Symposium:
Rights-Based Fisheries Management

Property Rights in Fisheries: How Much Can Individual Transferable Quotas Accomplish?

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Introduction

Although most ocean fisheries are biologically and technically capable of yielding high net economic returns on a sustainable basis, tragically few actually do. In fact, taken as a whole, ocean fisheries appear to yield very small or even negative net economic returns. A study by the World Bank and FAO (2009) found that in 2004 the global ocean fishery operated at a significant net economic loss financed by government subsidies. By contrast, the study found that if properly managed, the global fishery could yield positive net returns of more than 50 percent of revenues on a sustainable basis. This global study confirms the findings of numerous case studies of individual fisheries.[1]

It is important to understand that the economic failure of ocean fisheries is not caused by the inherent attributes of the resources themselves. From an economic perspective, ocean fish stocks are not fundamentally different from other renewable natural resources such as forests, grasslands, or salmon rivers from which substantial sustainable economic benefits are routinely generated. The economic failure of ocean fisheries is entirely manmade. It is the result of an inappropriate institutional framework for the harvesting activity. This institutional framework is known as the common property—or common pool—arrangement (Hardin 1968, Ostrom 1990), according to which anyone belonging to a certain social group, often the whole nation, is entitled to harvest from the fish stocks. The outcome of this common property rights arrangement usually consists of decimation of valuable fish stocks, distortion and damage to the marine

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I would like to thank the editor of the journal and two anonymous referees for extremely useful comments on an earlier draft of this article. Thanks to them, this version is much improved. All remaining defects are, of course, my responsibility.

[1]There are a great number of case studies of this kind of widely varying quality and publication form. References to some of these studies can be found in Rodrigues (1990), Wallace and Olafsson (1994), National Research Council (1999), Shotton (2000), Hatcher et al. (2001), and World Bank and FAO (2009).

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ecosystem, and a virtually complete loss of any attainable net economic benefits from the fishery. This outcome was aptly described by Hardin (1968) as the "tragedy of the commons." It is usually referred to as the common property or common pool problem, but it is more helpful to view it as a result of inadequate property rights.

It has been recognized for a long time that property rights constitute a foundation for economic efficiency (Aristotle 1981/322 BC; Hume 1969/1739; Smith 1977/1776). This role of property rights has been explained more systematically by the New Institutional Economics (e.g., see Eggertsson 1990; Furubotn and Richter 2003) and enjoys considerable support from numerous empirical studies especially in connection with land use (e.g., see Alston, Libecap, and Cueller 1999; Scott 2008). The theoretical arguments are simple enough. It is well known that the two pillars of economic efficiency and progress are specialization in production and accumulation of capital (Barro and Sala-i-Martin 1995; Smith 1977/1776). Neither can occur without property rights. Specialization in production cannot occur without trade. Trade, in turn, requires property rights: after all, trade is nothing but the exchange of property rights. Without property rights, the accumulation of capital is not individually attractive because any accumulated capital will be seized by others. With property rights, however, savings and accumulation of physical, human, and natural capital can become individually profitable. Thus, with property rights in place, both specialization in production and accumulation of capital can take place. In fact, if it is individually beneficial, it will. Moreover, trade gives rise to markets, and the resulting market prices will serve as a guide for Pareto optimal allocation of resources and overall coordination of economic activity (Debreu 1959).

On this basis, it should be clear that to generate efficiency in fisheries, that is, to solve the fisheries problem, it is sufficient to establish adequately high-quality property rights in the fishery.[2] The problem is that, in contrast to land-based production, we do not have good property rights technology for fisheries. At sea, there is nothing corresponding to the barbed wire to keep fish enclosed, nothing corresponding to cattle or sheep markings to identify the owner of individual fish, and no way to keep fertile ocean masses within a predesigned area. It follows that less than perfect property rights have to be employed in fisheries.

The most common types of these less than perfect property rights used in ocean fisheries are territorial use rights (TURFs) and individual quotas (IQs) that may be transferable (ITQs). Under TURFs, fishers are allocated a certain area of the ocean, very much like a plot of land, for their exclusive use. The problem with this approach is that most species of fish (not to mention their eggs and larvae) move around so much that either the TURFs would have to be huge in order to enclose them (White and Costello 2011) or additional coordination mechanisms are required (Kaffine and Costello 2011). As a consequence, TURFs are generally applied only to relatively sedentary species such as certain species of shellfish. ITQs are rights to harvest a certain volume of fish. While ITQs are more widely applicable than TURFs, they are not property rights in the resources themselves (i.e., the fish stocks and their ocean habitat). This limitation severely reduces the quality of ITQs as property rights and therefore their effectiveness in maximizing the flow of economic benefits from the fishery.

[2]High-quality property rights are sufficient to generate efficiency because (a) they make efficient operations possible and (b) the initial lack of efficiency implies that the opportunity to obtain efficiency will be used.

This article, which is part of a symposium on rights-based fisheries management,[3] examines the properties of ITQs and their ability to generate economic efficiency in fisheries. It is shown that ITQs can greatly improve the efficiency of fishing compared to the common property arrangement. Moreover, including commercial and recreational fishers in the same ITQ system will, virtually automatically, generate the socially optimal balance between commercial and recreational fishing. However, it is also shown that ITQs, on their own, are not capable of generating full efficiency in the use of marine resources. In particular, the existence of an ITQ system is not sufficient for setting the socially optimal total allowable catch (TAC), ensuring the optimal use of the ecosystem, or harmonizing the fishing activity with other uses of marine resources that affect or are affected by fishing. For these purposes, the property rights embedded in ITQs are simply too limited.

The good news is that ITQs generate individual incentives and provide a certain platform for ITQ holders to collectively set up auxiliary arrangements to maximize the overall benefits of marine use (Arnason 2009a). This is because the market value of the ITQ rights increases with the overall efficiency of the fishery and, under certain circumstances, the efficiency of marine resource use in general. Thus, for instance, ITQ holders seeking to maximize the value of their ITQ asset have an incentive to collectively manage ecosystem use so as to maximize the total value of the fishery (Arnason 2009a). Generally, this implies a much higher degree of ecosystem conservation and protection than is usually associated with fisheries, even relatively well-managed ones. Moreover, and potentially even more importantly, ITQ holders as a group have an incentive to negotiate a mutually beneficial arrangement with other users of the marine resources whose activities affect or are affected by the fishery. These alternative marine uses include coastal or marine tourism, ocean energy production, mining, and conservation.

The next section provides a brief review of property rights theory and how property rights promote economic efficiency. A thorough understanding of this theory is essential for judging the potential effectiveness of fisheries management systems, including ITQs. This is followed by a section on the key properties of ITQs and how they can promote efficiency in fishing. The next two sections deal respectively with (s) theoretical limitations of ITQs as a tool for generating efficiency in fisheries and (b) inefficiency caused by imperfect application of ITQs in actual fisheries. Following this is a section outlining how ITQs may help in optimally balancing fishing with other types of marine resource use. The application of ITQs in the world's fisheries is summarized in the ensuing section. The main findings of the article are recounted in the final section.

