotiation between commercial and recreational fishermen. As a Pareto-Coordination game, the players jointly select an efficient Nash-Equilibrium (JA, JA) in accordance with their self-enforced contract. A self-enforced contract contains the individual incentives necessary for players to abide by its terms (Watson 2002). This contract facilitates a Pareto Improvement from the inefficient strategy (IA, IA) to the efficient strategy (JA, JA). The diagram reflects this improvement by quantifying the distance between the initial equilibrium (E_3) and the final equilibrium (E_4). Most importantly, the triangle represents the total efficiency-gain of bilateral agenda-coordination and rational partnership.

C. Economic Analysis

The Gordon Model is dynamic [in that] all equilibrium catch-levels are sustainable, but static [insofar as] it does not consider future costs and benefits (Kahn 1995, 279). In order to evaluate the basic fishery-model, we must examine both its static and dynamic aspects. From a static perspective, Gordon's model assumes that fishermen face a low opportunity-cost with respect to both wages and time. This assumption implies that anglers prefer fishing to other occupational or recreational pursuits. Cost-benefit analysis may validate these implicit preferences. However, traditional methods of cost-benefit analysis have proven irrelevant in light of the "political and bureaucratic realities [underlying] the fishery management-process" (Sylvia & Cai 1995, 88). In other words, bureaucratic red-tape thwarts economists' efforts to calculate the net present-value (NPV) of a fishery.

In cost-benefit analysis, NPV equals the present value of benefits (PVB) minus the present value of costs (PVC). The discount factor (δ) influences NPV by adjusting an investment's time value in light of its opportunity costs and the expected interest-rate (r). From a dynamic standpoint, bionomic equilibrium (BE) is only optimal for an infinite discount-factor ($\delta = \infty$) (Munro 1982). Since a high δ lowers NPV, fishermen incur zero economic π at BE under open access. In this vein, Kahn (1995) notes that "discount rates [from] zero [to] infinity imply a dynamically optimal level of effort between the statically optimal level and the open-access level" (279). Therefore, the statically optimal effort-level generates positive economic π for a low δ, while the dynamically optimal effort-level yields zero economic π for a high δ.

D. Psychosocial Analysis

Rationality underpins all strategic behavior in our mathematical and game-theoretic models. According to Ragnar Arnason (1990), "The expectations of [fishermen] are the best available predictors of future conditions in [a] fishery" (646). For fishermen, expectations portend future management-success insofar as self-interest inclines them toward resource sustainability. In an ITQ market-system, self-interest promotes Pareto Optimality through Adam Smith's "invisible hand" of equilibrium prices. In this vein, Quentin Grafton (1996) asserts that "ITQs operate on the principle that incentives should be used to manage a fishery" (135). Incentives effectively prevent market failure and deadweight loss by tapping both individual and joint self-interest.

VI. Case Study of Bluefin Tuna (*Thunnus thynnus*)

Figure 13: Bluefin Tuna (*Thunnus thynnus*)

Bluefin Tuna (*Thunnus thynnus*) are "unique among bony fish for maintaining elevated body temperatures and attaining large sizes" (Block *et al.* 1998, 9384). As the largest tuna species, *Thunnus thynnus* may reach 1,500 pounds in total weight. According to Barbara Block (1998), "The Bluefin Tuna has the widest thermal-niche of all Scombridae" (9388). This high tolerance for temperature variance enables the tuna to migrate long distances in search of forage.

A. Fishery Depletion

Figure 13 depicts a Bluefin Tuna.

Despite historically abu oast from Maine to North Carolina, Bluefin Tuna have dramatically declined over the past two decades. In "A New Satellite Technology for Tracking the Movements of Atlantic Bluefin Tuna," Block (1998) observes that throughout their range, Bluefin Tuna "are intensively exploited by commercial and recreational [fishermen]" (9384). Commercial over-harvest by east-coast long liners has significantly lowered stock biomass and recruitment. For long liners, the presence of competitors forces individual fishermen to overexploit the resource. In "Minimum Information Management in Fisheries," Arnason (1990) argues that "common-property fisheries generally operate in a socially sub-optimal manner" (630). This social sub-optimality stems from the power vacuum in international law-enforcement.

In both the private and public realms, pervasive apathy and ignorance have aided the tuna fishery's collapse. *Thunnus thynnus'* apparent scarcity has raised the market price of fresh tuna to exorbitant levels. The decline of giant tuna—specimens weighing over 500 pounds—has spawned a new market for premium-quality sushi in Japan. For instance, giant tuna may fetch upwards of $150 per pound at Tokyo fish-markets. These high prices provide an incentive for American long-liners and purse-seiners to dry freeze fresh tuna and air-ship them directly to Japan. Consequently, American consumers preferring Bluefin Tuna must substitute either Bigeye Tuna (*Thunnus obesus*) or Yellowfin Tuna (*Thunnus albacares*) at local fish-markets due to the ostensible absence of *Thunnus thynnus*.

