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Keith R. Criddle
Utah State University

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ECONOMIC PRINCIPLES OF SUSTAINABLE MULTI-USE FISHERIES MANAGEMENT

by

KEITH R. CRIDDLE

Department of Economics
Utah State University
3530 Old Main Hill
Logan, UT 84322-3530

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ABSTRACT

Economic prescriptions for the sustainable management of fisheries have typically been framed in the context of commercial fisheries. Fishery management failures have been characterized as a consequence of disjointedness between individually rational decisions and globally sensible outcomes—the “tragedy of the commons”. The solutions proposed by economists flow from the insight that rational self-interest can lead to socially beneficial outcomes when ownership is secure and prices reflect the opportunity cost of resource use. Theoretical and empirical analyses have demonstrated that sole ownership, individual quotas, territorial use rights, fishing cooperatives, and common property management regimes can promote biologically and economically sustainable fisheries. Nevertheless, implementation of these “solutions” has met with resistance, due in part to the impossibility of uncoupling species within ecological systems and conflict between the proposed solutions and broadly accepted concepts of social justice. The problem of devising a sustainable management strategy is exacerbated in fisheries with diverse consumptive and non-consumptive users. An empirically based simulation-optimization model is used to characterize the biological and economic effects of alternative management regimes in a fishery with commercial and sport fishers. The results are generalized to the case of additional use and nonuse values.
ECONOMIC PRINCIPLES OF SUSTAINABLE MULTl-USE FISHERIES MANAGEMENT

Introduction

Sustainable fisheries management means different things to different people. From a narrowly single-species biological perspective, sustainable management of fisheries reduces to the adoption of regulatory measures designed to ensure that the probability of stock or recruitment levels falling below specific critical values does not exceed an acceptable risk level. Charles (2001) proposes comprehensive perspective that incorporates ecological, socioeconomic, community, and institutional sustainability concepts. In this chapter, sustainable fisheries management will be characterized as practices intended to ensure that the expected flows of use, option, and nonuse benefits provided by the fishery are not degraded through time.

Use benefits include the value of commercial, recreational, subsistence and other cultural harvests, the value associated with observing fish in situ, the harvest value of trophically related species, and the value of ecosystem services contributed by a sustainable fishery. Option value reflects the value of preserving the opportunity to use a fishery resource at some future time as well as the value of preserving the opportunity to use any other resource that is dependent on the sustainable fishery (Bishop 1982; Freeman 1984). Nonuse benefits are those obtained by vicarious consumers of the resource: benefits derived from knowledge of the existence of a fishery resource; value associated with bequesting a sustainable fishery resource to future generations; the altruistic value of preserving a fishery for other unrelated users; and, the value associated with the belief that a sustainable fishery contributes to a desirable state of the ecosystem (Brown and Goldstein 1984; Miller 1981; Miller and Lad 1984; Walsh et al. 1984).

The fundamental problems faced by fishery managers are that nature cannot satisfy all of the use and nonuse demands and, in most jurisdictions, fish are unowned until they are reduced to possession. Because the benefits associated with use and nonuse of fishery resources accrue to different people, the distribution of benefits cannot be dismissed in a narrow focus on the magnitude of those benefits. When considering the sustainable management of fisheries, managers are first and foremost faced with the question of which set of benefits to maximize and consequently, the question of who will benefit from the fishery. For example, management strategies that support commercial or recreational use benefits imply a concomitant reduction in the magnitude of nonuse benefits. Allocations between user groups are typically determined through a political process. Secondary allocations of use benefits are typically based on first-come-first-serve ownership by capture (derby) rules. Because nonuse benefits are largely nonrivalrous, they are less likely to engender inefficiencies in the secondary allocation.

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1 This definition is similar to that proposed in NRC (1999a), where sustainable fishing is defined as "fishing activities that do not cause or lead to undesirable changes in biological and economic productivity, biological diversity, or ecosystem structure and functioning from one human generation to the next; sustainable fishing does not lead to ecological changes that foreclose options for future generations". The difference is that the definition adopted in this chapter characterizes the value of ecosystem services as nonuse economic benefits and formally recognizes the stochastic nature of the time stream of benefits.
When allocations take place through the operation of political processes, every action advantages one sector relative to another. The preponderance of evidence from fisheries suggests that allocations between commercial, recreational, and vicarious users are unlikely to be definitively settled by any single allocation decision. Instead, these allocation battles are reprised whenever a set of stakeholders believes that their negotiating position has improved. Even in the fortuitous circumstance that an initial allocation is optimal, changes in exvessel price, factor costs, stock abundance, recreation trip costs, angler success, willingness to pay for nonuse benefits, etc., will render that allocation suboptimal in subsequent periods unless a self-correcting mechanism is provided.

The problem of fisheries management has often been characterized as a consequence of disjointedness between individually rational decisions and globally sensible outcomes. The economic approach to sustainable resource management flows from the insight that rational self-interest can lead to socially beneficial outcomes when ownership is secure and prices reflect the opportunity cost of resource use. The challenge for economic theorists and policy analysts arises from the incompleteness of ownership and the failure of markets to fully reflect opportunity costs. These problems arise from when the rights to a resource are nonexclusive or when the exercise of those rights is nonrival (Randall 1983).

Honoré (1961) identifies attributes that characterize comprehensiveness of property rights: the right to possession—the right to exclusive physical control of the thing owned; the right to usufruct—the right to enjoyment and use of the thing owned; the right to manage—the right to decide how and who gets to use the thing owned; the right to income—the right to compensation for foregoing use of the thing owned; the right to capital—the rights to consume, waste, modify, or destroy the thing owned; the right to security—the right to rely on the police powers of the state to defend against expropriation; the right to alienate—the right to bequest, sell, or otherwise dispose of the thing owned; the absence of term—the right to infinite durability of ownership; the liability to execution—the thing owned can be used as collateral and taken as repayment for debt; and the residuary character—the right to determine succession of ownership. In practice, property rights to resources are attenuated to varying degrees along each of these dimensions. The potential attenuation of property rights along a continuous gradation in each of these dimensions creates an infinite degree of variability in the attributes of ownership and leads to confusion when terms are incautiously used to describe broad ill-defined categories of property. The terms “common property” and “public goods” are notorious in this respect.

In the United States and many other nations, the legal definition of property rights is based on Roman law. In brief, Roman law recognized things that belonged to someone (rez in patrimonio) and things that were outside private ownership but could be acquired (rez extra patrimonium). The rights attached to the latter category depended on specific characteristics. Roads, harbors, and rivers were classified as public property (rez publicae). Public edifices were identified as

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2 It is important to differentiate between the role that fishery scientists play in predicting the likely outcome of alternative management actions and their advocacy for particular policies or outcomes. The goal of developing sustainable fisheries is a normative choice. The prediction that a particular management regime is unlikely to result in sustainability is a positive assessment and should not be assumed to represent a normative preference for that outcome.
institutional property (*rez institutiones*). Water, shorelines, fish, and wildlife were identified as common property (*rez communes*). Things that were incapable of ownership, had been abandoned, or had not yet been acquired by private interests were defined as unowned property (*rez nullius*). Common property and unowned property could be transformed into private property through capture (*occupatio*) or accretion (*accesio*). Thus fish in the wild are unowned but become private property when reduced to possession. (For additional detail see e.g., Adams 1993.)

These categories of property are represented in Figure 1 in terms of the extent to which nonowners are or can be excluded from using the property and in terms of the degree to which use by one person detracts from the amount or quality of resource available for use by others.

![Categories of property ownership and types of goods.](image)

Activities related to fisheries differ in exclusivity and rivalry. The owner of a private stocked pond has exclusive harvest rights and if she chooses to exercise those rights to take and consume a fish, the act of eating that fish is strictly rivalrous. An individual who sport fishes on a public stream is prohibited from excluding others from sportfishing on that stream. If he retains his catch, his activity is rivalrous. If he releases his catch, his fishing is nonrivalrous, but his presence on the stream may contribute to congestion. Benefits derived by individuals from knowledge of the continued existence of fish stock are nonrivalrous and nonexclusive. The "tragedy of the commons" (Hardin 1968) arises when resource use is rivalrous, access is nonexclusive, ownership is established by capture, and the individual benefits of resource use exceed the capture costs.

Because the beneficiaries of public goods are a large and diverse group, none of whom expects to capture exclusive benefits from any expenditure that they incur to provide the public good, many of those who benefit from the provision of the public good will freeride, gaining benefit in excess of their willingness to pay for actions that preserve or enhance the public good (Calabresi 1968). Consequently, individual consumers have an incentive to understate their willingness to
pay for goods that they cannot be excluded from enjoying and markets will provide suboptimal levels of public goods (Samuelson 1954).

There are two basic solutions to externalities and freerider problems: the adoption and enforcement of regulations and standards; or, design and adoption of more complete rights. Regulations are attempts to prevent undesirable but rational responses by fishers to the perverse incentives created by nonexclusive rights to rivalrous goods (NRC 1999b). Rights-based systems rely on the definition of more comprehensive rights in order to change the incentives presented to fishers.