The Essential Theory of Property Rights

Property rights are multidimensional. They consist of a bundle of characteristics or sub-rights, the most important of which seem to be (a) exclusivity, (b) durability, (c) security, and (d) tradability (Scott 1989, 2008). Exclusivity refers to the ability of the property rights holder to utilize his property as he sees fit and prevent others from using it. Obviously, the greater this ability, the higher is the exclusivity. Durability refers to the time span of the property right. The

[3]The other articles are by Deacon (2012), who focuses on harvester cooperatives, and Wilen, Cancino, and Uchida (2012), who examine TURFs. Costello (2012) introduces the symposium and provides an overview of the main issues and challenges concerning rights-based fisheries management.

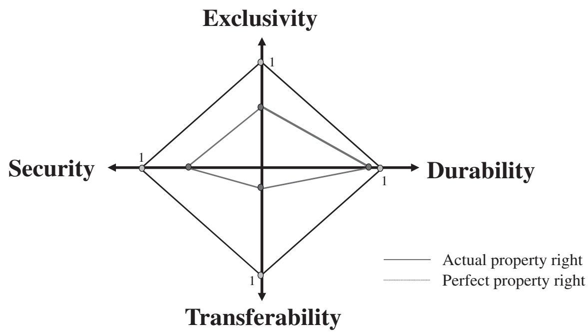

Figure 1 The characteristic footprint (quality map) of two property rights

longer this time span, the more durable the property right. Security refers to the ability of the property rights holder to hold on to his property rights in the face of challenges such as theft or other types of expropriation. Finally, tradability refers to the ability of the property rights holder to sell his or her property right in whole or in part.

The Characteristic Footprint of Property Rights

Obviously, the extent of all of these property sub-rights can be greater or smaller. It is convenient to measure their extent on a scale from zero to unity, with zero meaning nothing and unity meaning full extent of the sub-right. With the help of this numerical convention, the quality map or characteristic footprint of any property right can be illustrated with a radar diagram as in figure 1. In this diagram the extent of each of the four sub-rights is measured along an axis over the interval [0,1]. Obviously, if more than four property sub-rights are thought to be important, they could be represented in the same way by additional axes. The lines connecting the extent of each sub-right form the characteristic footprint of the property right. The larger the characteristic footprint of a property right, the higher is its quality (Arnason 2000).

Figure 1 presents the characteristic footprints of a perfect property right and a less than perfect property right, labeled "actual property right." The perfect property right, with quality values at unity for each sub-right, has the highest quality and the largest characteristic footprint possible. Real property rights cannot be perfect in this sense. For instance, there is always some, albeit minuscule, likelihood that it will be lost. Therefore, by necessity, the characteristic footprint of any real property right is totally enclosed within the characteristic footprint of the perfect property right. The ratio of the area enclosed by the actual property right in figure 1 relative to that of the perfect property right (always less than unity) provides some idea of the quality of the actual property right.

Drawing of the characteristic footprints of the property rights defined by different fisheries management regimes[4] provides an effective and convenient way to quickly compare the quality of these rights and, as a result, the probable economic efficiency of the management regimes. Notably, this approach has been used extensively to compare dozens of rights-based fisheries management systems, including ITQs, in the European Union (MRAG et al. 2009).

[4]The term *fisheries management regime* incorporates the fisheries management system as well as the enforcement of this system.

A Numerical Measure of Property Rights Quality

Given the multidimensional nature of property rights, it is useful to have a numerical measure of the quality of a given property right. Many such measures are conceivable. One such, the so-called *Q*-measure of property rights, was defined in Arnason (2000). For the four sub-rights discussed earlier, the *Q*-measure is defined by:

$$Q = E^{\alpha} \cdot D^{\beta} \cdot S^{\gamma} \cdot \left(w_1 + w_2 \cdot T^{\delta}\right),$$

where *E*, *D*, *S*, and *T* denote the degree of exclusivity, durability, security, and tradability, respectively, measured, as previously discussed, from zero to unity. The parameters α, β, γ, and δ are positive weights reflecting the impact of the respective sub-right on the *Q*-value. The positive parameters w_1 and w_2, which sum to unity, indicate the weight of tradability relative to the other three sub-rights. Note that this formula for the *Q*-value can be extended to include any number of sub-rights (Arnason 2000).

The *Q*-measure just defined always lies in the interval [0,1] with "0" indicating a property rights quality of zero and "1" a perfect property right. Note also that if any of the sub-rights, exclusivity, durability, and security are zero, the *Q*-value of the property right will be zero. This is to reflect that a positive level of these sub-rights is necessary for any property right to have a value. Thus, for instance, a property right with duration of zero is obviously worthless. The same applies to a property right with no exclusivity or no security. By contrast, tradability is obviously not an essential sub-right. The *Q*-value of a property right, therefore, could be positive even if its tradability was zero. In this way, as well as by allowing different weights for the various property sub-rights, the *Q*-measure is more general than the graphical information contained in the characteristic footprint of a property rights. Note further that the *Q*-measure as defined here allows for substitutability between the various sub-rights. Thus, for instance, given a certain level of security and tradability, there is a range of exclusivity and durability combinations that would produce the same *Q*-measure.

Property Rights and Economic Efficiency

Property rights and their quality are of key economic importance because of their close connection to economic efficiency and progress. In a fundamental sense, property rights are necessary for a high level of production per capital and economic growth (Arnason 2000; Demsetz 1967). More to the point, it has been shown that economic efficiency in resource use, including fisheries, increases monotonically with the quality of the property rights on which the resource use is based (Arnason 2007; Grainger and Costello 2011). The detailed arguments for this result are too lengthy to be recounted here. The basic rationale, however, is that with perfect property rights (implying inter alia no externalities), individual maximization problems coincide with the social problem. Reducing the quality of property rights by shortening their duration, limiting tradability, reducing the security by which the rights are held, or diminishing the exclusivity of the rights leads, via the process of benefit maximization, to adjustments in how the right is used. Thus it implies diverting production activity away from what is socially optimal. Moreover, as is easy to show, the greater the deviations from perfect property rights the greater the distortions.

These general results about the relationship between the quality of property rights and efficiency in resource use apply also to fisheries. It follows that the effectiveness of an ITQ or another fisheries management system in generating efficiency in fisheries depends positively on the quality of the property rights defined by that system. This is a potentially very useful result because it is usually much easier to assess the changes in property rights quality associated with some proposed changes in the fisheries management system than to investigate the efficiency of the proposed system more directly.