B. Current Status of Fishery

The [pop-off] tag [attaches] externally to a fish, releases at a preprogrammed time [due to] a corrosive linkage, floats to the surface, and then transmits continuously to ARGOS satellites. [This] tag provides an independent measure of the straight-line distance traveled from the tagging [location] (Block *et al.* 1998, 9384).

During the late winter and early spring of 1998, Block and her research team conducted a tagging study designed to assess the current status of Atlantic Bluefin-Tuna stocks. The scientists tagged thirty-seven tuna on the Gulf Stream's western edge—approximately 20 nautical miles southeast of Cape Hatteras, North Carolina. Block and her associates pioneered usage of pop-off tags, which disengage from host fish at a designated time and transmit the location to ARGOS satellites. These tags enable researchers to calculate the linear distance traveled by each tuna from the initial tagging site, as well as to plot the water-temperature variance for every fish.

Figure 14: Pop-Off Tag Study (Outer Banks, NC)[19]

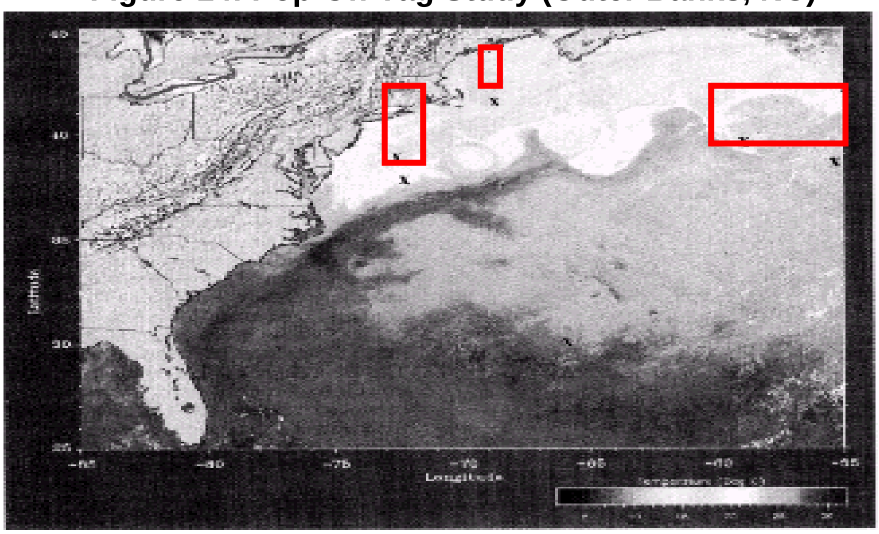


Figure 14 maps tuna migration to the north and east of North Carolina's Outer Banks. In the satellite image, dark areas indicate a warm sea-surface, while light areas signal a cold sea-surface. The dark current denotes the Gulf Stream, while the light flow evinces the Labrador Current. Figure 14 implies that Bluefin Tuna migrate northeastward along the Gulf Stream and southwestward along the Labrador Current.

Figure 14 displays data from Barbara Block's tagging study. The rectangles enclose tag returns from five individual tuna. These three rectangles correspond to areas of Bluefin density: the Mid-Atlantic Canyons,[20] Georges Bank, and the Gulf Stream. Specifically, the eastern rectangle suggests that tuna migrate across the Atlantic Ocean with the Gulf Stream's aid. Incidentally, data from pop-off tags indicate stock overlap between eastern and western Atlantic-Bluefins (Block *et al.* 1998). These data imply that Atlantic Bluefin-Tuna require *multilateral management* insofar as they comprise one large stock.[21]

C. Fishery Management

A program's restrictiveness is positively correlated [with] its economic success. The most restrictive programs have either reduced [fishing] effort significantly, or closed entry before [reaching] rent-dissipating levels (Townsend 1990, 371).

In a fishery, restrictive management-policy fosters resource sustainability. However, bureaucratic red-tape often cripples management restrictions imposed by federal and international agencies. In "Sustainable Exploitation of Renewable Resources," Hilborn, Walters, & Ludwig (1995) note that "there is a negative correlation between institutional complexity and the health of fish stocks" (61). Effective management tailors policy to fit each species' natural behavior. In this vein, pelagic-fishery managers must "treat the resource of an entire geographic region as one" (Gordon 1954, 129). The Bluefin Tuna's demise reflects management's failure to implement this type of cohesive plan.