Commercial and recreational fisheries have traditionally been managed under command and control systems consisting of regulations and standards that stipulate minimum or maximum size, open and closed seasons (days), maximum target and bycatch retention limits, sex, and permissible gear. For example, the Bristol Bay, Alaska salmon fishery is subject to maximum vessel length standards (32 feet), minimum gillnet mesh size standards (4 inches), limitations on the total number of participants (limited entry), and restrictions on fishing locations and times. Similarly, trout anglers may be subject to allowable gear standards (e.g., artificial flies only), retention limits (2 fish per day, 4 fish in possession), and slot size standards (e.g., a prohibition on the retention of fish under 14 inches or over 24 inches). The efficacy of command and control actions depends on the extent to which fishers can substitute unconstrained inputs or avoid being detected in violation of standards or regulations. Command and control systems may also include the use of fines, fees, taxes, or subsidies to induce fishers to internalize the negative or positive externalities associated with their actions. For example, the Vessel Incentive Program in the Bering Sea and Aleutian Islands groundfish trawl fishery was intended to induce avoidance of chinook bycatch by assessing a fine for each chinook caught. Similarly, recreational user fees reduce the extent to which recreators freeride on the cost of maintaining recreational areas.

Instead of arbitrarily specifying taxes, fees, subsidies, etc. in an effort to cause fishers to internalize the costs and benefits of their actions, the rights bundle could be more completely specified. Rights-based approaches involve the definition and enforcement of rights such that externalities and the opportunity to freeride are reduced. When the rights bundle is well specified, individuals have an incentive to defend the value of their property through negotiation and civil action (Coase 1960; Buchanan and Tullock 1962; Libecap 1989).

A Brief Review of the Development of Economic Thought About the Management of Fisheries

The underlying cause of problems in open-access fisheries has been attributed to incompletely specified property rights. Although theoretical and empirical analyses have demonstrated that sole ownership, individual quotas, territorial use rights, fishing cooperatives, and common property management regimes can promote biologically and economically sustainable fisheries, the focus of such analyses has been on the provision of use and option benefits and consequently may not address the sustainability of nonuse benefits.

Although Gordon (1953; 1954) and Scott (1955) established the economic benefits of sole ownership vis a vis open access, the special legal character of fishery resources has been has
been found to restrict the conditions under which exclusive use rights can be conveyed to individuals. The special legal attributes of fishery resources arise in part from what is commonly referred to as the Public Trust Doctrine. The Public Trust Doctrine is a portion of common law, derived from Roman civil law, which provides that certain waters, the lands beneath those waters, and the living resources within those waters are held in trust by the state for the benefit of citizens. One of the earliest applications of the Public Trust Doctrine argued before the U.S. Supreme Court was *Illinois Central R.R. Co. v. Illinois*, 146 U.S. (1892). The court found that title to public trust lands is:

"... different from the title the United States holds in the public lands which are open to pre-emption and sale. It is a title held in trust for the people of the States that they may enjoy the navigation of the waters, carry on commerce over them, and have liberty of fishing therein freed from the obstruction or interference of private parties.

... The State can no more abdicate its trust over property in which the whole people are interested, like navigable waters and the soils under them, so as to leave them entirely under the use and control of private parties than it can abdicate its police powers in the administration of government and the preservation of the peace."

Because public trust resources are held on behalf of the citizens, the State may be precluded from transferring comprehensive ownership rights to individuals. In general, conveyance of public trust resources to private ownership does not terminate the public's right of access or the State's responsibility for stewardship. Consequently, when a usufructuary right to harvest fishery resources is conveyed to individuals, the State continues to have responsibility for safeguarding the sustainability of those resources. The Endangered Species Act (ESA), the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), and international treaties reinforce the stewardship responsibilities implicit in the Public Trust Doctrine.

Because sole ownership is not legally viable or politically feasible, resource economists sought alternatives that might achieve comparable benefits. Christy and Scott (1965) and Gulland and Robinson (1973) suggested that binding input restrictions could potentially achieve efficiency gains comparable to those expected under sole-ownership. Several limited entry programs were implemented in the 1970's. However, wherever unrestricted substitute inputs existed, and unrestricted substitute inputs invariably existed, input limitation *per se* failed to control the race for fish and ensuing dissipation of resource rents. Evaluations of the outcome of limited entry programs can be found in *inter alia* Rettig and Ginter (1978), Adasiak (1979), Fraser (1979), Meany (1979), Pearse and Wilen (1979), and Wilen (1979). Despite the many documented examples of the inefficacy of input limitations, commercial fishery managers continue to implement input limitation programs. One recent example is the Individual Transferable Pot Quota (ITPQ) for spiny lobster (SAFMC 1992). While ITPQs place a limit on the number of units of fishing gear, they leave open the possibility of capital stuffing in unconstrained input factors and fail to address the externalities associated with gear conflict or stock depletion.

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The failure of input control programs led economists to suggest output controls in the form of individual quotas (Moloney and Pease 1979; Pease 1980; Morey 1980). The MSFCMA defines individual fishing quotas (IFQs) as limited access permits to harvest quantities of fish. Thus IFQs convey an exclusive usufruct to decide when and how to use the quota shares, but do not extend to ownership of the resource itself or the authority to decide how much of the resource can be harvested in aggregate. These latter remain the trust responsibility of the state. IFQs are best suited to fisheries managed by setting a Total Allowable Catch (TAC). Indeed, IFQs are commonly expressed as shares of the TAC, so that the annual realization of the IFQ fluctuates with variations in the level of the TAC. The TAC is usually determined on an annual basis by applying a target exploitation rate to an estimate of the current stock size. Determining the target exploitation rate and measuring the stock size are both subject to considerable uncertainty because of large variability in the relationship between stock size and subsequent recruitment and to general difficulty of accurately counting and measuring fish in the wild. Wilen (1985) and Scott (1988), among others, argue that harvest rights are secure, cheating is precluded, and there are no unique spatial or temporal concentrations that could lead to a race for fish, usufructuary rights will induce IFQ holders to behave in a manner analogous to a sole owner. Other authors (e.g. Johnson and Libecap 1982; Keen 1983) argue that more comprehensive rights, including the authority to independently determine harvest levels, are a necessary condition for economic efficiency.

Several IFQ programs were implemented during the 1980’s and 1990’s, including three in the U.S.: mid-Atlantic Surf Clam-Ocean Quahog (MAFMC 1990); South Atlantic Wreckfish (SAFMC 1992); and, North Pacific Halibut-Sablefish (NPFMC 1991). Evidence from the three U.S. IFQ fisheries suggests that IFQs have increased net revenues for the harvesters and integrated harvester-processors that were initial recipients of the IFQ, consolidated the number of active harvest platforms, and distributed landings over longer seasons (Gauvin et al. 1994; Casey et al. 1995; Wang 1995; NRC 1999b; Herrmann 1996, 2000). Evidence with respect to quota busting, highgrading, and bycatch is mixed (NRC 1999b). In addition, stock and production externalities have not been eliminated (Boyce 1992), wealth and opportunity of other stakeholders, e.g. processors, may have been reduced (Matulich et al. 1999; Matulich and Sever 1999), and rent-seeking associated with acquisition and defense of the IFQ may have dissipated much of the windfall gain associated with the initial distribution.

According to the conventional argument, adopting an IFQ will increase economic efficiency, improve conservation and stewardship, and improve safety. It is argued that excess harvesting and processing capacity leads to temporally compressed seasons, reduced exvessel prices, elevated harvesting costs, and consequently drives the expected value of net revenues to zero. Accordingly, the introduction of an IFQ program is expected to lead to increased exvessel prices (due to improved product handling and improved product flow to market) and cost savings (due to the discontinuation of the high-cost fishing practices followed under open access). Figure (2) depicts the effects of cost savings and a price increase.
In the absence of exclusive harvest rights, effort is expected to expand until the costs faced by the last entrant equal their expected average revenues, an outcome depicted in the first panel of Figure (3) as the intersection between the exvessel demand and average cost curves and corresponding to the intersection of the total revenue and total cost curves in the second panel of Figure (3). In contrast, a sole-owner would equate marginal revenue with marginal cost, thereby maximizing net revenues.

In this example, open access results in a sustainable yield of about 72 million pounds at an exvessel price of US$1.42 per pound, average costs equal to US$1.42 per pound landed, and zero net revenues. The sole owner would harvest a sustainable yield of about 42 million pounds at an exvessel price of US$2.21 per pound and earn net revenues of about US$72 million. The magnitude of net revenues gained by IFQ holders depends on the extent to which they collectively mirror the behavior of a sole owner.

Gear loss and gear conflict are commonly reported problems in temporally compressed fisheries. In addition, the ownership-by-capture rule discourages individual fishers from taking
conservation actions that could increase future catches but would reduce their current individual catch because they cannot be assured of benefiting from those increased future catches. Moreover under open access, other fishers would simply increase their current period catch to take advantage of any leftover TAC. Under IFQs, there is greater flexibility in selecting fishing time and area, with the possibility of reduced bycatch and greater product recovery. In addition, IFQ fishers may set (and lose) less gear, thereby reducing ghost fishing and damage that lost gear may cause to the marine environment. Consequently, IFQs are likely to reduce some of the stewardship problems that arise under open access. However, because IFQs are usufructuary rights to a share of the common resource and not rights to particular fish, shareholders have no assurance that others will refrain from practices that are contrary to the overall maximization of sustainable benefits and may conserve at less than the socially optimal level, especially when shareholders are numerous and heterogeneous (Ostrom 1990; Ostrom et al. 1994; Criddle and Macinko 2000). In addition, if the initial allocation of IFQs is through a political process, much of the potential net benefits of the IFQs could be dissipated in a race for quota shares (Kruger 1984; Anderson and Hill 1990; Criddle 1994).