ITQs: Basic Theoretical Properties

As discussed in the introduction, ITQs are rights to harvest a certain volume of fish. They may (but are not required to) be held by individual agents, and they have at least some degree of tradability. It is important to recognize that because ITQs are not property rights in fish, fish stocks, or the aquatic habitat, they cannot constitute high-quality property rights in these underlying natural resources. At best, ITQs provide certain indirect rights in these resources. Thus, even a perfect ITQ right would usually confer only limited-quality property rights in the fundamental marine resources that sustain fisheries.

ITQs: Essential Structure

The essential structure of an ITQ system is simple enough. It consists of two fundamental components: (a) the total allowable catch and (b) individual shares therein. The first is usually referred to by the acronym TAC. The second may be referred to as *quota shares*. It is convenient to refer to quota shares symbolically as $a(i,t)$, where i refers to the agent holding the share and t to time. By the design of the ITQ system, the quota shares sum to unity.

The multiple of the TAC and an agent's quota share defines his or her *quantity quota* at time, t:

$$q(i, t) = a(i, t) \cdot TAC(t)$$

Thus the ITQ system gives rise to two assets: the quota share, $a(i,t)$, and the quantity quota, $q(i,t)$. The quota share is the basic asset. The quantity quota is a derived one. The quota share has a degree of permanence (durability). It can even be of infinite duration. The quantity quota, by contrast, lasts only as long as the season for which the TAC is defined.

Variants of the ITQ System

There are many possible variants of the basic ITQ system defined here. The variants are often in terms of the key property sub-rights already discussed and thus affect the property rights quality of the ITQ system. An ITQ system with full exclusivity, security, duration, and tradability may be called perfect. Real ITQ systems are not perfect in this sense. Most often the deviations are in terms of (a) duration of the rights, (b) the degree of tradability of the rights, and (c) the extent of quota use exclusivity. Security is high in most systems. In addition to this, there are commonly limitations on who can hold ITQs. This, however, is rarely restrictive enough to have a significant impact on the quality of the ITQ property rights. Nontradable ITQs are referred to as IQs. ITQs attached to fishing vessels are sometimes referred to as individual vessel quotas (IVQs). The term *individual fishing quotas* (IFQs) incorporates both IQs and proper (i.e., tradable) ITQs.

For analytical purposes it is important to distinguish between continuous ITQ systems with TACs set continuously at each point of time and discrete ITQ systems where the TACs are for certain discrete periods. Real ITQ systems are invariably of the discrete type. Continuous ITQ systems are analytically more tractable. For that reason, theoretical analysis of the properties of ITQ systems is usually conducted in terms of continuous ITQ systems. The implicit assumption is that the practical difference between the two types of systems is negligible.

ITQ Prices

The two assets defined by the ITQ system, the quantity quota and the quota share, may be traded. Trading modifies individual quota holdings over time and generates market prices for the two assets. These prices, usually referred to as quota prices, reflect the economic efficiency of the system. As such they convey important information that can be of great use to fisheries managers.

Let us now briefly review some basic results for quota prices in a continuous ITQ system. First, if quantity quotas can be freely traded, it can be shown that in temporary market equilibrium the price of quantity quotas equals the marginal profits of using these quotas (Arnason 1990).[5] This result is economically obvious. Why would anyone sell their quota for less or buy it for more than the marginal profits they obtain from using it for fishing? Therefore, in trading equilibrium, it must be true that the marginal profits of using a quantity quota equal the quantity quota price. It immediately follows (provided that at each point of time there is only one market price for quantity quotas) that all active fishing firms must be operating at the same level of marginal profits. In other words, the fishing activity is efficiently allocated among the fishing firms. Importantly, by simply monitoring the quantity quota prices (usually easily observed in the market), the fisheries authorities can follow the development of marginal profits in the fishery.

It can also be shown (Arnason 1990) that trading equilibrium implies a certain dynamic relationship between the quota share price and the quantity quota price. The essence of this relationship is that the instantaneous opportunity cost of holding quota shares must equal the instantaneous gain of holding these quota shares in terms of (a) fishing profits and (b) capital gains or losses stemming from changes in the quota share price.[6] If this condition does not hold, then profit maximizing firms can obviously gain by buying or selling quota shares. Thus this relationship is essentially a market arbitrage condition familiar from modern finance theory (Neftci 1996). The relationship is also the fundamental economic condition for socially optimal quota share allocation over time that is implied by the maximization of the present value of benefits from the fishery over time (subject, of course, to the TAC). That this optimality relationship is generated by the ITQ system further establishes its inherent dynamic efficiency.

[5]Formally this is expressed as $v(t) = \pi_h(t)$, where $v(t)$ is the quantity quota price and $\pi_h(t)$ represents the marginal profits of harvest at time t.

[6]The formal expression is $r \cdot s(t) = v(t) \cdot TAC(t) + \dot{s}(t)$, where r represents the rate of discount, $s(t)$ the price of quota shares at time t, $v(t)$ the price of quantity quotas at time t, TAC(t) the total allowable catch at time t, and $\dot{s}(t)$ is the instantaneous change in the price of quota shares at time t.

Note, however, that this relationship only holds perfectly if the quota shares are (a) fully exclusive, (b) fully secure, (c) fully transferable, and (d) have at least some degree of permanence. In other words, if the property rights quality of the quota shares is diminished along any of these dimensions, optimal quota share allocation is unlikely to occur over time.

Further, it can be shown that the price of the quota shares equals the expected present value of the economic rents from using them for fishing in the future (Arnason 1990).[7] The practical importance of this relationship is that if the duration of the ITQ right is infinite in addition to being fully exclusive, secure, and transferable, then the current market value of quota shares will equal the expected present value of the fishery. Moreover, the expected value of the fishery depends only on the future path of TACs (in addition, of course, to the current biomass). Thus the fisheries manager only has to observe the quota share prices in order to set TACs that maximize the value of the fishery (Arnason 1990). It is important to note that this result also proves that an ITQ system with full exclusivity, security, durability, and tradability of quota rights maximizes the value of the fishery subject to the TACs that are set.

For discrete ITQ systems, similar but more complicated expressions for quota prices can be obtained. Although it is possible to show that discrete ITQ systems are economically superior to many management alternatives, they cannot attain the theoretical full efficiency property of continuous ITQ systems. This is because discrete quota periods allow ITQ holders to strategically arrange their harvesting activities over the TAC period and thus reintroduce some of the competition for catch that ITQs are designed to eliminate (e.g., see Arnason 1990; Boyce 1992; Costello and Deacon 2007).

Efficiency of ITQs

Efficient fishing operations may be divided into static allocative efficiency and dynamic allocative efficiency. The first consists of an efficient application of current fishing capital to fishing, employment of the most efficient fishing gear, fishing methods, and so on. Dynamic allocative efficiency includes the most efficient timing of the fishing activity and landings and optimal investment/disinvestment in fishing capital and similar decisions. It may be noted that static and dynamic allocative efficiency is essentially the same as what Grafton et al. (2000) refer to as technical and allocative efficiency in fishing.

