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Individual transferable quotas in multispecies fisheries

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Introduction

Individual transferable quotas (ITQs) are an increasingly popular form of fisheries management [1–9]. By providing fishers with a harvesting right, individual quotas have the potential to reduce excess competition and investment common in limited entry and open-access fisheries. Transferability of individual quotas fosters economic efficiency because more efficient fishers tend to harvest a greater share of the total allowable catch (TAC) and because it provides incentives for inefficient fishers to exit the fishery [10–12].

A major concern of regulators is how to implement ITQs in multispecies fisheries. The issues in multispecies fisheries also apply to multiple stock fisheries. How should a mix of species be managed where incidental catches of non-target species are common, or where the mixed species are targeted but the proportions of each species caught are uncertain?[1] How can incentives for fishers to avoid catching and discarding non-target species be increased? [14–23]. How can the problem of highgrading, where less valued fish are discarded be addressed? How should overages or catches in excess of quota holdings be regulated? How should the TAC of a mix of species be set so as to ensure the sustainability of the stocks and the profitability of fishers? Which species should receive ITQs? Additional problems include potential changes in industry structure and community impacts because of ITQs (e.g. a few firms gain a large share of a quota and the social structures of fishing communities are substantially altered).

This paper addresses these questions by reviewing the literature and experience with ITQ-managed fisheries around the world. Because of the paper's diverse authorship, the unsettled nature of the management issues and different experiences in countries where ITQs have been introduced, we can offer a range of perspectives and management

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[1]Bycatch, also called incidental catch, refers to a catch of one or more species other than the one or more species of direct intention (the latter being "the target species of directed fishing effort"). For an analysis of targeting ability see [13]. Technically, the issue is one of joint production.

alternatives. In this paper, we: (1) examine the multispecies harvesting technology; (2) address discards, highgrading and overages under ITQs and list the possible solutions to the problems; (3) detail possible impacts of ITQs on other fisheries; (4) discuss the effects of ITQs on the harvesting flexibility of fishers; (5) examine how the prices of ITQ shares are formed in multispecies fisheries and the effect of the harvesting technology and transaction costs on quota share prices; (6) evaluate how ITQs may affect economic efficiency and overcapitalization; (7) describe the nature of the resource rents that may arise with ITQs; (8) review problems with monitoring and enforcement; (9) present options for setting ITQs; and (10) provide concluding remarks.

Harvesting technology

Understanding the economic and technological structure of the harvesting process is crucial to designing and implementing an effective ITQ programs for multispecies fisheries [24–32]. There are several different possible types of technical interactions among the different species harvested and economic inputs. The two defining features are whether or not (1) species or economic inputs can be aggregated into groups (composites) and (2) there are separate, distinct harvesting processes for different species or groups of species, i.e. the extent of joint production. The most common harvesting technology in a multispecies fishery is likely to be joint harvesting. In this case, the stocks of all species are harvested jointly or together, using all economic inputs, such as the vessel, labor, gear, equipment and fuel. The basic question is the degree of control individual fishers have over catch rates and catch composition. Given the stochastic environment of fisheries, however, a fisher's luck may be a decisive factor. This makes it extremely difficult to manage fisheries using methods which assume an exact harvesting technology and precise or identical behavior by fishers [33].

Targeting

A critical concern with multispecies harvesting is the ability to "target" and more generally, the technical interaction of one species stock with another in the harvesting process. When a species is not jointly harvested with other species, i.e. there is perfect "targeting" or "non-joint harvesting" there are no technical or cost interactions between the harvesting processes for each species stock. When there is not perfect targeting, and harvesting is instead joint, the issue becomes: as the harvest of one species changes, what happens to the harvest of the other species? Two species are called substitutes if the catch of one increases or decreases as the catch of the other species decreases or increases, respectively. When harvesting is joint and there is some degree of substitution, then the degree of targeting relates to the ability to discriminate or substitute one species for another. Two species are called complements if the catch of one species increases as the catch of the other species increases and fishers cannot trade-off the catch of one species for the other.

When a fisher can "target" one or more species the problem of matching catches and quota allocations declines in importance [34, 35]. The ability to target is enhanced if species are relatively few in number and/or there are relatively distinct stocks by area or depth. For example, Iceland may have a limited bycatch problem, in part, because the different fish stocks are relatively segregated which allows fishers to target individual stocks [4].[2] Also, with a gear that tends to be non-selective, targeting potential can be increased by modifying the way in which it is employed. For example, bottom trawls can be used more selectively by modifying the speed, depth and area of tow to alter the species mix. Advances in vessel electronics and Geographical Position Systems also allow greater discrimination between fish species and stocks. Another factor is whether or not there are different harvesting strategies for the different species being sought during a fishing trip or if there is only one harvesting strategy for all species. In addition, during relatively short time periods, such as a fishing trip, fishers have less control over catch rates and species compositions than they do over longer time periods when they can more readily change the area fished, net, and even the vessel and gear type to improve their targeting ability.

Species aggregation

Aggregation of species is also an important issue in multispecies ITQ fisheries. In a multispecies fishery where catch rates are in fixed proportions and the vessel cannot alter the species mix,[3] an ITQ placed on a single species in the mix can determine the total catch of all species. In contrast, it may be possible to have a high degree of control over the catch such that select species can be caught without harvesting other species. In many fisheries, however, there will inevitably be some mix of species harvested which will necessitate transfers of quotas or other changes by fishers to match their catches with their quota holdings [27, 29–31, 37, 38].