Territorial Use Rights in Fisheries (TURFs) are spatially based individual or collective harvest privileges (Christy 1982; Sejo 1993). They are a special case of spatial harvest restrictions and have often been applied in less industrialized and smaller-scale coastal fisheries where management has been based on restricting participation to a localized population in a limited geographical area. Examples of TURFs include nearshore fisheries in Japan (Ruddle 1989) and Norway (Jentoft and Mikalsen 1994). Similar rights have been documented for fisheries in South America (Cordell and McKeans 1992; Gonzalez, 1996), the Caribbean (Berkes 1987), Asia Minor (Berkes 1986), the South Pacific (Goodenough 1951; 1963; Johannes 1978; Carrier 1987; Lieber 1994), and in North America (Higgs 1982; McEvoy 1986; Bay-Hansen 1991; Newell 1993; Agnello and Donnelley 1975; McCoy 1998; Acheson 1988).

Under a secure TURF management structure with durable and transferable rights, harvesters will select efficient levels of capital investment, and if the rates of larval dispersion and adult migration between areas are low, they will internalize the benefits of stock conservation (Criddle et al. 2001). However, it may be rational for TURF leaseholders to deplete the target stock if the stock has low productivity or if there is a high level of uncertainty about future stock abundance, price, or costs. Moreover, if the boundaries of the TURF are porous, that is, if it is difficult to control the number of participants, or if there is significant larval dispersion or adult migration, there will be an increased incentive to deplete the stock.

Commercial fishing cooperatives (Co-Ops) have recently emerged in fisheries off the Pacific Northwest and Alaska. Like IFQs, the Co-Op shares are use privileges that permit the shareholders to decide when and how to exercise their shares, but do not include ownership of the resource itself or the authority to select aggregate harvest levels above limits set by the State. Co-Op members rely on civil law to enforce contracts that partition the Co-Op’s share of the TAC. Co-Op formation depends on the existence of a closed class of similarly situated and motivated fishers and on an assessment by the Justice Department that the formation of the Co-Op is not a prima fascia violation of statutory prohibitions on anti-competitive behavior (Larkin and Sylvia 1999). Co-Ops are, effectively, sole-owners of a fixed percentage of the TAC and, through negotiated contract, partition that ownership among the Co-Op members. Initial
assessment of the outcomes of pollock Co-Ops in the Bering Sea suggests that product recovery rates have increased, that the mix of products has shifted to include a greater percentage of higher valued product forms, that product prices have increased, and that increased flexibility in harvesting and processing are thought to present opportunities for cost savings (NPFMC 2001). Felthoven (2001) demonstrates that the technical efficiency and capacity utilization of actively operated catcher-processors has increased under the Co-Ops when compared for the same vessels or firms in the years immediately preceding Co-Op formation. In comparison to IFQs, Co-Ops offer the potential advantage of smaller numbers and greater homogeneity among shareholders, thereby reducing transactions, monitoring, and enforcement costs (Olson 1965; Ostrom 1990; Ostrom et al. 1994). Consequently, Criddle and Macinko (2000) argue that Co-Ops are likely to generate greater aggregate net revenues and fewer stock externalities than IFQs. Townsend (1995; 1997) explores the hypothetical characteristics of a corporate approach to fisheries management similar to the North Pacific fishing Co-Ops.

While limited entry and IFQs, and to a lesser degree TURFs and Co-Ops, have attracted most of the attention of economists focused on commercial fisheries, it is important to note that numerous fisheries have been or continue to be managed as traditional commons without engendering a pathological race for fish. For example, most TURFs are based on custom and tradition and lack formal legal standing. The allocation of grazing resources in the western US during the late 1800’s (Anderson and Hill 1975; Dennen 1976) was based on a similarly extra­legal foundation. Although the establishment of mineral and water claims in the western US during the late 1800’s lacked a basis in US law, it was recognized and enforced in the mining camps and eventually codified as the Mining Law of 1872 and the doctrine of prior appropriation that governs water allocation in most of the western US. The decision to allocate a resource as a private or collective good is a matter of public choice. The consequences of the decision depend on the interplay between the intrinsic characteristics of the good (Figure 1) and the institutions created to support the allocation. Olson (1965), Ostrom (1990), Stevenson (1991), and Ostrom et al. (1994) develop theoretical conditions under which collective action may be preferred to private action. McCay and Acheson (1987), Berkes (1989), and Bromley (1992) include case studies of fishery and other resources that have been successfully managed as common property. However, when resource use is rivalrous, current resource appropriators are numerous, additional appropriators cannot be denied access, current and potential appropriators are heterogeneous, monitoring and enforcement is difficult, the commons devolves into open access, dissipating economic value an increasing the likelihood of overexploitation.

Thus far, the discussion has focused narrowly on the use benefits that accrue to commercial and artisinal fishers with no attention to changes in the welfare (consumer surplus) of those who purchase fish from the harvesters, no attention to the provision of sportfishing and related use values, and no discussion of the provision of nonuse values. In general, management regimes that reduce the quantity of fish harvested also reduce the magnitude of consumer surplus. Consequently, to the extent that IFQs, TURFs, Co-Ops, etc., successfully mimic sole ownership, they simultaneously reduce consumer surplus. The consequences of a tradeoff between harvester net revenue and consumer surplus will be explored in the theoretical model and empirical example developed below.
Although the model also includes a measure of the net economic benefits of sportfishing, it does not address the question of how the magnitude of sportfishing net benefits varies under alternative management regimes. Most North American sport fisheries are regulated open access resources; the number of entrants is unconstrained, but there are regulations to limit the choice of fishing technology and daily catch and possession. In a small number of sport fisheries, the total catch may be restricted with annual catch limits (e.g., no more than 5 king salmon per year from streams on Alaska’s Kenai Peninsula) or lotteries for a limited number of fishing-days on a particular stream system. In addition, some private firms use price to allocate sportfishing opportunities in put-and-take ponds. While most North American sport fisheries operate under some form of regulated open access, there are examples of rights-based sport fisheries in Europe and IFQs are being considered for the charter-based halibut sport fishery in Alaska. Private sport fisheries can exist in Europe because wild animals in situ were the property of the Crown rather than the people and in certain locations the Crown transferred durable ownership of fish and wildlife resources to private individuals. Consequently, private sportfishing clubs exist on many stream reaches in Europe where they hold comprehensive rights including the right to possession, the right to use, the right to manage, the right to compensation for damage to the resource, the right to consume the resource and the right to transfer ownership to others. When the U.S. gained independence from Great Britain, the Crown’s claim to fish and wildlife resources as well as the derivative claims of Crown grantees were disallowed and fish and wildlife became property of the citizens as a whole. The proposed implementation of an IFQ for charter-based halibut fishing has been motivated primarily as a pragmatic approach to depoliticize the allocation between sport and commercial fishers. The economic consequences of transforming a sport fishery from regulated open access to TURFs, IFQs, or another rights-based management regime are not yet well understood and the legality of such privatizations of public trust resources has not yet been established.

The provision of nonuse benefits is problematic because such benefits are usually assumed to be nonrival and nonexclusive. That is, one person’s enjoyment of nonuse benefits does not affect the supply of nonuse benefits available for the enjoyment of others and, it is difficult to exclude individuals from obtaining nonuse benefits. The consequence of these features is that individuals’ demand for nonuse benefits will be under-represented in market transactions. Unfortunately, the same factors that lead individuals to under-represent their value for nonuse benefits in market transactions lead them to over-represent their value for nonuse benefits when the cost of providing the benefits are shared with others. When the State retains stewardship responsibility for the resource, interested parties can lobby for management actions that are expected to increase nonuse benefits. Rights-based management regimes could be designed to allow interested parties to acquire harvest rights in an initial allocation or through subsequent transfer. Because limited entry programs do not convey a right to catch shares, acquisition and nonuse of limited entry rights is not likely to generate increased nonuse benefits. Although IFQs and Co-Ops entitle holders to shares of the TAC and thus unfished shares represent actual reductions to annual catch, any biomass carried over from one year to the next would simply increase the magnitude of quota shares for all shareholders in the ensuing year. Unfished TURFs are de facto aquatic reserves. Consequently for species with low migration rates, TURFs may offer greater potential for generating long term increases in nonuse benefits than other management regimes.
Maximizing Sustainable Net Benefits

The objective of sustainable fisheries management can be characterized as a constrained maximization of the net present benefits associated with the flow of use, option, and nonuse benefits over time:

\[
\text{Maximize } \quad NB = \sum_{t=t_0}^{T} \left( \frac{1}{1+r} \right)^t \left( NB_{\text{use}}, NB_{\text{option}}, NB_{\text{nonuse}} \right).
\]  

(1)

subject to  \( x_t = f_t \left( x_{t-k}, X_{t-k}, Y_{t-k} \right) - h_{t-1} \),

where  \( x_t \) is the current biomass of the  \( i \)-th age-class of the target species,  \( x_{t-k} \) is the lagged biomass of the target species,  \( X_{t-k} \) is a vector of the lagged biomass of species that are related to the target species through trophic or bycatch relationships in  \( t-k \), and  \( Y_{t-k} \) is a vector of lagged environmental factors that influence stock dynamics. Target species biomass is assumed to be an increasing (at a decreasing rate) function of the previous year’s biomass, a decreasing function of past harvests, and influenced by current and lagged environmental conditions and the current and lagged abundance of other species through trophic or bycatch relationships. That is,

\[
\frac{\partial x_t}{\partial x_{t-l}} > 0, \quad \frac{\partial^2 x_t}{\partial x_{t-l}^2} < 0, \quad \text{and} \quad \frac{\partial x_t}{\partial h_{t-1}} < 0, \quad \text{while}
\]

\[
\frac{\partial x_t}{\partial X_{t-k}}, \quad \frac{\partial^2 x_t}{\partial x_{t-j} \partial X_{t-k}}, \quad \frac{\partial x_t}{\partial Y_{t-k}}, \quad \text{and} \quad \frac{\partial^2 x_t}{\partial x_{t-j} \partial Y_{t-k}}
\]

could be positive or negative depending on the particular combination of variables and lags.