ITQs, provided they represent high-quality property rights in the sense of exclusivity, durability, security, and tradability, almost automatically guarantee efficient fishing (Arnason 1990; Grafton, Squires, and Fox 2000; Shotton 2000). With secure quantity quotas in hand, there is no sense in excessive application of capital to fishing and every reason to use the most efficient fishing gear and fishing methods as well as finding other ways to enhance the net value of the quota. Moreover, with the help of quota trades, the harvesting activity will be allocated to the right number of the most efficient fishers. If at any point that is not the case, there will be profitable quota trading opportunities. Finally, with secure long-term quota shares, fishers are in a position to make long-term plans and, consequently, adjust their capital holdings to what is

[7]Formally, this may be expressed as $s(t) = E\left(\int_t^T \pi_h(\tau) \cdot TAC(\tau) \cdot e^{-r \cdot \tau} d\tau\right)$, where $s(t)$ is the total market value of quota shares, $\pi_h(\tau) \cdot TAC(\tau)$ is economic rents at time τ, and the term $e^{-r \cdot \tau}$ is the discount factor at time τ. The upper limit of the integral, T, is the time at which the quota share is terminated (possibly infinity); and the symbol "E" is the statistical expectation operator. This is needed because the variables under the integral are all uncertain future values that quota traders need to know in order to form expectations.

optimal in the long term. Needless to say, these efficiency gains will be faster and more complete the higher the quality of the property rights embedded in the ITQs. It is important to realize, however, that this efficiency of the fishing activity is conditional on the TACs that are set.

Inherent Limitations of ITQs

Fisheries efficiency involves at least four distinct components:

(1) An efficient fishing activity
(2) The optimal path of biomass over time
(3) Optimal evolution of the marine ecosystem and habitat
(4) Optimal harmonization of fishing with other uses of marine resources

We have already seen that the ITQ system, provided the ITQ rights are of sufficiently high quality as property rights, will lead to efficient fishing activity. We now consider the other dimensions of fisheries efficiency.

Optimal Path of Biomass over Time

For optimal fishing, the biomass has to evolve optimally over time. This path is partly controlled by the TACs that are set. The optimal TAC at a point of time depends on all the current and future conditions in the fishery and is therefore very difficult to determine. The ITQ system does not automatically set the optimal TAC. However, certain features of the ITQ system greatly facilitate the identification and setting of the best possible TAC (Arnason 1990). As discussed earlier, the optimal TAC at each point of time corresponds to the maximization of the quota share price, provided, of course, that the ITQ property rights are of sufficiently high quality. This implies that the TAC-setting authority does not have to engage in extensive data collection and calculations to set the best possible TAC. It only needs to adjust the TAC until the share quota price is maximized. Another implication is that profit maximizing ITQ holders will be greatly in favor of setting this optimal TAC because that also maximizes the market value of their share quota asset. Thus sociopolitical opposition to sensible TACs, common under many other fisheries management systems, tends to be transformed into support under the ITQ system. This effect, however, depends critically on the property rights quality of the ITQs. The weaker it is, the weaker this effect will be.

Optimal Evolution of the Marine Ecosystem

There is nothing in the ITQs system that deals with the problem of optimal management of the marine ecosystem and habitat. ITQs, as previously mentioned, are merely harvesting rights. They do not confer property rights in fish, fish stocks, or the ocean habitat. It immediately follows that ITQs can never generate the same efficiency in the use of marine resources as, say, farmers can in the use of their land. ITQs simply do not offer the same degree of individual control. For instance, again drawing the parallel with farming, optimal use of marine resources for fishing would require selective breeding, feeding, and protecting of individual fish. Since ITQs only confer property rights in the volume of harvest, the individual incentives to undertake these activities under an ITQ system simply do not exist.

However, since the marine ecosystem as a whole imposes a constraint on the possible volume of harvest, ITQ holders will take an interest in the ecosystem and would like to see it in the state most favorable to their fishing at least for the duration of the ITQ system. Thus ITQ systems, especially those with long-lasting quota shares, provide quota shareholders with some of the same incentives that an owner of the marine resources would have. Moreover, the ITQ system provides ITQ holders with a certain collective control over the evolution of the ecosystem. That is, ITQ holders as a group may adapt their fishing practices and harvesting volumes to improve the productivity of the ecosystem. Note, however, that this possibility relies on the ITQ holders acting collectively. By virtue of their ITQ rights they have a certain, often quite strong, incentive to do so. However, they would have to overcome significant organizational and bargaining obstacles. The likelihood of ITQ holders being able to do this is hard to judge. In general, it would depend on the empirical particulars of each situation. Johnson and Libecap (1982) recount examples of cooperative agreements among fishers in essentially common property fisheries and discuss the problems of achieving and sustaining them. By contrast, ITQ holders form a well-defined group with common interests and comparatively strong individual property rights. Consequently, they are in a much better position to achieve and maintain mutually beneficial agreements than the fishers discussed by Johnson and Libecap. In fact, ITQ holders are probably better placed to do this than Elinor Ostrom's (1990) fishing communities, which according to her are nevertheless often able to self-manage quite effectively.

Harmonizing Fishing with Alternative Marine Use

Marine resources are not only for fishing. They can be used for transportation, mining, tourism, and conservation, to name a few other uses. Many of these alternative uses conflict with fishing and each other in the sense that one use affects the benefits from other uses. Thus we find ourselves in the classic economic situation of having to allocate limited resources to conflicting uses. The overall optimal use will allocate these limited resources to the various uses so as to maximize total benefits.

ITQs as such cannot provide this allocative service. For that they are far too limited as property rights. Conflicting uses of marine resources appear as externalities between the different uses. In order to eliminate these externalities, or rather adapt optimally to them, each particular use must be seen as violating a property right and thus result in the appropriate compensatory payment. The problem, as we have seen, is that ITQs do not confer property rights in the fundamental marine resources subject to conflicting uses. Therefore, since ITQ rights are not directly violated, no price (or compensatory payment) can be legally charged. However, as in the case of ecosystem use, the ITQ system comprises certain features that facilitate the alleviation if not the resolution of these problems. This is discussed further in a separate section later.

Imperfect Application of ITQs

Not only does the ITQ system suffer from certain inherent limitations previously discussed, but the application of the system systems to fisheries often leaves a great deal to be desired. Five types of imperfect application are most common:

(1) Reduced quality property rights
(2) Discrete TAC periods

(3) Aggregate quotas
(4) Inappropriate TACs
(5) Inadequate enforcement

Reduced Quality Property Rights

Many ITQ systems impose limitations on the property rights aspects of the ITQs. In particular, the duration of the rights and quota tradability are often limited. The reasons for these restrictions are usually of a sociopolitical rather than economic nature. The cost of entry by new fishermen, unearned gains from quota trades, and loss of local employment due to quota trades are often the reasons cited for imposing limitations. Exclusivity is often reduced by restrictions on how ITQs may be used. Reduced exclusivity in the form of special taxation is also sometimes proposed. This reduces exclusivity by expropriating a part of the returns from using the property.