Fisheries management is simplified if species can be aggregated into a single TAC and quota. For example, perch and redeye are treated as an aggregate species in the British Columbia individual quota trawl fishery. In New Zealand, eight species of flatfish form an aggregate. The value of the aggregate flatfish quota varies considerably between New Zealand fishery management areas, reflecting the value of the predominant flatfish species in each area. Based on biological criteria, it is doubtful that species should be managed as an aggregate in many fisheries. There are likely to be substantial differences with respect to the age structure, recruitment and year class strength for the different species stocks comprising an aggregate. Moreover, these stock attributes may vary by area [27, 29, 30, 33, 36]. An implicit form of aggregation may be practised, however, if the species in a complex are routinely caught in the same ratio. In such fisheries, setting a total catch which consists of a mix of species still provides control over the harvest of each individual species.[4] Nonetheless, even if economic conditions warrant aggregation, there may be biological, ecological, or other reasons why aggregation should not be considered in setting a TAC.

Discarding, highgrading, bycatches and averages

Problems with highgrading, bycatches and discarding usually exist whether or not fisheries are managed by ITQs [39].[5] These problems can

[2]In addition, there may also be fewer price differentials in Iceland than elsewhere, contributing to lower bycatch and high-grading.

[3]This case of fixed proportions harvesting, a Leontief harvesting technology, was found for the Malaysian gill net fishery and is discussed in [36].

[4]Alternatively, if certain economic criteria are satisfied, it may be possible to aggregate species. For example, if the marginal rate at which production of one species substitutes for the production of another species, given fishing effort is held constant, does not change as the harvests of other species change, it is possible to aggregate on an economic basis. Constant catch ratios (Leontief separability) or constant ex-vessel price ratios (Hicks spearability) are also economic criteria.

[5]The problems of quota overage would still plague most TAC-managed fisheries, whether or not ITQs were used. It has been observed that the problem of bycatch is inevitable in multispecies fisheries [40].

become more aggravated in multispecies fisheries, however, where there are complex technical and biological interactions among species.

Highgrading

Under an ITQ system the incentive to highgrade—discarding lower valued in favor of higher valued fish—may increase because fishers can increase their total revenue per unit of quota [15, 16, 21, 23]. Highgrading may lead to biased estimates of fishing mortality depending upon the survival rate of discards [8, 9, 39]. The survival rate for a particular species will hinge partly on the gear used, onboard handling and the depth and area in which it is caught. For example, species such as lingcod caught in trawls can have a high survival rate provided trawling time is kept to a minimum, and almost all crabs caught in traps will survive when returned to the sea.

Highgrading is inefficient from a broad, resource utilization perspective, because harvested fish are not fully utilized. Highgrading can be economically efficient at the firm level, however, if the firm's costs of handling and landing fish with comparatively low market value exceed the ex-vessel price, plus discarding costs. The unpriced value of the resource stock does not enter into this calculation. Moreover, a firm's incentive to highgrade will be greater, the more ex-vessel prices are differentiated by size or quality of individual fish.

Highgrading will occur to a greater degree if there is no monitoring of fishers at sea or no penalties for discarding. Highgrading may become more widespread if TACs are reduced or if the quota allocation does not reflect recent catch patterns [15, 16, 23, 39, 41]. In either case, fishers try to maintain their incomes in the face of reduced quota allocations by increasing the return per fish landed. In this sense, highgrading may be viewed as an alternative to "quota busting" as a means to circumvent management [8, 9].

The evidence of highgrading in ITQ-managed fisheries is mixed. Bycatches, highgrading, discards, and quota overages all exist in the Australian Southeast Fishery (SEF) and New Zealand multispecies ITQ programs, although the discard problem in New Zealand is not considered severe.[6] In contrast, the Icelandic multispecies demersal ITQ program does not seem to have experienced significant highgrading and discarding [45–47].[7] Highgrading has been reported in the Wisconsin lake trout and Ontario walleye ITQ fisheries. Highgrading does not appear to be a significant problem in the Australian bluefin tuna and San Francisco Bay herring roe fisheries [4, 5, 48, 49].

To address the problem of highgrading in the multispecies British Columbia ITQ trawl fishery, all trips are monitored by on-board observers. Dumping at sea is permitted but the amount discarded is deducted from the assigned quota using expected mortality rates of discards, which are based on towing times and handling of catches [50]. Observer information on the ratio of species caught at different times and locations can be used to close the fishery, when necessary, to protect vulnerable stocks. In the absence of observer coverage, highgrading is likely to be less of a problem if (1) there are minimal price differentials by fish size or quality; (2) there are limited opportunities to catch the fish at another time; (3) the gear employed effectively targets species of the preferred size; or (4) there are mesh

[6]Quotas are currently allocated only to the trawl component of the SEF, but all gear types are included in the fishery for management purposes. It is expected that these other sectors of the fishery will be brought under ITQ management in the near future. Part of the problems arises from increasing reliance on TAC management, albeit in the form of ITQs rather than input controls [8, 9, 39, 40, 42–44].

[7]Arnason [15] notes that in Iceland, measurement of discarding in the multispecies demersal fisheries indicates no discernable increase in discards under the ITQ system compared to the previous limited entry fisheries management system. Palsson [47], in contrast, states that the problem is more serious.

size or other gear restrictions which limit the catch of small fish [4, 5, 49].