The discount rate  \( r \) reflects societal time preferences. Net use benefits (  \( NB_{\text{use}} \) ) in period  \( t \) include the benefits associated with commercial, recreational, subsistence, and other uses of the fishery resource:

\[
NB_{\text{use}} = f \left( NB_{\text{commercial}}, NB_{\text{sport}}, NB_{\text{subsistence}}, NB_{\text{other}} \right).
\]

Because net option benefits (  \( NB_{\text{option}} \) ) can be motivated as the present value of securing an option to derive net use benefits at some future time, they can be subsumed in the time stream of expected net use benefits. Net nonuse benefits (  \( NB_{\text{nonuse}} \) ) in period  \( t \) are related to the magnitude of present and future stock biomass:

\[
NB_{\text{nonuse}} = f \left( x_{t+k} \right).
\]
Limiting the solution to equation (1) to those cases where the expected stock is time invariant satisfies the requirement of biological sustainability. The additional requirement that the expected flow of net benefits not degrade through time, suggests that the solution to equation (1) must be subject to the constraint

\[
\frac{dNB}{dt} \geq 0.
\]

This constraint is satisfied if net benefits are constant through time and the discount rate is set to zero \((r = 0)\) or if the rate of increase of net benefits through time equals the social rate of discount. One characteristic of the optimal solution is that resources will be shifted among use and nonuse activities until marginal net benefits are equal across all activities.

Before proceeding to explore the properties of a specific application of this model, it is important to acknowledge some of the difficulties and limitations to this approach. Equation (1) assumes that all net benefits can be reified, estimated, and expressed in a dollar metric, and that it is meaningful to sum the suite of net benefits. In fact, nonuse benefits and some use benefits do not lend themselves to quantification, are difficult to estimate, and are not easily expressed in monetary terms. Moreover, a simple summation of net benefits may not reflect social preferences with respect to the mix of benefits provided or their distribution. A complaint often levied against models similar to equation (1) is that future generations are not expressly represented. This concern about intergeneration equity applies particularly to the case of exhaustible resources and irreversible investments. The concern about intergeneration equity does not apply for sustainably managed fishery resources except to the extent that it may take time to move from one particular sustainable allocation to another. If changes in social preferences could be predicted through time, it would be possible to arbitrage the transition from a currently preferred sustainable combination of use and nonuse benefits to a future preferred solution, thereby ensuring an optimal sustainable solution across generations. Perhaps the greatest limitation to the model developed in equation (1) is that uncertainty has been omitted. Figure 4 repeats the second panel in figures 2 and 3, but includes random draws from the distribution of the conditional residuals associated with the estimated price, cost, and fish population dynamic relationships.

![Figure 4. Variability in total revenues, total costs, and net revenues when prices, costs, and fish population dynamics are stochastic. In the first panel, total revenues are represented by diamonds and total costs are represented by circles.](image-url)
Neglect of uncertainty may lead to undue confidence in the choice of optimal sustainable harvest levels and allocations. Moreover, because society is unlikely to be neutral to the risks associated with uncertainty, the optimal sustainable solution when stock dynamics and economics benefits are stochastic fishery is likely to differ from the optimal solution when there is no uncertainty. There are three principle sources of uncertainty. First, the form of structural relationships governing the creation of net benefits and stock dynamics are unknown and may depend on unobservable causal factors. Second, structural relationships may change over time. Third, even when the structures of functional relationships are known stationary processes, there is error in the observation of outcomes. Standard stochastic simulation-optimization techniques can be used to address uncertainty associated with the estimation of structural relationships. Criddle and Havenner (1991) develop an approximation approach that addresses the problem of model specification. The solution of an optimal control problem similar to equation (1), but with approximate structural relationships, is presented in Criddle (1993). Addressing the uncertainty associated with nonstationarities in the structural relationships is particularly challenging. If the nature of possible changes is predictable, conditional stochastic simulations (see e.g., Criddle et al. 1998) can be used to address the problem of nonstationary structural relationships. Uncertainty associated with changes in the behavior of structural relationships cannot be modeled if the character of such changes cannot be anticipated. Management strategies developed without consideration of uncertainty are unlikely to be optimal and are likely to be infeasible (see e.g., Criddle 1996; Criddle and Streletski 2000) when model structure is unknown or when observation of the structural relationships is subject to error. Nevertheless, for didactic simplicity, the model developed below will assume that structural relationships are known, time-invariant, and observed with certainty.

A Simulation-Optimization Model of the Commercial and Sport Fisheries for Pacific Halibut in the North Pacific

The general results derived above can be demonstrated in an empirically based model of the commercial and sport fisheries for Pacific halibut (*Hippoglossus stenolepis*) in the North Pacific. For simplicity, the model will ignore age-class structure and interactions among species. In addition, the model only considers net use benefits associated with commercial and recreational fishing. The representations of commercial and sport fishery bioeconomics are based on Criddle (1994) and Herrmann et al. (2001), respectively.

The net benefits of commercial and sportfishing can be defined as the sum of net revenues and post-harvest surplus in the commercial fishery, and the net benefits of sportfishing:

\[
NB_{\text{use}} = NB_c + NB_s = TR_c - TC_c + CS_c + NB_s.
\]

(1')

where \(NB_s\) is the net benefit of sportfishing and \(NB_c\) the net benefit of commercial fishing. The net benefit of commercial fishing is equal to the sum of commercial consumer's surplus (\(CS_c\)) and the difference between total commercial revenues (\(TR_c\)) and total commercial costs (\(TC_c\)). Total commercial revenues are the product of exvessel price (\(p_x\)) and the commercial harvest
If exvessel demand is represented by a simple linear price dependent relationship and average costs are modeled as a function of fishing effort, the exvessel market for halibut can be represented by

\[ p_t = a + b(h_{c,t}) = 3.301 - 0.026(h_{c,t}) \]

\[ AC_{c,t} = \frac{1}{h_{c,t}} cca h_{c,t}^{0.5} x_t^{0.5} = 5.015 \left( \frac{h_{c,t}^{0.322}}{x_t^{0.598}} \right) \]

Figure 5.—Exvessel demand and supply of halibut.

where commercial consumer’s surplus \( C_{Se} \) is represented by the integral between the exvessel demand curve and the market clearing price and commercial net revenues \( TR_c - TC_c \) are represented by the integral between the market clearing price and average cost.

The magnitude commercial net revenues can also be represented as the difference between total commercial revenues and costs:

\[ NR_c = TR_c - TC_c = ah_c + bh_c^2 - ccx h_c^{0.5} x_t^{0.5} \]

This relationship is depicted in Figure (6).

Figure 6.—Commercial net revenues.

The sustainable yield \( h_{SY,t} \) is represented as a simple polynomial of biomass:

\[ h_{SY,t} = \frac{1}{h_{c,t}} cca h_{c,t}^{0.5} x_t^{0.5} \]

\[ $125 \]

\[ $100 \]

\[ $75 \]

\[ $50 \]

\[ $25 \]

\[ $0 \]

0 20 40 60 80

Sustainable Yield (million lbs.)
Equations (2) and (3) can be combined to identify total and net sustainable commercial revenues.

\[ h_t = (\gamma_1 - 1)x_t + \gamma_2 x_t^2 = 0.443(x_t) - 0.00068(x_t^2). \]  

(3)

Consequently, the magnitude of the sustainable yield varies in relation to biomass.

\[ \text{Figure 7.—Sustainable yields.} \]

Equations (2) and (3) can be combined to identify total and net sustainable commercial revenues.

\[ \text{Figure 8.—Commercial net revenues.} \]

Because exvessel price is inversely related to the magnitude of commercial harvests, commercial total revenues are maximized at harvest levels below \( h_{MSY} \). In addition, because search costs are inversely related to biomass, commercial net revenues are maximized when biomass is above the biomass that maximizes sustainable yields (\( x_{MSY} \)).

Because exvessel demand was modeled as a simple linear price dependent function of commercial catches, the corresponding consumer’s surplus can be represented as:

\[ CS_{c,t} = \int \left( f(h_{c,t}^*) - p_t^* \right) dh_{c,t} = \frac{1}{2} \left( a - (a + bh_{c,t}) \right) h_{c,t} = 0.013(h_{c,t}^2) \]

(4)

\[ \text{Criddle and Havenner (1991) motivate this simple representation as a formal approximation of latent dynamic processes.} \]
That is, commercial consumer’s surplus is a strictly increasing function of the level of commercial harvests. Because the sustainable yield is maximized at intermediate levels of biomass, commercial consumer’s surplus is largest at $x_{MSY}$.

![Graph](image)

Figure 9.—Commercial consumer’s surplus.

Commercial net revenues (equation 2) and commercial consumer’s surplus (equation 4) combine to form total commercial net benefits

$$NB_c = TR_c - TC_c + CS_c = ah_c + bh_c^2 - c\alpha h_c^{\beta} x^{\beta}; - \frac{1}{2} bh_c^2 = ah_c + \frac{1}{2} bh_c^2 - c\alpha h_c^{\beta} x^{\beta};$$

(5)

Figure (10) depicts the relationship between total costs, total revenues, and net revenues as a function of the magnitude of sustainable yields and the status halibut stocks.

![Graph](image)

Figure 10.—Consumer’s surplus, harvester net revenues, and total net benefits of commercial fishing.