On the state and federal levels, two agencies regulate U.S. fisheries: the Atlantic States Marine Fisheries Council (ASMFC) and the National Marine Fisheries Service (NMFS). The ASMFC—a consortium of fifteen coastal states from Maine to Florida—prepares management plans providing "for the conservation of fishery resources within state waters" (Scarlett 2002, 28). Since its jurisdiction encompasses only state waters lying within 3 miles of the U.S. coast, ASMFC does not regulate most pelagic species. As an arm of the federal government's Executive Branch, NMFS enforces legislation ratified by Congress. NMFS' goals include preventing resource overexploitation, rebuilding over-utilized stocks, promoting fishery conservation, and facilitating long-term protection of essential fish-habitats (Scarlett 2002). Under the Magnuson-Stevens Act, NMFS' jurisdiction extends outward from 3 to 200 miles off the U.S. coasts, thereby encapsulating most pelagic species.

On the international front, two agencies regulate pelagic fisheries in non-territorial waters: the International Commission for North Atlantic Fisheries (ICNAF) and the International Commission for the Conservation of Atlantic Tunas (ICCAT). However, neither commission has proven effective at fishery management due to lax policy-enforcement. In light of this problem, conservation organizations and special-interest groups have united to end the overexploitation of pelagic stocks. The International Game Fish Association (IGFA) pools financial resources from recreational fishermen as a means of lobbying Congress to protect endangered species such as White Marlin (*Tetrapturus albidus*) and Swordfish (*Xiphias gladius*). Statewide, the Coastal Conservation Association (CCA) mobilizes recreational anglers to promote conservation-oriented legislation by raising public awareness of the current plight. Nationally, the Recreational Fishing Alliance (RFA) lobbies both the Executive and Legislative Branches of the federal government, in order to facilitate a long-term recovery plan for pelagic fisheries.

D. Failure of Current Management

Current fishery-management has failed miserably at the state, federal, and international levels. NMFS has continually fueled rancor in the recreational sector by misallocating annual harvest-quotas in favor of commercial fishermen. Despite high quota-levels, many commercial fishermen advocate open access to pelagic stocks, and lobby Congress for exploitation-oriented legislation, thereby reinforcing recreational anglers' enmity toward them. By restricting access to pelagic fisheries, ICCAT and NMFS have merely distorted anglers' incentives. In restricted-access fisheries, "the need to purchase a license may reduce the value of [both physical and] human capital" for individual fishermen (Townsend 1990, 360). Consequently, access restrictions may hinder Pareto Optimality by fueling high costs and wholesale inefficiency.

In "Entry Restrictions in the Fishery: A Survey of the Evidence," Townsend (1990) asserts that "limited entry has generated economic benefits by reducing short-run externalities" (372). In other words, limited-entry policies may redress the crowding externalities associated with an open-access fishery. However, these policies cannot foster long-term sustainability insofar as they are inherently sub-optimal. In "On Models of Commercial Fishing," Vernon Smith (1969) states that "crowding externalities occur if [a] fish population is sufficiently concentrated to cause vessel congestion over the fishing grounds" (181). Vessel congestion impedes anglers in many pelagic fisheries, since species like tuna tend to congregate in large schools over a relatively small area when foraging.

ITQs may eliminate both short-run and long-run externalities in an open-access fishery. However, non-compliance with quota restrictions has limited ITQs' efficacy in the international realm. According to Townsend (1990), "Quota compliance is clearly the Achilles' heel of ITQs" (368). Nonetheless, quota compliance is paramount for an effective ITQ program (Grafton 1996). Therefore, ICCAT must prohibit all unilateral exemptions from international ITQ-programs among Third-World countries in which commercial fishermen legally overexploit the resource.

E. Urgency for a New Approach

In the future, fishery management must implement institutional arrangements aimed at creating incentives for sustainability (Hilborn *et al.* 1995). Through management systems such as ITQs, MSY confers a Pareto Improvement over MEY/MTY by benefiting both fish and anglers. In "Experiences with Individual Transferable Quotas: An Overview," Grafton (1996) contends that ITQs yield "a high net-return from the resource, [so long as] they are perceived as a durable and exclusive property-right" (138). From a psychosocial standpoint, durability and excludability eradicate any incentive to overexploit a fishery by privatizing the resource. Most importantly, ITQ programs may raise biomass and recruitment levels for pelagic stocks, thereby fostering the gradual recovery of fisheries worldwide.