Matching industry catch rates with TACs

Matching individual vessel's catch rates and total industry catch rates for different species to TACs is a significant challenge in managing multispecies fisheries. In most cases TACs are set for individual species without considering the mix of species jointly harvested by fishers and without regard for ecosystem effects in general. At the industry level, this may cause problems because it may not be possible to combine actual catches of each species in the same relative proportions as their separate TACS [30, 39, 51]. Even if TACs for the whole fishery matched actual fishery-wide harvest capability, a similar problem occurs at the individual vessel level when fishers try to adjust their multispecies catch rates to their individual quota shares.

Discarding arises when harvest rates in a multispecies fishery do not match the quota share for each species. There is an incentive to dump fish at sea if the total industry catch of one or more species reaches its TAC before the TACs of other jointly harvested ITQ-managed species are achieved. If fleet fishing effort is restricted at this point, then the TACs of some species may remain unharvested, generating "underages". Evidence of this is reported in New Zealand [48, 52] . Conversely, if fleet fishing effort is allowed to continue unchecked, the TACs of some species will be exceeded. In such a situation, total returns to fishers may appear comparatively high in the short run but over a longer period of time these returns may not be sustainable. In sum, there may exist a contradiction between individual species TACs, determined on biological grounds, and harvest rates for the fishery as a whole, which are decided by the harvesting technology, biological, environmental and economic conditions, fishers' skill and luck.

Several factors will compound the problem of matching catches and annual TACs in multispecies fisheries. Some populations of jointly harvested species are slow-growing and stable, while others are not. This makes it more difficult to initially establish and subsequently adjust TACs for jointly harvested species [8].

Other factors contribute to complexity in setting TAC, including the need to achieve target stock levels, the need to rebuild stocks of some species while other species are abundant, reallocation of TAC for non-commercial users, mingling of species on fishing grounds, and biological or price differences between species' age and size classes. Migratory patterns and stocks straddling international political boundaries can also affect the relationship between stock abundance and TACs. Boundaries established to subdivide fishing areas, such as those in New Zealand, Pacific halibut stocks straddling the US–Canadian border, Pacific whiting stocks straddling the US–Canadian border, and northern anchovy stocks straddling the US–Mexican border, require more localized TAC setting and more intensive management.

TAC overruns and underages may decline over time after an ITQ system and TACs for different species are established [39, 40, 48].[8] Reductions in TAC overruns follow from several factors: (1) fishers gaining experience with ITQ management; (2) gear innovations, as well as fishers refining their gear and fish handling practices; (3) quota holdings at the vessel level eventually matching expected joint catch

[8]Some of the factors mentioned are directly related to the ITQ system while others are inherent to TAC management even without ITQs.

rates more closely as fishers buy and sell quota shares over time; and (4) improved monitoring and enforcement.

Difficulties in matching harvests to quotas may also affect ITQ prices. For example, when the TAC is not realized, the expected value of quotas to fishers holding excess quota is negligible but quotas might still trade at a positive price [53].[9] For fishers who do not have a quota, the option value of owning a quota is not zero.[10] The unused quota has an option value because if fishers find a school of fish, they are able to harvest it if they hold quota, but may be unable to exploit it if they do not. Where the species with the unfulfilled TAC is still being caught as bycatch, holding a quota also enables the fisher to land that species rather than discarding it. An unused quota can also have option value if less efficient fishers have significant, but uncertain, fishing options outside the fishery covered by ITQs, and they hold the quota to diversify their fishing opportunities, insuring themselves against possible closure in these other fisheries; this has occurred in the US wreckfish fishery [56].

Bycatches[11]

At the vessel level, ITQ holdings may not match catches or catch rates. One difficulty this may cause is the bycatch of species for which fishers do not have quota. This problem is aggravated when there are multiple gear types operating in a multispecies fishery and each gear type is regulated separately. Considerable variation in catch mix and bycatch among vessels, even for vessels using the same gear and harvesting the same stocks, may also add complexity to management. The bycatch problem may be further exacerbated when different gear types harvest the same multiple species complex and all the gear types are not under ITQs, even though the target species may differ for each gear type. In this sense, one group's target species is another group's bycatch. Whenever this arises, the bycatch issue becomes an allocation problem and the management of each gear type is subject to the bycatch constraint [17, 20, 59, 60].

With ITQs, the bycatch problems can be more acute because fishers face the problem of reconciling their catches with their quota holdings [39]. Other factors that affect the bycatch problem include: (1) the distribution of species (it will be easier to gauge harvest rates for different species in the multispecies complex the more uniformly distributed they are); (2) time of year fished; (3) species targeted; (4) depth fished in the water column; (5) fisher skill; and (6) the current state of harvesting technology (e.g. current effectiveness of turtle excluder devices) [17, 59].