The association between commercial net benefits and biomass indicates that combined net revenues and consumer’s surplus is maximized at a lower level of biomass and correspondingly higher sustainable yield that the maximization of commercial net revenues alone. That is, when benefits to consumers are treated on an equal footing with benefits to harvesters, the optimal harvest level differs from the level that would be optimal from the perspective of a sole-owner or a group of quota shareholders who behave analogously.
The net benefits of sportfishing are defined as the sum across individuals of the net benefits received conditional to the decision to participate in the sportfishing activity. Herrmann et al. (2001) use a random effects probit model to estimate the probability of taking a halibut sportfishing trip based on trip attributes and demographic characteristics:

$$P(participation_i) = \eta_0 + \eta_i P_t + w_i^T B w_i + n_i^T \lambda n_i + z_i^T v,$$

(6)

where $P_t$ is the price of taking a halibut sportfishing trip, $n_t$ and $w_t$ are vectors catch by species, number, and weight, and $z_t$ are demographic characteristics used as proxies for unobservable tastes and preferences that influence the probability of participation. Conditional individual participation probabilities are aggregated into estimates of total demand using a simulation-based sample enumeration method (BenAkiva and Lerman 1985) that takes into account differences in demographic characteristics and variability in the number of days fished per year by developing forecasts for each individual in the sample. Changes in the probability of individual participation lead to shifts in the total demand for sportfishing trips and to changes in angler welfare.

If all factors except expected catch per trip are held constant, the relationship between changes in expected catch and changes in participation is represented by:

![Figure 11.—Percentage change in the probability that the average sport fisher will participate as a function of changes in expected halibut catch.](image)

Following Hanemann (1999), conditional estimates of angler welfare ($NB_s$) are calculated from the estimated participation rate model as the product of the weighted average compensating variation per trip taken and the total number of angler-days spent fishing. The relationship between sportfishing net benefits and percentage changes in expected angler success is represented in Figure 12.
Figure 12.—The effect of changes in expected halibut catch on the magnitude of total compensating variation.

These percentage changes can be rescaled as changes in the expected number of trips taken as a function of changes in the average catch per trip.

Figure 13.—Changes in the number of sportfishing trips taken as a function of average catch per trip.

The demand for sportfishing trips can also be mapped as a function of the number of trips taken:

Figure 14.—Angler demand and average cost per trip.
In this projection, sportfishing net benefits are the integral between angler demand and the average cost function. This relationship can be projected into a space representing sportfishing net benefits as a function of total sportfishing catches.

\[ NB_s \left( \frac{\$}{lb} \right) = \theta \left( \frac{1}{h_s + 1} \right) = $19.872 \left( \frac{1}{h_s + 1} \right) \]  \hspace{1cm} (7)

Figure 15.—Marginal sportfishing net benefits.

The associated total level of sportfishing net benefits is the integral of the marginal net benefits

\[ NB_s = \phi \ln(h_s + 1) = 17.634 \ln(h_s + 1) \]  \hspace{1cm} (8)

This relationship can be represented graphically as:

Figure 16.—Total angler surplus as a function of the sustainable yield.

Taken alone, the sportfishing model suggests that angler net benefits \( NB_s \) will be maximized under a maximum sustainable yield management strategy, but that the incremental net benefits are very low for allocations greater than 20-30 million lbs.

The commercial and sport fishing models represented in equations (5) and (8) and Figures (10) and (16) represent exclusive allocations to either sport or commercial fishing. The problem posed in equation (1') involves equating marginal net benefits across sport and commercial fishing. That is, the problem requires a simultaneous selection of a level of sustainable yield and an allocation of that sustainable yield between sport and commercial fishers. The commercial and
sport fishing models developed in equations (5) and (8) can be combined to restate the optimization model in equation (1):

\[
\text{Max}(NB_c + NB_s) = TR_c - TC_c + CS_c + NB_s = ah_c + \frac{1}{2} b h_c^2 - ca h_c^{\beta_1} x^{\beta_2} + \phi \ln(h_s + 1) \tag{1''}
\]

\[
\text{s.t. } h_t = h_{c,t} + h_{s,t} = (\gamma_1 - 1) x_t + \gamma_2 x_t^2
\]

The solution to this constrained optimization can be found by solving a related unconstrained (Lagrangian) function formed by augmenting the objective with the constraint:

\[
\text{Max}(L) = ah_{c,t} + \frac{1}{2} b h_{c,t}^2 - ca h_{c,t}^{\beta_2} x^{\beta_2} + \phi \ln(h_{s,t} + 1) + \lambda_t \left( h_{c,t} + h_{s,t} - (\gamma_1 - 1) x_t - \gamma_2 x_t^2 \right) \tag{1'''}
\]

Setting the derivatives of this Lagrangian function with respect to the control variables \((h_{c,t}, h_{s,t})\) and Lagrange multipliers \((\lambda_t)\) equal to zero, yields a set of necessary conditions for an optimum.

If \(w = x_t^{\beta_2}\) and \(z \equiv (\gamma_1 - 1)^2 + 4 \gamma_2 h_t\), then \(x_t = \left( \frac{1}{2 \gamma_2} \right) (\gamma_1 - 1) \pm \left( \frac{1}{2 \gamma_2} \right) z^{\frac{1}{2}}\), and the marginal net benefits of commercial fishing are:

\[
\frac{dL}{dh_c} = a + bh_c - ca \left( \beta_1 h_c^{\beta_1 - 1} w + h_c^{\beta_1} \frac{dw}{dh_c} \right) = a + bh_c - ca \left( \beta_1 h_c^{\beta_1 - 1} w + h_c^{\beta_1} \frac{dw}{dx} \frac{dx}{dz} \frac{dz}{dh_c} \right) + \lambda. \tag{7}
\]

Where

\[
\frac{dw}{dx} = \frac{d(x^{\beta_2})}{dx} = \beta_2 x^{\beta_2 - 1}
\]

\[
\frac{dx}{dz} = \frac{d \left( \left( \frac{1}{2 \gamma_2} \right) (\gamma_1 - 1) \pm \left( \frac{1}{2 \gamma_2} \right) z^{\frac{1}{2}} \right)}{dz} = \pm \left( \frac{1}{4 \gamma_2} \right) z^{-\frac{1}{2}} = \pm \left( \frac{1}{4 \gamma_2} \right) \left( (\gamma_1 - 1)^2 + 4 \gamma_2 (h_c + h_s) \right)^{-\frac{1}{2}}
\]

\[
\frac{dz}{dh_c} = \frac{d \left( (\gamma_1 - 1)^2 + 4 \gamma_2 (h_c + h_s) \right)}{dh_c} = 4 \gamma_2
\]

So,

\[
\frac{dw}{dh_c} = \pm \beta_2 x^{(\beta_2 - 1)} \left( \frac{1}{4 \gamma_2} \right) \left( (\gamma_1 - 1)^2 + 4 \gamma_2 (h_c + h_s) \right)^{-\frac{1}{2}} (4 \gamma_2) = \pm \frac{\beta_2 x^{(\beta_2 - 1)}}{\sqrt{(\gamma_1 - 1)^2 + 4 \gamma_2 (h_c + h_s)}}.
\]

\[\text{See e.g., Clark (1976, 1985); Bjørndal (1988); Hannesson (1993).}\]
Thus the marginal net benefits of commercial fishing can be represented by:

\[
\frac{dL}{dh_c} = a + bh_c - ca\left(\beta_1 h_c^{(\beta_1-1)} w + h_c^{\beta_2} \frac{dw}{dh_c}\right) + \lambda
\]

\[
= a + bh_c - ca\left(\beta_1 h_c^{(\beta_1-1)} x^{\beta_2} \pm h_c^{\beta_1} \beta_2 x^{(\beta_2-1)} \left((\gamma_1 - 1)^2 + 4\gamma_2 (h_c + h_s)^2\right)^{\frac{1}{2}}\right) + \lambda
\]

\[
= a + bh_c - ca\beta_1 h_c^{(\beta_1-1)} x^{\beta_2} \pm ca h_c^{\beta_1} \beta_2 x^{(\beta_2-1)} \left((\gamma_1 - 1)^2 + 4\gamma_2 (h_c + h_s)^2\right)^{\frac{1}{2}} + \lambda
\]

The marginal net benefits of sport fishing are:

\[
\frac{dL}{dh_s} = \frac{d\phi \ln(h_s + 1)}{dh_s} + \lambda = \theta\left(\frac{1}{h_s + 1}\right) + \lambda.
\]

The total net benefits of commercial and sport fishing are maximized when the marginal net benefits of commercial fishing are equated with the marginal net benefits of sport fishing:

\[
\frac{dL}{dh_c} = a + bh_c - ca\beta_1 h_c^{(\beta_1-1)} x^{\beta_2} \pm \frac{ca h_c^{\beta_1} \beta_2 x^{(\beta_2-1)}}{\sqrt{(\gamma_1 - 1)^2 + 4\gamma_2 (h_c + h_s)^2}} + \lambda = \theta\left(\frac{1}{h_s + 1}\right) + \lambda = \frac{dL}{dh_s}.
\]

The Lagrange multiplier \(\lambda\) represents the marginal net benefit of an increase in the sustainable yield associated

\[
\frac{dL}{d\lambda} = h_c + h_s - (\gamma_1 - 1)x + \gamma_2 x^2
\]

Using equations (7) and (8) to allocate the sustainable yield between commercial and sport fishers results in the sport and commercial catch levels depicted in Figure (17):

Figure 17.—Optimal allocation of sustainable yield.
The optimal allocation of the sustainable yield to commercial and sport fisheries depends on the level of stock biomass. Because the marginal net benefits of sport fishing exceed the marginal net benefits of commercial fishing at low sustainable yields, catch is first allocated to the sport fishery. As the quantity of fish allocated to the sport fishery increases, the marginal net benefit of additional sport fish catches declines. When the marginal net benefit of sportfishing drops below the marginal net benefit of commercial fishing, subsequent harvest shares are allocated to the commercial fishery. The optimal total net benefits of commercial and sportfishing are represented in Figure 18.