VII. Conclusion

Despite its limitations, Gordon's fishery model appears valid in light of our economic and psychosocial analysis. With respect to contract negotiation, an endogenous tension permeates the players' strategy sets insofar as we assume that both commercial and recreational fishermen prefer some type of conservation agenda to none at all. Exogenously, conservation organizations may attempt to influence the players' preferences by lobbying in favor of resource sustainability. In this vein, lobbyists operate as a viable third-player, even though they elude our models.

The feasibility of implementing a multilateral ITQ-program depends upon support from political-action committees (PACs), lobbyists, and special-interest groups. This international plan also requires both private and public endorsement. Commercial and recreational anglers must jointly advocate ITQs as a remedy for pelagic-fishery depletion. In New Jersey, recreational anglers spend $750 million annually on saltwater fishing tackle (McDowell 2002). Thus, segments of the recreational fishing-industry such as tackle manufacturers, boat builders, electronics companies, retail vendors, and media (magazines) may benefit from ITQs. Healthy stocks boost revenue for the industry insofar as anglers re-allocate disposable income toward pursuit of their favorite quarry.

In the future, scientific research must accurately assess biomass and recruitment for endangered species such as Bluefin Tuna (*Thunnus thynnus*), White Marlin (*Tetrapturus albidus*), and Swordfish (*Xiphias gladius*). ITQ implementation mandates *empirical analysis* of annual harvest-levels, in order to establish quotas commensurate with resource sustainability. Most importantly, a multilateral ITQ-program requires diplomacy and tactful negotiation among constituent nations. Upon implementation, time-series data must validate the program's efficacy vis-à-vis MSY. Multilateral ITQ-management may stem the tide of pelagic-fishery decimation by ensuring long-term sustainability for stocks worldwide.

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IX. Endnotes

[1]In figure 1, P_T denotes the tax price, and Q_X signifies the external quantity of fish.

[2] Fishery decimation engenders a negative consumption-externality insofar as resource overexploitation imposes costs upon *both* anglers and fish under open-access management. Therefore, overharvest precipitates an externality in a publicly owned fishery by reducing angler’s potential catch, and by precluding the stock’s sustainability.

[3] The short-run firm diagram depicts a commercial fisherman in a perfectly competitive market. In reality, commercial anglers exercise market power, and thereby operate in a monopolistically competitive market.

[4] For a low discount rate (δ), fishermen rationally prefer MSY to MEY because profit maximization hinges upon resource sustainability.

[5] Indifference-curve analysis indicates that commercial fishermen prefer MEY to MSY, while recreational anglers prefer MSY to MEY. These preferences coincide with each sector’s rational strategy.

[6] For commercial fishermen, B_C allocates most funds toward MEY and maximum total-yield (MTY).

[7] For recreational fishermen, B_R allocates most funds toward MSY and conservation.

[8] In Edgeworth’s Box, utility maximization reveals that the optimal point (E_O) rates higher for MSY than MEY, thereby evincing the strength of recreational fishermen’s preference combinations.

[9] In the free-rider problem, the players never achieve Pareto Optimality, since they face a prisoners’ dilemma.

[10] The basic fishery-model’s simplicity derives from the linearity of its three constraints: equation 2, equation 3, and equation 4.

[11] In equations 2, 3, and 4 of Gordon's mathematical model, λ does not signify the Lagranian multiplier, but rather denotes the model's *MSY constraints*.
[12] Gordon's fishery model depicts a solely regulated fishery. Thus, BE $\neq$ MSY because fishermen may earn positive economic π under sole ownership by fostering resource sustainability.
[13] In the basic fishery-model, MTY equals long-run MEY, while MSY equals short-run MEY. However, the validity of these two conditions hinges upon sole ownership.
[14] In extensive form, the partnership game contains infinite payoff-vectors.
[15] E_2 reveals the players' joint preference for conservation effort. However, this preference is not rationalizable in light of diminishing marginal-returns to conservation effort.

[16] In stage #1 of contract negotiation, the players face a prisoners' dilemma, since neither one has an incentive to favor the joint agenda.
[17] In stage #2 of contract negotiation, an external agency induces utility transfers, in order to alter the players' incentives. NMFS appeals to "utility transfers" as a result of asymmetric information vis-à-vis player preferences.
[18] In stage #3 of contract negotiation, the players coordinate to realize a Pareto Improvement ($E_3 \rightarrow E_4$).
[19] The western rectangle denotes the Mid-Atlantic Canyons; the northern rectangle encompasses Georges Bank; and the eastern rectangle demarcates the Gulf Stream. Most tag returns came from either the eastern or western regions due to the warm surface-temperatures.
[20] The Mid-Atlantic Canyons include those lying between Hudson Canyon (north) and Norfolk Canyon (south).
[21] The Eastern Atlantic tuna-stock comprises the Mediterranean tuna-stock as well.