All of these limitations reduce the property rights quality of the ITQs and, therefore, also their economic efficiency. The efficiency impacts of reductions in the various property sub-rights of ITQs are thoroughly discussed in Arnason (2007). The specific impacts of limited duration are dealt with in Costello and Kaffine (2008). Kroetz and Sanchirico (2010) discuss the impacts on limitations on tradability as well as other restrictions on ITQ property rights.

Discrete TAC periods

In real-world applications of ITQs, the TACs are invariably set not continuously but at discrete intervals, usually a year. This means that ITQ holders can choose when to harvest their quota within the quota period. As a result, there is an infinite number of possible biomass paths during the TAC period. Not all of these paths can be optimal. Moreover, which path is realized depends on the harvesting choices made by individual ITQ holders. This reintroduces a part of the original common property problem. By affecting the evolution of biomass during the TAC period, harvesting decisions by one firm impose external effects on all other firms (Boyce 1992; Costello and Deacon 2007). As an example, consider the case where fish behavior or market conditions make it socially optimal to harvest late in the TAC period. In spite of this, there will be an individual incentive to move harvesting forward in time to take advantage of a larger biomass.

The obvious way to alleviate this problem is to simply define shorter TAC periods. In fact, while continuous TACs are hardly administratively feasible, there does not seem to be a good economic reason for not having considerably shorter TAC periods in most fisheries.

Aggregate Quotas

In practical applications of ITQs, the TACs, and consequently the ITQ rights, are generally defined in terms of the aggregate biomass. In reality, however, the biomass often consists of several sub-stocks, contains various size classes (cohorts), and is unequally distributed over the fishing area. Many other types of biomass heterogeneity may exist. Optimal fishing must reflect all of these characteristics of the biomass (Costello and Deacon 2007; Sanchirico and Wilen 1999). Under ITQs, this can be accomplished by setting TACs by sub-stocks, cohorts and areas, and so on. However, this is rarely done, resulting in external effects as fishers concentrate on the individually most profitable segments of the biomass. For example, consider the case where large fish are more valuable than small fish. Under an aggregate ITQ system, the ITQ holders will have an incentive to fill their quotas by landings of large fish. This, however, may well be biologically counterproductive as well as causing other problems.

The obvious way to counteract this problem is simply to set sufficiently disaggregated TACs and, therefore, ITQ harvesting rights. This, however, obviously requires added research and adds to the monitoring and enforcement costs of the ITQ system.

Inappropriate TACs

For a fishery to achieve full economic efficiency, it is necessary to follow the optimal biomass (stock) path. Under the ITQ system, this evolution of the biomass is controlled mainly by the TAC policy. In most ITQ systems, the TAC is set by fisheries authorities, usually a government agency. Being a part of the government, the fisheries authorities are subject to the same influences and concerns as the government in general. The profitability and economic efficiency of the fishing industry is only one of the government's concerns. Consequently, the TACs may be set with other objectives in mind such as short-term employment, conservation, regional economic stability, and political expediency. In fact, it appears that in many countries that have adopted ITQs, the TACs set by the authorities have been well above what has been suggested by maximization of present value principles (Sandal et al. 2004). As a result, stocks have remained less for longer than they should have been.

The setting of optimal TACs is particularly difficult in the case of multispecies fisheries, especially when there is not perfect species selectivity in the harvesting process. In those cases, ill-advised TACs may lead to species mismatch in the catch and therefore discards and/or extra costs. The main point is that in multispecies fisheries, the optimal TAC for each species depends on the stock size of all the species. The most common practice, however, is to set TACs for each species separately.

Inadequate Enforcement

ITQs, like other property rights, will only function to their full potential if they are properly enforced (Anderson 1989; Hatcher 2005). Imperfect enforcement of ITQs weakens them as property rights in the fishery. First, it subtracts from the exclusivity of the ITQ right—excessive fishing by others inevitably reduces the harvesting benefits supposedly conferred by the ITQ. Second, it affects the evolution of the fundamental marine resources, on which fishing is based, and thus weakens the role of ITQ rights in this evolution. In extreme cases of nonenforcement, the ITQs confer no exclusivity and therefore have no property rights value. Accordingly, the fishery will be conducted as a common property fishery.

So for the ITQ system to function as well as possible, the enforcement of the ITQ constraint must be adequate (Anderson 2000). This enforcement involves two key components: a monitoring activity to identify possible violations and a sanctioning activity to penalize violations (Sutinen and Andersen 1985). In combination, these activities generate a deterrent against ITQ violations. Obviously, this deterrent has to be sufficiently strong to make it uneconomical for fishers to violate the ITQ constraint. Unfortunately, it appears that the enforcement of ITQs is often wanting in this respect, As a result, the property rights value of the ITQs is reduced and their economic effectiveness correspondingly diminished.

It is important to keep in mind that there is always a cost associated with ITQ enforcement. It follows that optimal enforcement of ITQ restrictions is rarely to the point of perfect compliance. Depending on the nature of the fishery and the basic legal framework, enforcement of an ITQ system may be very costly. Indeed, in certain fisheries, adequate enforcement of ITQs may be prohibitively expensive, implying that some other fisheries management system is preferable. However, somewhat surprisingly, it turns out that in many countries that had adopted ITQs by 2000, the cost of enforcement was no greater and, in fact, usually considerably smaller than in the other countries (Schrank, Arnason, and Hannesson 2003). The reason may be that the ineffectiveness of other management systems led the authorities to increasingly complicated and costly management.

ITQs and Conflicting Uses of Marine Resources

The marine resources sustaining commercial fisheries (i.e., fish stocks, marine ecosystems, and the marine habitat) have many other uses. These uses include recreational fishing, mariculture, marine tourism, marine transportation, ocean mining, ocean dumping of refuse, marine conservation, and so on. In many respects these different uses conflict with fishing as well as each other. Thus, for instance, most ocean mining will reduce opportunities for fishing. Fishing may be conflict with certain fish and ecosystem conservation sentiments. It immediately follows that the optimal use of marine resources must strike the appropriate balance between these conflicting uses.

In most land-based economic activities, it is left to the market system to solve these kinds of resource allocation problems. The guiding hand of market forces, however, can only exist when there are property rights to be traded. Unfortunately, as we have seen, when it comes to marine resources, this is generally not the case. As a result, most of the marine resource allocation problems discussed here are not solved by the market. Indeed, it is important to realize that the well-known common property problem in fisheries, made famous by the work of Gordon (1954), applies a fortiori to the wider use of marine resources. There is a difference in scale, however. Due to the much greater potential benefits from all possible uses of marine resources, the waste associated with the common property problem in overall marine use is probably much greater than that in the fisheries alone.