Figure 18.—Net benefits of optimal allocations of sustainable yield. Thin lines in the second panel represent sustainable yields at biomasses below \( x_{MSY} \). Thick lines in the second panel represent sustainable yields at biomasses above \( x_{MSY} \).

At low biomass levels, the marginal net benefits of commercial fishing are so small that most of the sustainable yield is allocated to the sport fishery. At intermediate levels of biomass, the marginal net benefits of commercial fishing increase and an increasing large share of the sustainable yield is allocated to the commercial fishery. At very high biomass levels, the sustainable yield is small and it is optimal to allocate most of the sustainable yield to the sport fishery. The sum of sport and commercial net benefits is maximized at a biomass of 443.5 million lbs. with catches of 44.9 million lbs allocated to the commercial fishery and 18.0 million lbs allocated to the sport fishery (Tables 1 and 2). The relationship between the sustainable yield and sport, commercial, and total net benefits is reflected in the second panel in Figure 18. The upper arms of the total and commercial net benefit curves correspond to biomasses above \( x_{MSY} \). The upper arm of the sportfishing net benefits curve corresponds to biomasses below \( x_{MSY} \).

---

8 It is important to acknowledge that this result is probably an artifact of the model specification. The data available for estimating a sportfishing net benefits function did not allow for estimation of the relationship between average trip costs and halibut population size. It is likely that the cost of catching a halibut increase as population size declines. Consequently, the net benefits of sport fishing are probably overstated at low levels of biomass.
The optimal allocation rule is perhaps easiest to recognize when the shares to sport and commercial fishers are represented as percentages of the sustainable yield (Figure 19):

![Graph showing optimal allocation of sustainable yield](image)

Figure 19.—Optimal allocations of sustainable yield. Thin lines in the second panel represent sustainable yields at biomasses below $x_{MSY}$. Thick lines in the second panel represent sustainable yields at biomasses above $x_{MSY}$.

Figures 17 and 18 depict the optimal allocation of sustainable yields and the net benefits associated with those yields. The overall optimal solution to equation (1'') is to manage for a biomass of 443.5 million lbs and to allocate 71% the 62.9 million lbs sustainable yield to the commercial fishery, with the balance allocated to sportfishing. The overall optimal solution is estimated to provide US$55.2 million in net revenue to commercial harvesters, US$26.2 million in consumer surplus to the purchasers of commercial catches, and US$51.9 million in net sportfishing benefits (Table 2). There are several reasons why the fishery might not be managed for the overall optimal solution. In addition to the problems of model misspecification and uncertainty described above, the presence (absence) and characteristics of rights-based management programs will influence the likelihood that the overall optimal solution will emerge. In addition, because the overall optimal solution is suboptimal with respect to the provision of net benefits to different stakeholders. Consequently, the actual solution may closely reflect the preferences of politically empowered stakeholders. Tables 1 and 2 characterize the distribution of catch and benefits under a variety of management regimes. Value to the sport and commercial fisheries is independently optimized in the solutions reported in Table 1 and jointly optimized in the solutions reported in Table 2.
Table 1.—Characteristics of alternative management regimes independently optimized for commercial or sport fishing.

<table>
<thead>
<tr>
<th></th>
<th>Open Access</th>
<th>Max(SY)</th>
<th>Max(NRc)</th>
<th>Max(CS&lt;sub&gt;c&lt;/sub&gt;)</th>
<th>Max(NB&lt;sub&gt;c&lt;/sub&gt;)</th>
<th>Max(NB&lt;sub&gt;s&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass (million lbs.)</td>
<td>444.5</td>
<td>326.1</td>
<td>536.5</td>
<td>326.1</td>
<td>490</td>
<td>326.1</td>
</tr>
<tr>
<td>Commercial catch (million lbs.)</td>
<td>62.7</td>
<td>72.3</td>
<td>42.2</td>
<td>72.3</td>
<td>54.0</td>
<td>0</td>
</tr>
<tr>
<td>Sport catch (million lbs.)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>72.3</td>
</tr>
<tr>
<td>Price (US$)</td>
<td>$1.12</td>
<td>$1.42</td>
<td>$2.21</td>
<td>$1.42</td>
<td>$1.90</td>
<td>-</td>
</tr>
<tr>
<td>Effort (million skates)</td>
<td>0.167</td>
<td>0.381</td>
<td>0.055</td>
<td>0.381</td>
<td>0.100</td>
<td>0</td>
</tr>
<tr>
<td>Commercial net revenue (US$ million)</td>
<td>0</td>
<td>-$41.9</td>
<td>$72.0</td>
<td>-$41.9</td>
<td>$64.4</td>
<td>0</td>
</tr>
<tr>
<td>Consumer's surplus (US$ million)</td>
<td>$51.1</td>
<td>$67.8</td>
<td>$23.1</td>
<td>$67.8</td>
<td>$37.9</td>
<td>0</td>
</tr>
<tr>
<td>Commercial net benefits (US$ million)</td>
<td>$51.1</td>
<td>$25.9</td>
<td>$95.1</td>
<td>$25.9</td>
<td>$102.2</td>
<td>0</td>
</tr>
<tr>
<td>Sport net benefits (US$ million)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$75.7</td>
</tr>
<tr>
<td>Total net benefits (US$ million)</td>
<td>$51.1</td>
<td>$25.9</td>
<td>$95.1</td>
<td>$25.9</td>
<td>$102.2</td>
<td>$75.7</td>
</tr>
</tbody>
</table>

The open access solution (Table 1) represents a fishery managed without consideration of benefits to commercial consumers or sport fishers and where the commercial fishers are unable to agree to behave like a sole owner. While the open access solution does not provide positive net benefits to sport or commercial fishers, it provides substantial (US$51.1 million) net benefits to the purchasers of commercially harvested fish. This result provides an explanation for why processors often oppose the implementation of rights-based fishery management programs. In a purely commercial fishery, maximization of sustainable yields generates US$67.8 million in net benefits to fish purchasers and net operating losses of US$41.9 million for commercial fishers. Consequently, it is extremely unlikely that commercial fishers would harvest the MSY. Net sportfishing benefits are maximized when commercial fishing is disallowed and catches approximate MSY. A sole owner of an exclusively commercial fishery would choose to harvest a sustainable yield of 42.2 million lbs, earning US$72 million in net revenues and coincidentally providing US$23.1 million in net benefits to fish purchasers. If fishery managers were interested in maximizing the total net benefits of commercial fishing, they would set the TAC equal to 54 million lbs and implement regulations to induce commercial harvesters to behave like a sole owner. In so doing, the commercial fishery would generate total net benefits of US$102.2 million; US$64.4 million in net revenue for harvesters and US$37.9 million in net benefits for fish consumers.

The solutions represented in Table 2 maximize net benefits to various stakeholders conditional on the optimal allocation of sustainable yields between the commercial and sport fisheries.
Table 2.—Characteristics of alternative management regimes jointly optimized for commercial and sport fishing.

<table>
<thead>
<tr>
<th></th>
<th>Max(SY)</th>
<th>Max(NRₜ)</th>
<th>Max(CSₜ)</th>
<th>Max(NBₜ)</th>
<th>Max(NBₛ)</th>
<th>Max(NB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass (million lbs.)</td>
<td>326.1</td>
<td>512.1</td>
<td>422.5</td>
<td>474.5</td>
<td>192.3</td>
<td>443.5</td>
</tr>
<tr>
<td>Commercial catch (million lbs.)</td>
<td>37.1</td>
<td>37.4</td>
<td>45.3</td>
<td>42.7</td>
<td>8.9</td>
<td>44.9</td>
</tr>
<tr>
<td>Sport catch (million lbs.)</td>
<td>35.2</td>
<td>11.4</td>
<td>20.6</td>
<td>14.6</td>
<td>51.2</td>
<td>18.0</td>
</tr>
<tr>
<td>Price (US$)</td>
<td>$2.34</td>
<td>$2.33</td>
<td>$2.12</td>
<td>$2.19</td>
<td>$3.07</td>
<td>$2.13</td>
</tr>
<tr>
<td>Effort (million skates)</td>
<td>0.136</td>
<td>0.066</td>
<td>0.117</td>
<td>0.089</td>
<td>0.048</td>
<td>0.107</td>
</tr>
<tr>
<td>Commercial net revenue (US$ million)</td>
<td>$34.9</td>
<td>$61.9</td>
<td>$51.7</td>
<td>$59.5</td>
<td>$9.2</td>
<td>$55.2</td>
</tr>
<tr>
<td>Consumer’s surplus (US$ million)</td>
<td>$17.8</td>
<td>$18.1</td>
<td>$26.7</td>
<td>$23.6</td>
<td>$1.0</td>
<td>$26.2</td>
</tr>
<tr>
<td>Commercial net benefits (US$ million)</td>
<td>$52.8</td>
<td>$80.0</td>
<td>$78.4</td>
<td>$83.1</td>
<td>$10.2</td>
<td>$81.4</td>
</tr>
<tr>
<td>Sport net benefits (US$ million)</td>
<td>$63.3</td>
<td>$44.3</td>
<td>$54.2</td>
<td>$48.5</td>
<td>$69.7</td>
<td>$51.9</td>
</tr>
<tr>
<td>Total net benefits (US$ million)</td>
<td>$116.1</td>
<td>$124.3</td>
<td>$132.6</td>
<td>$131.6</td>
<td>$80.0</td>
<td>$133.3</td>
</tr>
</tbody>
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The first thing to notice in Table 2 is that the overall optimal solution is inferior to all other solutions from the perspective of at least one of the three stakeholders represented in the optimization model. From the perspective of commercial fishers, the solutions that maximize commercial net revenues, commercial net benefits, and even net benefits to fish consumers are all preferred to the solution that maximizes overall net benefits. Similarly, sport fishers prefer solutions that maximize net angler benefits, maximize sustainable yields, or maximize net benefits for commercial consumers. Another important result presented in Table 2 is that consideration of the joint benefits of commercial and sport fishing provides larger overall net benefits than are generated when the goal of fishery management is solely motivated by an interest in maximizing net benefits to commercial or sport fishers (Table 1). The results also emphasize the importance of considering the benefits that accrue to those who purchase commercial catches.