When establishing an ITQ scheme in a multispecies fishery it is also necessary to consider bycatch of any non-market or undesired species. For example, in the US northwest Atlantic sea scallop fishery, scallops are harvested with summer and yellowtail flounder, witch flounder, monkfish, American lobster, black sea bass, cod, haddock and several species which are landed and sold. Numerous starfish, crabs and other species are also harvested. Even though catches of these latter species have no market value (i.e. bycatch in the non-market sense), they do have important ecological ramifications, in which case they may have to be factored into the development of an ITQ system. They may also have non-market value such as "existence" or "preservation" value,

[9]This is a specific instance of a general problem that arises in mathematical programming models when slack variables remain in the solution, so that the constraint is not satisfied (an underage) and hence are not valued at the margin, i.e. do not have a shadow price. Similar problems are encountered in computable general equilibrium models. This general problem is called mixed complementarity and includes nonlinear complementarity and variational inequality complementarity.

[10]See [54] for a discussion of option-based models to value entry licenses, and by extension, ITQs. See also [43][55] for an analysis of quota trading prices in New Zealand's multispecies fisheries.

[11]Reviews of bycatch management policies are given in [57, 58]. See also [14].

where the public places value upon the continued existence of a healthy or even pristine population of a species, such as dolphins jointly harvested with yellowfin tuna in the Eastern Tropical Pacific.

A bycatch problem, growing in importance as fisheries are increasingly fully or over-subscribed worldwide and as ITQ management spreads, is that of rebuilding severely threatened or over-harvested stocks that are bycatch in other fisheries. Examples of these off the US Pacific coast include Pacific ocean perch, which is a bycatch in the trawl rockfish fishery, and yellowtail rockfish, which is a bycatch in the Pacific whiting fishery. Pacific ocean perch has been "rebuilding" for 20 years but with few visible signs of improvement.

The crucial question is the degree of protection to be given to the threatened or rebuilding species. A high degree of protection, which would encourage faster recovery (if recovery occurs at all), can severely constrain fishing on other target species and thereby impose high economic penalties in the form of foregone economic profits. In contrast, low degrees of protection slow recovery of over-harvested species but allow economically viable rates of harvest on healthy target species. The problem is particularly complex when there is more than one threatened bycatch species, such as yellowtail rockfish and salmon in the US Pacific whiting fishery, since different bycatch rates occur for each bycatch species. Bycatch from the use of multiple gear types with different catch rates further complicates the problem.

Potential solutions to discarding, highgrading, bycatches and overages

All solutions to discarding, highgrading and bycatch problems attempt to ensure that total removals from stocks, including bycatch, discards and directed catch, are landed and accounted for by managers. This is usually viewed as important for management and conservation as well. The solutions adopted for the multispecies and bycatch problems in New Zealand and elsewhere attempt to introduce flexibility into management, to improve transferability of quotas and to offer positive incentives and rewards to fishers for reducing overages and discards once overages have occurred. Wheeler *et al.* note that in New Zealand, "Experience has shown that problems are created if there is a too rigid adherence to enforcing upper bounds on the catch. Attempts to do so, short of putting observers on all vessels, create incentives for dumping catch in excess of TAC at sea, rather than bringing it to shore and face severe penalties" [44]. A closer examination of the policies introduced by New Zealand and other countries to deal with quota overages, discarding and bycatches follows.

Initial allocations. Initial allocations of quotas that closely match recent catch rates of multiple species and fishing patterns may mitigate overages [39].[12] Problems may occur, however, if fishers sell quotas for some species, particularly those thought to be incidental or bycatch, and end up with unbalanced quota holdings that fail to match their catches [39]. Restrictions on sales of quotas in the initial allocation of quotas may alleviate such problems [62]. Quotas can also be set for bycatch to shift effort to other areas with less bycatch potential, or, in some fisheries, to create incentives to invest in equipment that would reduce bycatch [63].

Banking of quotas. Overages and underages of quotas may be banked. During a fishing year, quota owners may exceed their permitted quotas

[12]Quota allocations that did not match catch patterns were identified as the major problem facing operators in the Australian South East Fishery [61].

by some amount—10% in New Zealand in the past and 5% in Iceland. In the following year, the quota must be under-harvested by the extent of the overrun. It may also be possible for underages to be banked for next year's use, perhaps with a rate of interest equal to net mortality and growth of the resource [64]. New Zealand is currently revising its rules to not allow overages or underages since the deemed value system (discussed below) is considered efficient and effective in handling overages, while Iceland allows fishers to transfer up to 20% of quota between years [65–67]. Whatever options are given to fishers, a concern to regulators is the bookkeeping and reconciling quotas over different time periods [5].

Landing fish against another fisher's quotas. In New Zealand, ITQ holders may allow other fishers to record their overages against another quota holding, often for a fee, provided it is registered within a set time period. This allows for greater flexibility in quota reconciliation, but such overages are not taken into account when determining the aggregate quota. In turn, this limits the ceiling on the maximum quota that may be held by one entity in New Zealand [44].

Retroactive trade of quota. Operators may be allowed some time period, such as 15 days from the end of month in New Zealand, with a final reconciliation by the end of the fishing year, to acquire quotas to cover a catch for which there is insufficient quota. If there are a limited number of trades these prices may be quite high, especially toward the end of the required reconciliation period, when many operators may struggle to balance overages with quota. It has also been proposed that retroactive trading be allowed only for those species where surrender programs are used [68]. Whatever the merits of retroactive trading, it may be desirable to limit it to jointly harvested species so as to prevent deliberate overharvesting.