These observations raise the question as to what extent the property rights embedded in ITQs can help resolve the broader marine resources allocation problem. We have already seen that ITQs, while quite limited as property rights in marine resources, nevertheless provide a certain basis or platform for an efficient use of these resources for commercial fishing. The question is whether this platform extends to other marine resource use as well. The reason why it may is the same as that which facilitates optimal commercial fishing under ITQs. It is simply in the collective interest to arrange conflicting use of marine resources so as to maximize total net benefits, and ITQs provide a certain basis for reaching an agreement for doing this. As pointed out by Coase (1960), the achievement and maintenance of an agreement maximizing joint benefits is greatly assisted by the existence of well-defined property rights. In this case, ITQs provide the property rights on which such an agreement can be based. From a more modern game theoretic perspective, the situation is a positive-sum bargaining game in which at least one equilibrium solution is the jointly optimal use of marine resources (Binmore, Rubenstein, and Wolinsky 1986; Nash 1950).

Resolving Conflicts between Recreational and Commercial Fishing

The conflict between recreational and commercial fishing is easily resolved by simply incorporating both types of fishing within the same ITQ system (Arnason 2009). The reason is simple enough. As regards the use of the underlying resources, there is really no fundamental difference between commercial and recreational fishing. Both activities extract from the biomass. As a result, remedies of externalities associated with the first will also do so for the second. Moreover, trading of quotas between the two types of fishing will ensure that their respective shares of the fishery will be economically efficient. Note, however, that there may be practical difficulties. In particular, the enforcement of recreational ITQs may be more difficult than that for commercial fishing (Abbott, Maharaj, and Wilen 2009).

Addressing Conflicts between Fishing and Other Marine Resource Uses

Uses of marine resources that do not derive benefits from fishing are not as easily dealt with. To help us understand the potential ability of ITQs to alleviate the external effects that may arise, it seems useful to divide marine resource use into two types: (a) fisheries, both commercial and recreational, and (b) other uses, whatever they may be. This division gives rise to four types of external effects as summarized in Table 1.

The first type of external effect is by the fishing activity on the fishing activity represented by box I in Table 1. These, of course, are the external effects traditional fisheries management is concerned with. The second type of external effect, represented in box II, is by the fishing activity on other uses of marine resources, such as conservations benefits and marine tourism. The third type of external effect, represented in box III, is by other uses of marine resources, such as ocean mining or mariculture, on fishing. The fourth type of external effect is by other uses of marine resources on themselves contained in box IV in Table 1.[8]

The ITQ system only controls the fishing activity and therefore can do nothing about externalities between other marine uses in box IV. The remaining question is to what extent the ITQ system can form a basis for alleviating the externalities in boxes II and III. The simple answer, as discussed earlier, is that the ITQ rights offer a certain basis for this. However, as in the case of the internal externalities of fishing, the extent to which this basis can be utilized depends on the ability of the parties to effectively achieve a bargaining agreement.

External Effects of Fishing on Other Marine Uses

Consider first the external effects of fishing on other marine uses (box II in Table 1). Here it is useful to distinguish between two cases: (a) fishing affects other users *individually* in the sense that the impacts of modified fishing can be restricted to individual users, and (b) fishing affects other users *collectively* in the sense that modified fishing will affect all of them.

[8]Clearly, the other marine use category could be divided into many more subcategories, which would produce a more detailed matrix of external effects. However, for the purposes of this article, little would be gained by disaggregating marine uses along these lines.

Table 1 Types of external effects in marine use

	To fishing	To other marine use
From fishing	I	II
From other marine use	III	IV

In the first case, individual other users will have an incentive to approach ITQ holders to request a modification of fishing practices (e.g., reduced fishing). Note that it would not be socially optimal for the other user to simply buy quotas from individual quota holders. The reason is that this generates a positive externality for all the other quota holders (they would have a larger biomass to exploit). These external benefits would not be reflected in the price the individual quota holder demands for his quota. Thus the extent of such individual trades would be less than optimal. However, quota holders as a collective would incorporate these externalities and would therefore be in an ideal position to conduct the appropriate level of trades. It may be noted that trades of harvesting quotas to other users of marine resources or, more generally, bargaining agreements about modified harvesting levels, are equivalent to modifying the TAC.

The second case is more complicated because the set of other users would have to join together in order to bargain collectively with the set of ITQ holders. The reason is the same as before. Any deals struck by individual other users with ITQ holders will have an external effect on other members of the set of other users. Therefore, for economic efficiency, there is a need for a two-sided bargaining process between the association of ITQ holders and the association of other users. Clearly, in addition to the problems of actually attaining a bargaining agreement, there may be severe difficulties in forming and maintaining these associations. The problem of free riders in this process and the associated problem of new entrants can, depending on the situation, easily be formidable.

External Effects of Marine Resource Use on Fishing

Consider now the external effect of other uses of marine resource on fishing, box III. In this case, the collection of ITQ holders must approach other users of marine resources requesting them to modify their activities. Otherwise the bargaining situation is pretty much as in the case of box II. Provided there are no externalities within the group of other users, this bargaining can be conducted by ITQ holders with other users individually. If, however, there are external effects within the group or subsets of other users, the bargaining must include all the members of this group.

Empirical Evidence

There is, of course, a plethora of empirical examples of the coordination of conflicting uses of a natural resource on the basis of well-defined property rights. For instance, the various demands for land use are routinely harmonized with the help of market trades. The more diffuse demand for wildlife and rain forest conservation has in recent years found a partial expression by collectively funded purchases of land for conservation. Thus, for example, the World Land Trust claims it has been instrumental in purchasing more than 0.5 million acres for wildlife conservation (http://www.worldlandtrust.org/). With well-defined property rights in fisheries, there is no reason why similar transactions could not occur. The question is whether ITQ rights are sufficiently high quality to overcome the transaction costs associated with such trades and thus make them mutually beneficial. So far, little empirical research has been conducted in this area. However, there is already a noticeable trend toward association formation and self-management by ITQ holders (Shotton 2000; Townsend, Shotton, and Uchida 2008). This is a key step toward successful coordination with other users of marine resources. In certain cases the evolution has progressed further. Thus Mincher (2008), for example, reports that the Challenger Scallop Enhancement Company, an association of ITQ owners in the New Zealand scallops fishery, has successfully coordinated activities with other commercial fisheries (oyster), recreational fishing, and aquaculture in the same area.

ITQs around the World

Over the past forty years there has been a great increase in the use of ITQ systems in fisheries around the world. This suggests that they are generally found to produce at least some benefits compared to the alternatives.

The design particulars of individual quota systems vary greatly, not least the degree of quota tradability. Consequently, it is often difficult to distinguish between ITQ systems and nontradable quota systems, IQs. Nevertheless, it may be safely asserted that ITQs have been adopted in hundreds, most likely in over a thousand individual fisheries in the world. The first ITQ systems in ocean fisheries were introduced in the 1970s, in the Netherlands flatfish fishery (1976) and the Icelandic herring fishery in (1976–79) (MRAG Consortium 2007). At the end of 2010, at least twenty-two significant fishing nations, including the United States, Canada, Chile, Peru, Iceland, New Zealand, Australia, Norway, Namibia, Russia, and several European Union countries, were using ITQ systems as a major component of their fisheries management. Table 2 indicates the number of countries adopting and using ITQs in each decade since the 1970s.