Although the solutions that maximize overall net benefits, maximize the net benefits for purchasers of commercial catches, or maximize the net benefits of commercial fishing produce similar levels of overall benefits, they involve quite different allocations between sport and commercial fisheries. This suggests that even when the fishery is managed to maximize net benefits across multiple stakeholders, there may be considerable flexibility in the choice of who to favor in the allocation. That is, there are multiple nearly equally efficient solutions with differing distributional consequences. Consequently, even if all of the stakeholders agree to abide by a solution that maximized net benefits across uses, they will probably contest the allocation decision.

If the demand for commercially harvested fish increases (decreases), the optimal solution can be expected to allocate a larger (smaller) catch to the commercial fishery. Decreases (increases) in the cost of commercial harvests can be expected to have similar effects. Increases in the cost of travel to Alaska can be expected to reduce the net benefits of sportfishing, implying that reallocating the sustainable yield in favor of the commercial fishery would maximize the overall net benefits. Changes in population (of people) or average income influence the demand for commercial catches and the demand for sportfishing opportunities and will have an indeterminate effect on the magnitude of the optimal sustainable yield and the optimal allocation of between sport and commercial fisheries. If sportfishing demand changes to favor an increased level of catch-and-release fishing, the overall optimal solution can be expected to include increased commercial catches. Changes in ocean productivity that affect the carrying capacity or
the intrinsic population growth rate of halibut will also affect the optimal sustainable yield and the optimal allocation of that sustainable yield.

Because changes in ocean productivity, changes in the demand or supply functions in the commercial fishery, and changes in the willingness to pay and participation cost function in the sport fishery affect the optimal sustainable yield and the optimal allocation of the optimal sustainable yield, any initially optimal allocation will be suboptimal in subsequent periods. Consequently, allocations would need to be revisited whenever the economic or biological conditions change. Rather that address the between user-group allocation decision through political processes, it might be possible to design a system of transferable harvest privileges or territorial use rights that could shift the burdensome allocation battles from the management arena into the market place.

Although the model developed in this section did not represent nonuse benefits or use benefits such as subsistence harvests, it is possible to anticipate how the optimal solution would change if such values had been modeled. Mathematically, the economics of subsistence fisheries resemble sport fishery economics. The net benefits of subsistence fishing could be estimated using contingent valuation techniques, perhaps developed in a willingness to be compensated framework rather than a willingness to pay framework. The net benefits of subsistence fishing are likely to be an increasing (at a decreasing rate) function of catch. Including a subsistence fishery would involve a three-way allocation of the sustainable yields and probably suggest an optimal solution closer to the maximum sustainable yield solution. If nonuse benefits were assumed to be an increasing function of biomass, including nonuse benefits in the model would shift the optimal solution towards higher levels of biomass with correspondingly lower sustainable yields partitioned among the users.

**Practical Opportunities and Limitations for Maximizing Sustainable Net Benefits**

Theoretical models and empirical evidence suggest that when compared to regulated open access, rights-based management systems increase harvester net revenues, increase overall net economic benefits, improve safety, and increase conservation and stewardship incentives. The opportunity for increased harvester net revenues is greatest when the rights are transferable, that less economically efficient fishers will find it advantageous to sell their quota shares or spatial use rights to more efficient fishers. To the extent that stock conservation and stewardship increase the capitalized value of quota shares, transferability encourages the most responsible fishers to acquire additional spatial use rights or quota shares. If rights can be defined in a way that is meaningful across use and nonuse values and to the extent that all use and nonuse values can be fully captured, self-interest and transferability will encourage the movement of the quota shares/spatial use rights to the use/nonuse that generates the greatest marginal net benefit, ensuring the maximization of overall net benefits. The appeal of rights-based management systems lies in their potential to channel rational self-interest in a way that coincidentally maximizes overall net benefit. Because they exploit an alignment of individually rational actions and socially optimal outcomes, rights-based management are potentially self-regulating. Although theoretically possible, the knowledge and control needed to maximize overall net
benefit through command and control systems is overwhelming and such systems have failed to yield sustain overall net economic benefits or the resource base on which they depend.

With the apparent advantages of rights-based management systems, it seems reasonable to wonder why IFQs, Co-Ops, and TURFs have not been warmly embraced and uniformly adopted. The answer is that the creation and enforcement of rights is not costless (Anderson and Hill 1975; Dennen 1976). Because it can be costly to change the legal and social institutions that have been developed to support current fishery management systems and because it can be costly to monitor and enforce quota shares or spatial use rights, especially when there are numerous rights-holders, rights-based management systems will be less prevalent than might otherwise be anticipated. Moreover, the advantages of rights-based systems are reduced when the rights cannot be defined in a way that allows meaningful transfer across categories of use and nonuse stakeholders, when the opportunity to freeride on nonuse benefits cannot be eliminated, or when the benefits (costs) of individual stewardship are not fully captured by the self-same individuals. With the foregoing caveats in mind, the following section will speculate on the practical opportunities for using economic incentives to ensure that the flow of use, option, and nonuse benefits is not degraded through time.

Commercial Fisheries—Economic incentives can be designed to increase the internalization of stock externalities in rights-based commercial fisheries. This could be accomplished by coupling the rights-based approach with performance standard or through unbundling the set of rights embodied in the quota share or spatial use right. Examples of the former include overlapping fixed period leases with renewal based on performance, zero-revenue auctions with performance standards reflected in the resale provisions, and combinations of fees, taxes, and subsidies based on performance standards.

The design and performance of an overlapping lease system are described in Young and McCay (1995). In brief, fixed period multi-year leases are granted to current fishers. Before the lease period expires, fishers are offered an opportunity to switch to new fixed period leases that would commence in the next time period and be operative for some time beyond the terminal year for the current lease. The new lease could include stewardship requirements that are more stringent than those required under the current lease. For example, the new lease might require reduced bycatches of non-target species or the adoption of gear designed to have fewer undesirable effects on benthic communities. Fishers who willingly shift to the new leases gain the advantage of longer economic planning horizons.

Zero-revenue auctions (Hausaker 1992) are used to encourage the adoption of sulfur dioxide emissions reducing technology in mid-west US power plants. Under the Clean Air Act Acid Rain Program, approximately 3% of all emission rights sunset annually. Government auctions the released rights, with all sales proceeds going to the individuals whose rights were attenuated. NRC 1999b suggests that inclusion of similar provisions in a rights-based fishery could be used to ensure that at least a minimum volume of rights would be released to the market at regular intervals and that the transactions would reveal information about the value of the rights. The zero-revenue auction structure lends itself to modifications that could improve resource stewardship. For example, organizations representing nonuse beneficiaries could acquire quota shares or spatial use rights through competing in the auction. In a similar manner, the
management agency could retire a portion of the attenuated rights, thereby reducing total catch, and in the case of TURFs, creating Marine Protected Areas. This type of fractional reduction of rights has been used in the Florida spiny lobster fishery to reduce fishing capacity (SAFMC 1992). It would also be possible for fishery managers to attach performance criteria to the rights released through the zero-revenue auction. For example, exercise of the auctioned rights might be subject to more stringent bycatch standards or gear restrictions. While differing from zero-revenue auctions in many respects, the annual contract negotiations related to community development quotas (CDQs) in Alaska’s groundfish fisheries suggest that a variety of social objectives (e.g. employment and training opportunities) can be built into the auction fishing rights (NRC 1998).

Overlapping leases and zero-revenue auctions use voluntary market transactions to influence resource stewardship. It is also possible to use regulations, taxes, fees, and subsidies in combination with rights-based management systems to encourage additional conservation and stewardship. For example, the CDQ and Co-Op fisheries for walleye pollock (*Theragra chalcogramma*) in the Bering Sea are subject to bycatch caps intended to minimize adverse impacts on other directed fisheries. The CDQs and Co-Ops are also subject to time and area closures intended to reduce the possibility that those fisheries could jeopardize recovery of Steller sea lion (*Eumetopias jubatus*) populations. Taxes, fines, fees, and subsidies affect harvester net revenues and consequently influence fishing activities. For example, the adoption of measure to reduce seabird bycatch has been accelerated by the US Fish and Wildlife Service’s decision to subsidize the purchase of paired streamer lines. Fines for individuals who exceed their quotashare or catch non-target species encourage fishers to avoid bycatch and overages. Differential taxes or fees can be designed to affect the amount of bycatch taken and the types of gear employed in the fishery.