Frequency of balancing catch against quota. The frequency with which actual catch and quota shares are required to balance can have an important affect on the quantities of overages and discards. The frequency may range from a fishing trip to annual quota reconciliation. The more frequent the reconciliation, the greater the administrative complexity and cost, but given adequate on-board and dockside monitoring, the regulator is better able to verify that TACs are not exceeded. Less frequent balancing requirements help ensure that quotas are not binding on every trip, introducing greater flexibility for vessels to harvest, but also raise the burden of matching catches and quotas during the reconciliation period.

Penalties. ITQ programs should provide a system of penalties and incentives to help fishers comply with their quota constraints. Stiff penalties can be applied to overages. If, however, there are no incentives to land fish, such penalties may encourage dumping of fish at sea, especially if there are no on-board observers. The setting of penalties may also be problematic in that it may lead to antagonism between fishers and the regulator [69]. Quota busting may also be encouraged if financial penalties are set lower than the return from selling overages at a given TAC [44]. Some trawl vessels, for example, can shift from bottom trawling to mid-water trawling if they reach their quota limits for bottom dwelling fish. Such a change will only arise if there is adequate monitoring and penalties for quota busting and dumping of fish.

Deemed value. A deemed value, or surrender price, allows fishers to pay the management authority the deemed or imputed value of their overage without legal penalty. In some instances, if an operator is able to subsequently obtain quotas to cover the overage, payments made to the quota authority are refunded. The deemed value should be set to discourage the active targeting of fish for which a quota is not held but yet encourage landing of fish already caught for which fishers do not have a quota. When surrender prices are set too high, fish may be dumped at sea [44, 57]. Very high deemed values are also likely to increase the incentive to highgrade.

New Zealand requires annual balancing with monthly reporting of catch and balancing of catch within the month. If a fisher catches fish for which a quota is not held, this is reported on the fisher's Quota Management Report, which records catch against quota. The fisher reports bycatch as an overage either above the quota or for species he/she has no quota by the 15th of the following month. The Ministry of Fisheries automatically invoices that fisher for the "deemed value". With the fish already landed and processed through the normal processing channel, the fisher has the balance of the year to purchase or lease a quota to balance this overage. If this is achieved, the fisher receives back the deemed value and if not, the money remains with the government. As a result of the deemed value system, there has been very active quota trading, with a very large amount of balancing occurring in the last month of the fishing year.

Several systems can be used to determine the surrender price or deemed value [57]. First, the deemed value can be set as a percentage of the landed value of the quota overage. This requires daily knowledge of market prices received by each vessel and creates considerable administrative cost and complexity if introduced as a requirement for each vessel. Second, aggregated or average price data can be used to set the surrender price. This ignores variations in prices and can either tax or subsidize vessels for landed overages depending on whether the aggregate surrender price is lower or higher than the price actually received. Third, a fixed surrender price can be set and only infrequently changed so as to reduce uncertainty. However, without fairly frequent updating, the surrender price and whole approach might lose credibility. Setting a deemed value for a species, or aggregate of several species, with wide price differentials poses a challenging task. For example, New Zealand set the deemed value for snapper at the highest price, which probably encouraged dumping of fish not suitable for premium export markets.

Quota substitution. Unfilled quotas of an under-harvested species may be substituted or exchanged for quotas of an over-harvested species using a schedule of species exchange rates. The difficulties of setting the exchange rate, given variations in market prices, are similar to those of setting an effective deemed value [41, 66, 67]. If the exchange rates are set inappropriately, it may encourage over-harvesting of less abundant and more valuable species, such as occurred when whaling quotas were based on blue whale equivalent units, and the under-harvesting of more abundant and less valuable species [70]. Quota substitution has the advantage that it gives flexibility to fishers of not having to part with liquid assets when reconciling quotas [71]. This may have important advantages where capital markets are imperfect and revenues and expenses occur at disparate times of the year.

Resource stewardship . In theory, if ITQs provide fishers with a longer term interest in a fishery, this should lead to improved resource stewardship. Collective management between fishers and the regulator may also be an outcome of resource stewardship which may be reinforced if fishers pay the costs of fisheries management [72–75]. Other factors that encourage resource stewardship include: (1) tenure and renewal of harvest rights for compliance; (2) small number of participants; (3) ease of monitoring and detection; (4) penalty structures; (5) peer pressure; (6) specifying ITQs as a share of the TAC; and (7) devolving control and responsibility to fishers [76, 77].

In principle, enhanced resource stewardship should reduce discarding and may create incentives to change harvesting technologies, allowing for more selective fishing. It may also lead to changes in product and market development with a shift in product forms from frozen to fresh fish which may reduce management problems [78, 79].

In practice, industry tendencies towards resource stewardship depend on specific conditions. For example, quota-holders may lease their quotas or hire skippers and crew with little long-term attachment to the fishery and whose incentives may be short term. Further, fishers may have a different perspective on the appropriate TAC than fisheries scientists, and may not wish to comply with reductions in the total harvest if their catch rates have not fallen. In terms of discarding, fishers may also believe that the survival rates are higher than those determined by managers. In ITQ fisheries, where there are a large number of fishers, individuals may also consider that their actions will not affect the viability of the fishery, reducing the incentive for long-term stewardship. The very small number of ITQ holders in the US wreckfish fishery and the presence of an under-harvested TAC are probably the crucial factors contributing to the resource stewardship found in this fishery (fishers now press to hold the TAC down, whereas prior to the ITQ program, fishers routinely pressed to increase the TAC). It is also possible that quota-holders with large debts, due to past investments in the vessel and gear, may be myopic in their behavior and need to catch more than their quota if they are to remain in business.[13] There is also no guarantee that self-enforcement of private property rights by owners provides the desirable amount of enforcement from the perspective of society, because with ITQs society retains ownership of the resource stock if not the harvest or catch right.[14] Limited duration of the property right may also restrain resource stewardship, since the full consequences of actions by fishers may not be known until after the right expires. Also, in New Zealand, where most of the product from ITQ fisheries is exported, the competitive pressures from supplying a highly competitive local market are absent, where there may otherwise be reasons to beat one's competitors. While there may be additional reasons, the absence of local market competition has probably resulted in a discard problem less than expected.