Since the number of individual fisheries managed on the basis of ITQs is very large, it is not easy to assess the exact volume of harvest taken under ITQs. Table 3 provides rough estimates of how the volume of catch taken under ITQs has evolved over time.

As indicated in Table 3, the volume of catch taken under ITQs has expanded at an increasing rate. At the present time (end of 2010), the total volume of marine catch taken under ITQs may be about 22 million metric tons. The annual global ocean harvest from capture fisheries has been just over 80 million metric tons in recent years. So the catch taken under ITQs could currently be as much as a quarter of the global harvest.

Table 2 Countries adopting and using ITQ systems

Decade	No. of new countries adopting ITQs	No. of countries using ITQs at the end of decade
1970–79	2	2
1980–89	5	7
1990–99	8	15
2000–9	7	22

Source: Arnason 2011.

Table 3 Volume of ocean catch taken under ITQs

Decade	Additional volume (million metric tons)	Accumulative volume (million metric tons)
1970–79	0.2	0.2
1980–89	2.8	3
1990–99	9	12
2000–9	10	22

Source: Arnason 2011.

The rapid adoption of ITQ systems around the world is indicative of their relative success in overcoming the common property problem and improving the economics of fisheries. There is a great deal of empirical evidence that ITQs have reduced excessive fishing effort and capital use in previously overexploited fisheries (Cemare 2002; MRAG Consortium 2007; National Research Council 1999; Shotton 2000) and significantly increased the unit value of landings (Herrmann 1996; Homans and Wilen 2005). There is also some evidence that under ITQs the previous long-term decline of fish stocks has been halted and even reversed (Costello, Gaines, and Lynham 2008). All of these outcomes are in accordance with the theory of ITQs. The first set of outcomes, improved economic results, reflects improved allocative efficiency, which, as we have seen, is a virtually inevitable outcome of any reasonably designed and enforced ITQ system. The second, stock improvements, is generated by more conservative TACs, which suggests that ITQ holders may have been able to translate their common interest in stronger fish stock and more long-term benefits into the TAC policy.

Conclusions

One of the most important findings in economic theory is that property rights are necessary and almost sufficient for economic efficiency, a high level of production, and economic growth. Moreover, the stronger the property rights, the greater the economic efficiency they generate. Indeed, weak property rights held by producers in fisheries are the fundamental cause of the so-called fisheries problem, a fact that appears to be recognized in the common characterization of the fisheries problem as "the common property problem."

This article has reviewed the potential for one type of property rights instrument, ITQs, to overcome the common property problem and generate economic efficiency in fisheries. It was found that both fisheries economics theory and empirical experience strongly indicate that ITQs can greatly improve fishing efficiency compared to the common property arrangement. Moreover, when recreational fishers are included in the system, theory suggests that ITQs can strike an efficient balance between commercial and recreational fishing.

These important advantages should not, however, close our eyes to the limitations of ITQs. As discussed in the article, ITQs on their own are not capable of generating full efficiency in fishing or in the wider use of marine resources. In particular, ITQs are not sufficient for setting the socially optimal TAC, ensuring the optimal use of the ecosystem, or harmonizing fishing with conflicting uses of marine resources. For these purposes, the property rights embedded in ITQs are simply too limited.

The ITQ system, however, contains certain features that can potentially alleviate these deficiencies and facilitate the attainment of full economic efficiency in marine use. The basic reason is that ITQ holders, by virtue of their ITQ property rights, have an incentive to collectively manage overall ecosystem use for the long-term benefit of the fishery and to negotiate adjustments of their fishing activity aimed at resolving the conflicting uses of marine resources. Since the ITQs are property rights, any reduction (or, more generally, modification) in these rights in order to increase overall benefits from marine resources will have to be adequately compensated. Thus, by the usual process of trading or negotiation, ITQ holders are in the position to benefit from increases in the overall value of marine resource use that is generated by alterations in fishing activity. Therefore, they will have an economic incentive to support such initiatives and even promote them themselves. Unfortunately, the organizational and bargaining problems in accomplishing this are often severe. Clearly, national and international governments can facilitate the negotiation and bargaining process by establishing the appropriate legislative framework. Given the value of fisheries and, even more so, other marine resource use, the formulation of a government policy in this direction appears most timely.

References

Abbott, J., V. Maharaj, and J. Wilen. 2009. Designing ITQ programs for commercial recreational fishing. *Marine Policy* 33: 766–774.

Alston, L., G. Libecap, and B. Cueller. 1999. *Titles, conflict, and land use: The development of property rights and land reform on the Brazilian Amazon frontier*. Ann Arbor: University of Michigan Press.

Anderson, L. 1989. Conceptual constructs for ITQ management policies. In *Rights Based Fishing*, ed. P. Neher, N. Mollet, and R. Arnason. Dordrecht, Netherlands: Kluwer Academic Publishers.

———. 2000. Selection of property rights management systems. In *Use of property rights in fisheries management*, ed. R. Shotton; FAO Fisheries Technical Paper 401/1. Rome: Food and Agriculture Organization of the United Nations.

Aristotle [384–322 BC]. 1981. *The politics*. Trans. T. A. Sinclair. Rev. T. J. Saunders. London: Penguin Classics.

Arnason, R. 1990. Minimum information management in fisheries. *Canadian Journal of Economics* 23 (3): 630–653.

———. 2000. Property rights as a means of economic organization. In *Use of property rights in fisheries management*, ed. R. Shotton; FAO Fisheries Technical Paper 401/1. Rome: Food and Agriculture Organization of the United Nations.

———. 2007. Property rights quality and economic efficiency of fisheries management regimes: Some basic results. In *Advances in fisheries economics*, ed. T. Bjorndal, D. Gordon, R. Arnason, and R. Sumaila. Oxford, UK: Blackwell.

———. 2009a. Conflicting uses of marine resources: Can ITQs promote an efficient solution? *Australian Journal of Agricultural and Resource Economics* 53: 145–174.

———. 2009b. How to compare the efficiency of fisheries management systems. In *Comparative evaluations of innovative fisheries management—Global experiences and European prospects*, ed. K. Hauge, and D. Wilson. Heidelberg, Germany: Springer.

———. 2011. Forthcoming. Individual transferable quotas in fisheries. In *Encyclopedia of energy, natural resource, and environmental economics*, ed. J. Shogren. San Diego: Elsevier.

Barro, R., and X. Sala-i-Martin. 1995. *Economic growth*. New York: McGraw-Hill.

Binmore, K., A. Rubinstein, and A. Wolinsky. 1986. The Nash bargaining solution in economic modelling. *RAND Journal of Economics* 17: 176–188.