Property rights represent a bundle of entitlements and obligations. It may be possible to encourage conservation and stewardship by refining the scope and scale at which the rights are defined and allowing transfer of fractional rights. For example, there is probably some price at which halibut IFQ holders would agree to forgo the right to fish in a region of particular interest to sport fishers. Because halibut quota shares are currently defined on a gross geographic scale, it would be difficult to engineer such an agreement. However, if managers agreed to help monitor and enforce voluntary small-scale spatial partitioning, for example by requiring vessel transponders and releasing data on locations fished, it is possible that commercial fishers could be induced to fish outside areas of interest to sport fishers. Note that in this example, the commercial fishers did not transfer their quotashare, they transferred their right to fish their quota share in a section of the management area. The Nature Conservancy and Ducks Unlimited have actively employed similar fractional rights transfers to obtain conservation easements from landholders. Similarly, if the bundled target-bycatch quotashares in the Bering Sea CDQ and Co-Op fisheries were unbundled, halibut or crab fishers could encourage bycatch reductions in the by purchasing the bycatch rights.

If rights can be defined on a natural spatial/temporal scale, a scale at which there is little overlap (through migration etc.) with the rights of other holders, stock externalities will be minimized and the value of good stewardship will be capitalized in the value of the quotashare or spatial use right. Stock externalities can also be minimized if the number of shareholders fishing a given
stock is small enough for the benefits of collective action to offset the private benefits of reneging on the collective agreement.

**Sport Fisheries**—The large number and complex motivations of actual and potential participants complicate the design of economic incentives to reduce stock and congestion externalities in sport fisheries. Command-control systems including site-specific user fees, gear restrictions, catch, and retention have the potential for constraining total removals and congestion, but they do not ensure that net sport fishing benefits will be maximized or that there is an optimal allocation among use categories or between use and nonuse of fishery resources. An option that could be useful in some sport fisheries would be to adopt an annual lottery based allocation such as that used for many big-game hunting opportunities. Because every applicant has an equal probability of receiving a permit and because the number of permits is set to avoid overexploitation of the stock, a lottery would be unlikely to conflict with interpretations of the Public Trust doctrine. If lottery winners are permitted to auction their permits, individuals who place the greatest value in sportfishing for a particular species at a specific location will be able to obtain permits. Equity concerns are at least partially satisfied by the fact that every applicant has an equal opportunity of being drawn and that permit sales are voluntary. By itself, a lottery-auction allocation does not address stock externalities as well as they might be addressed under longer-term rights. However, it is difficult to imagine how long-term rights could be designed to be consistent with current interpretation of the Public Trust doctrine.

The potential utility of economic incentives for encouraging sustainable sport fisheries is perhaps greatest in the interface between sport fisheries and rights-based commercial fisheries. While there are few such interfaces at this time, there are several fisheries where sport fishing is a substantial component of fishing mortality and where the commercial sector could be organized under a rights-based system. The proposed introduction of IFQs for halibut charter vessels in Alaska and the possibility that quota shares may be transferable between the sport and commercial fisheries has the potential to reduce allocation battles between commercial and a large share of the sport fishery. Although it is difficult to imagine individual sport fishers or charter operators acquiring enough quota shares to internalize the stock externality, it is not inconceivable that groups of operators could collectively manage their quota shares to avoid localized depletion problems.

**Nonuse Beneficiaries**—The challenge of eliminating the freerider problem is central to any attempt to reflect nonuse values in the design of sustainable fisheries. While freeriders are an important problem in the sport fishery, the set of participants provides a good indication of who benefits from sportfishing. In the case of nonuse benefits, it may be impossible to identify the set of beneficiaries let alone estimate the magnitude of net benefits that they would derive under alternative fishery management strategies. Nevertheless, the freerider problem has not prevented the Nature Conservancy or Ducks Unlimited from obtaining conservation easements or outright ownership of lands that provide nonuse benefits to their memberships. Consequently, the existence of freeriders may pose a lesser impediment to the expression of nonuse benefits than is posed by the lack of property rights. Suppose for a moment that all nonuse beneficiaries could be convinced to contribute their full willingness to pay into a fund dedicated to sustainable fisheries. If the fishery is managed under regulated open access rules, the way to express the nonuse value would be to engage in lobbying the management agency and any gains in nonuse benefits would
be obtained as uncompensated losses to fishers. It would be as though Ducks Unlimited were precluded from purchasing lands and conservation easements and reduced to buying advertisements that encourage landowners to voluntarily adopt duck friendly farming practices. While the advertisements might influence some landowners, it is likely that more could be influenced if they were offered cash compensation. In a rights-based fishery it could be possible for nonuse values to be reflected in the acquisition of spatial use rights or quotashares. As an added consequence of owning fishing rights, the nonuse beneficiaries would face the opportunity cost of leaving their rights unfished. When faced with those opportunity costs, it is not unlikely that they would choose to exercise a portion of the fishing right. (See e.g. Baden and Stroup 1981)

**Conclusion**

The NRC review of sustainability in marine fisheries (NRC 1999a) concludes: “universal application of conservative management on a single-species basis would go a long way toward reducing overexploitation of the world’s marine fisheries.” Similarly, good management of fisheries for use benefits would go a long way towards preserving the time stream of use, option, and nonuse benefits. The OECD Committee for Fisheries (OECD 1997) concludes that: “Experience has shown that a regime which does not adequately limit fishing capacity may lead to overexploitation and poor economic performance. In addition, management regimes which limit the total catch, or the number of fishing vessels, or which restrict the efficiency of the harvesting sector, including technical measures and TACs, have generally yielded poor results when used in isolation i.e. without complementary measures.” The suggested complementary measures include limited entry permits, IFQs, TURFs, and community based management systems. Hanna and Munasinghe (1995a, 1995b) conclude that property rights regimes can play a crucial role in harnessing market forces to support sustainable resource use. In the conclusion to his examination of sustainable fishery systems, Charles (2001) emphasizes the advantage of rights-based self-regulatory institutions. He notes that rights-based management systems “help to clarify the roles and responsibilities of the various players in the fishery, and thereby steer incentives in the desired direction.” However, he cautions that “an inappropriate rights system can lead to undesired consequences, such as a loss of resilience in communities of institutions”.

This chapter has little to add to the findings of previous studies; the key impediment to sustainable use and option values is the lack of clearly articulated property rights. In commercial fisheries, the ownership by capture rules lead harvesters to dissipate net revenues and encourages uneconomic and biologically unsustainable harvest levels. In sport fisheries, the lack of effective limits on the number of sport fishers and magnitude of sportfishing catches has led to substantial reductions in the commercial TACs that may have reduced overall net benefits to society. When political muscle is the basis for allocating TAC among commercial, sport, and subsistence users, the resultant allocations cannot be expected to maximize overall net economic benefits. The key impediments to the provision of nonuse benefits arise from their character as public goods and the difficulty of eliminating opportunities for beneficiaries to freeride.

A necessary condition for fully harnessing the self-regulating power of markets to constrain harvests and adjust the allocation fishery resources is the creation of meaningful and enforceable
in situ rights. While it may not be possible to create an ideal set of rights, it should be possible to improve on the status quo. IFQs, Co-Ops, and TURFs have been found to address many of the economic inefficiencies that characterize traditional commercial fisheries. Broadening the ownership criteria to allow other stakeholders the opportunity to acquire and own quota shares or spatial use rights may be possible. For example, it is easy to imagine that a group of sport or subsistence fishers or nonuse beneficiaries could ensure their interest in the fishery through acquisition of TURFs: TURFs have been used to allocate harvest rights in some European sport fisheries; TURF-like rights have been recognized for Native Americans in several US and Canadian fisheries; and, TURFs are analogous to the land holdings and conservation easements that the Nature Conservancy, Ducks Unlimited, and similar organizations have acquired to secure use and nonuse benefits for their membership. Annual individual harvest rights are being considered as a mechanism for allocating sportfishing opportunities in big game fisheries. Permanent IFQs are being examined as a mechanism for addressing the allocation of halibut TAC between commercial fishers and charter operators in Alaska. Because IFQs and Co-Op shares are based on a percentage of the annual TAC, the potential nonuse benefits of acquiring and holding quota shares generate a stock externality in favor of commercial, sport, and subsistence fishers. Nevertheless, nonusers could potentially acquire enough quota shares to influence overall stock levels for some species in some regions. While these solutions will not eliminate all externalities or opportunities to freeride, they are likely to promote sustainability to a greater degree than the status quo.

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ECONOMIC PRINCIPLES OF SUSTAINABLE MULTIPLE-USE FISHERIES MANAGEMENT

by

KEITH R. CRIDDLE

Department of Economics
Utah State University
3530 Old Main Hill
Logan, UT 84322-3530

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Keith R. Criddle

ABSTRACT

Economic prescriptions for the sustainable management of fisheries have typically been framed in the context of commercial fisheries. Fishery management failures have been characterized as a consequence of disjointedness between individually rational decisions and globally sensible outcomes—the “tragedy of the commons”. The solutions proposed by economists flow from the insight that rational self-interest can lead to socially beneficial outcomes when ownership is secure and prices reflect the opportunity cost of resource use. Theoretical and empirical analyses have demonstrated that sole ownership, individual quotas, territorial use rights, fishing cooperatives, and common property management regimes can promote biologically and economically sustainable fisheries. Nevertheless, implementation of these “solutions” has met with resistance, due in part to the impossibility of uncoupling species within ecological systems and conflict between the proposed solutions and broadly accepted concepts of social justice. The problem of devising a sustainable management strategy is exacerbated in fisheries with diverse consumptive and non-consumptive users. An empirically based simulation-optimization model is used to characterize the biological and economic effects of alternative management regimes in a fishery with commercial and sport fishers. The results are generalized to the case of additional use and nonuse values.