[13] See [80] for an example of how TACs can affect the profitability of fishers.

[14] Thus, an external cost remains because ITQ holders own the right to harvest (the resource flow) but society remains owner of the resource stock (from the flow emanates) and fishers may (at best) provide an overall level of self-enforcement appropriate for their harvest right but not for the resource stock itself [81].

Value-based ITQs. A value-based ITQ (VITQ) would establish a maximum landed value of harvest for each participating vessel, where the harvest would consist of the species comprising the multispecies complex [22, 82]. In the simplest case, a total allowable value (TAV) is established for the fishery by multiplying the TAC by the weighted average price for the different species and grades in the landings. The TAV would then be sub-divided into individual value quotas assigned to vessels.

When harvests are composed of more than one economic grade, VITQs have appeal in that they would lessen the quota-induced incentive for highgrading. In a VITQ system, the incentive is to minimize the costs of producing a given value of landings. Given positive discarding costs, profit maximization strictly requires discarding be zero under VITQs.

VITQs also hold promise with regard to flexibility and having an inherent compensatory mechanism. When quota trading is costly, ITQs may lock in inefficient production technologies and fishing strategies because these are influenced by vessels quota holdings rather than by the available production possibilities. Value-based quotas would tend to avoid undue technological specialization, allowing fishers to react appropriately to changes in resource abundances.

Under VITQs, species exploitation would tend toward optimal levels through a compensatory effect between unit harvesting costs and ex-vessel prices. Fish prices and cost per unit harvested would move in opposite directions, as prices would be influenced by the quantity supplied and unit harvesting costs by species abundance. Higher supplies from overly targeting one species would push market prices down, while a corresponding decline in catch per unit effort would force unit harvesting costs up. The resulting decline in profit per unit harvested would prompt a change in target species.

Instituting mechanisms

Mechanisms that enhance flexibility and provide incentives for behavior that is in accordance with the purpose of the regulation may be more effective than penalties and "command and control" regulations.[15] If a range of mechanisms are available, fishers will choose those which will penalize them the least. Consistently aligning all the mechanisms, however, is as difficult as predicting their effect. A large number of mechanisms may also over-tax administrative systems, be expensive and be prone to error. Some of the mechanisms to deal with sources of overage are viewed as costly and cumbersome [42]. Other limitations, primarily administrative, have been raised [68, 69]. Some of the mechanisms lack transparency or are not readily understood by industry, with the effective financial penalty depending on a range of economic factors, such as the current lease prices of different species.

The progressive imposition of constraints upon a harvesting technology, such as the expansion of ITQs to additional jointly harvested species, can restrict the response of fishers to changes in market or resource conditions or TACS (this topic is more extensively discussed in [32, 83–85]). These constraints may reduce the harvesting possibilities and flexibility of vessels and make it increasingly difficult to match harvests with quota holdings.

Finally, changes in market conditions and ITQ-induced changes in the

[15]This is an application of agency theory, where the fisher is the agent and the regulator is the principal.

types of gear used can help reduce the likelihood of unwanted bycatch. For example, in 1986 many of the stressed inshore fisheries in New Zealand were mixed trawl fisheries, supplying domestic markets or international markets that were not particularly discerning with regard to product quality. Since then, however, market demand has changed significantly. The international market in particular (which accounts for 90% of production) now requires a high quality product, as fresh and in as good a condition as possible. In response, New Zealand fishers have made a very significant shift away from trawling to longlining and from frozen headed and gutted exports to either fresh fish exports, or even live fish exports. The shift to longlining substantially reduced bycatch.

Thus, while a national "blanket" penalty or program may not provide sufficient flexibility among different fisheries, it may be better to use a single or a limited number of overage mechanisms. Whatever instruments are used, there is no perfect mechanism for balancing catches with quota allocations.

Spillovers from ITQs to other fisheries and species

ITQ management of some species can induce spillover effects into other, open-access or limited entry fisheries or on to other species. For example, when ITQs were placed on bluefin tuna in Australia, many vessels sold quotas and exited to participate in other fisheries [86]. Another form of spillover occurs when species not covered by ITQs but harvested in a multispecies fishery where some of the species are subject to ITQs, receive more fishing effort and targeting than before ITQs were introduced.[16] In Iceland, vessels less than 10 tons were exempted from ITQ programs from 1984 to 1990 and expanded their capability and landings until brought under the ITQ system in 1991. Vessels less than 6 tons remain exempt. Higher net returns from an ITQ fishery may be used by quota holders to invest in gear and/or vessels in fisheries where there are no individual output controls. This problem may be accentuated if fishers believe that unregulated species may eventually be subject to ITQs, giving an incentive to fishers to establish a "catch history", thereby increasing their future allocation of quota shares.