Boyce, J. R. 1992. Individual transferable quotas and production externalities in a fishery. *Natural Resource Modeling* 6: 385–408.

Coase, R. H. 1960. The problem of social cost. *Journal of Law and Economics* 3: 1–44.

Costello, Christopher. 2012. Introduction to the symposium on rights-based fisheries management. *Review of Environmental Economics and Policy* 10.1093/reep/res007.

Costello, C., and R. Deacon. 2007. Efficiency gains from fully delineating rights in an ITQ fishery. *Marine Resource Economics* 22: 1–15.

Costello, C., S. D. Gaines, and J. Lynham. 2008. Can catch shares prevent fisheries collapse? *Science* 321 (5896): 1678–1681.

Costello, C., and D. Kaffine. 2008. Natural resource use with limited-tenure property rights. *Journal of Environmental Economics and Management* 55: 20–36.

Deacon, Robert T. 2012. Fishery management by harvester cooperatives. *Review of Environmental Economics and Policy* 10.1093/reep/res008.

Debreu, G. 1959. *Theory of value*; Cowles Foundation. Monograph 17. New Haven: Yale University Press.

Demsetz, H. 1967. Toward a theory of property rights. *American Economic Review* 57: 347–359.

Eggertsson, T. 1990. *Economic behaviour and institutions*. Cambridge: Cambridge University Press.

Furubotn, E., and R. Richter. 2003. *Institutions and economic theory*. Ann Arbor: University of Michigan Press.

Grafton, Q., D. Squires, and K. Fox. 2000. Private property and economic efficiency: A study of a common-pool resource. *Journal of Law and Economics* 43 (2): 679–713.

Grainger, C., and C. Costello. 2011. The value of secure property rights: Evidence from global fisheries. National Bureau of Economic Research; Working paper 17019.

Hardin, G. 1968. The tragedy of the commons. *Science* 162: 1243–1247.

Hatcher, A. 2005. Non-compliance and the quota price in an ITQ fishery. *Journal of Environmental Economics and Management* 49: 427–436.

Hatcher, A., S. Pascoe, R. Banks, and R. Arnason. 2001. *Future options for UK fish quota management*; CEMARE Report 58. Portsmouth, UK: University of Portsmouth.

Herrmann, M. 1996. Estimating the induced price increase for Canadian Pacific halibut with the introduction of the individual vessel quota system. *Canadian Journal of Agricultural Economics* 44: 151–164.

Homans, F. R., and J. E. Wilen. 2005. Markets and rent dissipation in regulated open access fisheries. *Journal of Environmental Economics and Management* 49: 381–404.

Hume, D. 1969. In *A treatise of human nature*, ed. E. C. Mossner. London: Penguin. (Orig. pub. 1739–40.).

Johnson, R., and G. Libecap. 1982. Contracting problems and regulation: The case of the fishery. *American Economic Review* 72: 1005–1022.

Kaffine, D., and C. Costello. 2011. Unitization of spatially connected renewable resources. *B.E. Journal of Economic Analysis and Policy* 11 (1): Article 15.

Kroetz, K., and J. Sanchirico. 2010. Economic insights into the costs of design restrictions in ITQ; Resources for the Future report.

Mincher, R. 2008. New Zealand's Challenger Scallop Enhancement Company: From reseeding to self-governance. In *Case studies in fisheries self-governance*, ed. R. Townsend, R. Shotton, and H. Uchida; FAO Fisheries Technical Paper 504. Rome: Food and Agriculture Organization of the United Nations.

MRAG, IFM, CEFAS, AZTI Tecnalia, PolEM. 2009. An analysis of existing rights based management (RBM) instruments in member states and on setting up best practices in the EU; Final report I and II. London: MRAG.

Nash, J. 1950. The bargaining problem. *Econometrica* 18: 155–162.

National Research Council. 1999. *Sharing the fish: Toward a national policy on individual fishing quotas*; Committee to Review Individual Fishing Quotas. Ocean Studies Board, Commission on Geosciences, Environment and Resources, National Research Council. Washington, DC: National Academy Press.

Neftci, S. 1996. *An introduction to the mathematics of financial derivatives*. New York: Academic Press.

Ostrom, E. 1990. *Governing the commons: The evolution of institutions for collective actions*. New York: Cambridge University Press.

Rodrigues, G. A., ed. 1990. *Operations research and management in fishing*. Dordrecht, Netherlands: Kluwer Academic Publishers.

Sanchirico, J., and J. Wilen. 1999. Bioeconomics of spatial exploitation in a patchy environment. *Journal of Environmental Economics and Management* 27: 129–150.

Sandal, L., R. Arnason, S. Steinshamn, and N. Vestergaard. 2004. Optimal feedback controls: Comparative evaluations of the cod fisheries of Denmark, Iceland and Norway. *American Journal of Agricultural Economics* 86: 531–542.

Schrank, W. E., R. Arnason, and R. Hannesson. 2003. *The cost of fisheries management*. Aldershot, UK: Ashgate.

Scott, A. D. 1989. Conceptual origins of rights based fishing. In *Rights based fishing*, ed. P. A. Neher, R. Arnason, and N. Mollett. Dordrecht, Netherlands: Kluwer Academic Publishers.

———. 2008. *The evolution of resource property rights*. Oxford, UK: Oxford University Press.

Shotton, R., ed. 2000. Use of property rights in fisheries management. FAO Fisheries Technical Paper 401/1. Rome: Food and Agriculture Organization of the United Nations.

Singh, R., and Q. Weninger. 2009. Bio-economies of scope and the discard problem in multiple species fisheries. *Journal of Environmental Economics and Management* 58: 72–92.

Smith, A. 1977. In *An inquiry into the nature and causes of the wealth of nations*, ed. E. Cannan. Chicago: University of Chicago Press (Orig. pub. 1776.).

Sutinen, J. G., and P. Andersen. 1985. The economics of fisheries law enforcement. *Land Economics* 61: 387–397.

Townsend, R., R. Shotton, and H. Uchida, eds. 2008. Case studies in fisheries self-governance. FAO Fisheries Technical Paper 504. Rome: Food and Agriculture Organization of the United Nations.

Wallace, S. W., and S. Olafsson. 1994. The Nordic Fisheries Management Model. *Nord 4*. Copenhagen: Nordic Council of Ministers.

White, C., and C. Costello. 2011. Matching spatial property rights fisheries with scales of fish dispersal. *Ecological Applications* 21 (2): 350–362.

Wilen, James E., José Cancino, and Hirotsugu Uchida. 2012. The Economics of Territorial Use Rights Fisheries, or TURFs. *Review of Environmental Economics and Policy* 10.1093/reep/res012.

World Bank. 2009. FAO (Food and Agriculture Organization of the United Nations). 2009. The sunken billions: The economic justification for fisheries reform. Washington, DC: Author.