If ITQs increase the fishing season and the flexibility of fishers, they may also increase fishing pressure in other fisheries by allowing quota holders to fish during periods that were previously impossible. There may also be problems if open access and ITQ fisheries exist for the same species in different locations, as currently exists in Atlantic Canada, if it facilitates illegal landings of fish [87]. Conversely, when all fisheries are under ITQs, spillover effects can still be expected as production patterns shift, effort readjusts and quotas are consolidated accordingly, but rates of industry exit and speed of restructuring may be slower because of the reduced or more costly alternatives to fishers. Also, at the fisher level, ITQs transfer a portion of the short-run profit, formerly capitalized into the vessel, to the ITQ asset. In turn, this reduction in vessel value, and even difficulty in selling the vessel or making payments, can retard restructuring or exit [88].

Resource managers in the USA have begun seeking ways to prevent spillovers from ITQ-managed fisheries to other fisheries and species. For example, discussion is under way in some of the New England and

[16] This spillover on to unregulated species depends on: (1) for any given level of effort, whether or not the regulated and unregulated species can be substituted for one another in the harvesting process or are complementarily caught together and (2) whether or not the level of effort decreases, decreasing all species caught or increases, increasing all species caught (substitutes and complements).

Mid-Atlantic fisheries, to disallow vessel owners from receiving any quotas unless they derive 50% or more of their total dockside sales from a particular fishery. Vessel owners would only receive quotas for that fishery and would be prohibited from harvesting fish in another fishery. Exceptions would be for those vessels that typically engage in several fisheries a year. In this case, quotas would be allocated and restricted according to some part-time definition in each fishery. To remain eligible for ITQs in certain southeast US fisheries, fishers must demonstrate, through federal income tax returns, that they receive some percentage of their income from fishing.

There can also be spillovers from fisheries unregulated by ITQs but under license limitation, to ITQ-managed fisheries. For example, most vessels in the British Columbia ITQ halibut fishery also harvest sablefish and salmon. British Columbia sablefish and salmon fisheries are managed through license limitation programs, but not ITQs. Restrictions on entry and exit and changes in vessel sizes under license limitation have spilled over to limit ITQ trades and quota consolidation in the halibut fishery.

Prices of ITQs, the harvesting technology and transaction costs

ITQ prices signal the alternative costs and benefits of expanding or contracting the scale of harvesting by buying or selling quotas, or by additional capital investment in vessel or equipment; or indicate the best species mix according to the relative ITQ prices. To assure the most competitive ITQ prices it is important to have many buyers and sellers, low transactions costs, a "market place", divisibility and relatively uninhibited transferability of quotas.

An important issue in the determination ITQ prices in multispecies ITQ fisheries is the harvesting technology of vessels [32, 84, 89]. The TAC for each species covered by an ITQ forms an exogenously determined, vertical supply curve. The market demand for ITQs is not a direct demand as found with many goods and services. Instead, it is a *derived* demand, that is demand which is *derived* from the vessel's harvesting technology, ex-vessel prices for fish, harvesting costs and the prices of economic inputs like fuel, gear, and equipment [90, 91]. The sum of each individual vessel's derived demand for ITQs then forms the market or industry derived demand for ITQs for each species.[17]

The degree to which vessels can target, and the degree to which there is substitutability and complementarity among species when harvesting is joint, affects the derived demand for ITQs. When the harvesting technology is either non-joint, so that there is perfect targeting, or is joint but species are complements or substitutes, the industry derived demand curve for ITQs is expected to be typically downward sloping. When species cannot be perfectly targeted and there is extreme substitutability or complementarity among species, and TACs are fully harvested, the industry derived demand curve for ITQs may be upward sloping [84, 85]. In this instance, ITQ market equilibrium is difficult to achieve, and when reached, is inherently unstable. Changes in prices of unregulated species or economic inputs such as fuel, or changes in TACs, can readily induce changes in ITQ prices that diverge, rather than converge to an equilibrium. Unstable ITQ prices can lead to

[17]Initially, while the ITQ market forms, the market derived demand is an inverse derived demand, in which the marginal quota value is endogenously determined by the quota holdings, harvesting costs, and exvessel prices of any species not covered by ITQs. After the market is formed, ITQ demand is still derived but no longer inverse so that the quantity demanded of ITQ is now a function of ITQ prices. With an existing market, each vessel decides upon buying and selling quota, adjusting its quota holdings, by comparing its inverse derived demand for quota to the ITQ market price, purchasing (selling) quota if the marginal valuation of quota from the vessel's inverse derived demand exceeds (falls short of) the ITQ market price. This adjustment is made for each species covered by an ITQ [85].

contradictory investment decisions—signaling fishers to invest with decreases in quota holdings and to disinvest with increases in quota holdings.

Price determination in quota markets is also affected by the costs involved in exchanging the property right (transaction costs). As the number of species regulated by ITQs increases, so does the number of transactions and the time needed to reconcile quota-holdings with catches. This raises transaction costs and may reduce the number of mutually beneficial exchanges. Fewer units of quota traded can in turn lead to more volatile prices and less stable markets. This creates a more uncertain economic environment. Thus, an important consideration in multispecies ITQs is to minimize the regulations faced by fishers when trading quota so as to reduce the costs of exchange. Extending ITQ coverage to additional species can also increase the volatility of ITQ prices with regard to changes in the prices of unmanaged species and TACs [84, 85].

ITQs, efficiency and overcapitalization

By providing greater assurance to fishers as to how much they can harvest, ITQs can reduce the "racing behavior" that exists in open access and limited entry fisheries. Moreover, individual quotas can change the incentives faced by fishers and their optimizing behavior. ITQs have the potential, therefore, to change both the output and input mix of fishers, to reduce harvesting costs, and improve economic efficiency. These potential benefits pertain to ITQs in both the single species fishery and multispecies fishery cases.

ITQ efficiency gains can also come from the output and revenue side of the profit equation [39, 78, 79]. Maximizing prices received by value-added processing, niche marketing, and shifts in product form represent the most immediate industry output responses under ITQs. Greater flexibility with respect to the length of the fishing season provided by ITQs can increase the prices received by fishers by allowing a more uniform flow of product to ex-vessel markets throughout the year. Increased flexibility of this nature is reflected in the switch from frozen to higher valued fresh product in the British Columbia halibut fishery. All of these changes in outputs and revenues in turn affect investment incentives.

Over time, ITQs may lead to changes in the level of capital investment in a fishery, and in the long run alleviate overcapitalization through reduced investment or reinvestment and exit from the fishery. Several factors affect the decision to exit a fishery managed under ITQs. Here we consider the usual case where quotas have been allocated without charge to historical participants in the fishery. First, and most importantly, the vessel owner must receive more from selling the initial quota allocation and any subsequent adjustments to the quota holdings, plus the salvage or sales value of the vessel, than the expected earnings from continued participation in the fishery.[18]

Second, in multispecies fisheries with joint harvesting, different investment and disinvestment incentives are created according to which species are subject to ITQs, and which are not [93]. It is possible that even a single species covered by ITQs could create sufficient disinvestment incentives to meaningfully reduce overcapitalization. When more than one species is covered by an ITQ, the effect upon

[18]The appropriate discount rate must be applied. This first argument draws from [23, 92]. More technically, the ITQ sales price plus the proceeds from sale or scrap of the vessel must exceed the opportunity cost of holding quota and the vessel. If the vessel owner simply exits the fishery and re-enters another without sale of the vessel, then the exit decision depends only on the opportunity cost of the quota holding without consideration of the vessel (see also [55]).

investment incentives becomes more complicated and sometimes ambiguous, and can even become contradictory to that desired. The latter is most likely to occur when there is extreme substitution or complementarity between different species, with vessels purchasing quotas desiring to disinvest and vice versa [84].

A third factor can affect the entry/exit decision after the introduction of ITQs. A vessel may have a distinctly lower value in an alternative fishery or the vessel sales price may be excessively low [55, 94, 95]. In some fisheries, there may be few alternative fisheries for vessels that would like to exit the fishery, or there may be few or no opportunities to sell the vessel at a "reasonable" price. This problem is aggravated to the extent that short-run profits, formerly capitalized into the vessel's value, are now capitalized into the value of ITQs and vessel values drop [23]. Under these circumstances, overcapitalization may persist, even until the ends of vessels' economic lives [92, 95]. The primary effect of ITQs on investment and capitalization may, in some instances, be to simply reduce the rate of new or replacement investment as the compelling pressures from the "race to fish" are reduced or eliminated. When investments in capital and labor are largely irreversible and sunk, vessel buyback programs and programs to retrain labor or encourage early retirement, may be appropriate. Without ITQs, decommissioning redundant capital and labor can become an endless treadmill.[19]

A fourth factor can affect a vessel's decision to enter or exit a fishery following implementation of ITQs. Uncertainty over the ITQ's price can impact an incumbent fisher's exit decision and a cost-efficient fisher's entry decision [92].[20] This helps explain the slow transition to the more cost-efficient fleet structure observed in many fisheries adopting ITQs.[21] When there is doubt regarding the true value of the ITQ asset due to uncertainty over its price, waiting has a value when the investment cannot be reversed without cost. Waiting to undertake an investment or disinvestment decision can allow a fisher to avoid some downside risk, thereby increasing the expected payoff. Hence, waiting can have a positive value in some circumstances, until the fisher observes a favorable (higher than average or expected) ITQ sales price. The expected payoff from employing this strategy can exceed the payoff from selling the initial ITQ allocation and exiting immediately if the fishery is only marginally cost inefficient. Thus, marginally inefficient vessels wait for a favorable ITQ price before exiting, while "very" inefficient vessels exit the fishery sooner. Similarly, vessels that might purchase ITQs to attain cost efficiency may benefit from delayed investment. Fleet capacity will then remain above that required for cost efficiency and rents will continue to dissipate.

Delayed exit and slow fleet restructuring has an important policy implication for the practice of allocating ITQs free of charge to incumbent participants [92]. Free allocation of ITQs retains fishery rents in the hands of initial recipients, thereby offering a means to garner industry support for the ITQ program, but to the extent that it delays the transition to a cost-efficient fleet configuration, inefficient vessels remain active and reduce the potential rent gains from the ITQ program over time. Several alternatives exist to free allocation of ITQs and/or to increase the rate of industry restructuring. These include: (1) an initial auction of ITQs; (2) rental charges; or (3) industry-financed buyback programs.[22]

Simply instituting an ITQ program will not, however, ensure that the

[19]The rent can alternatively be invested in alternative sectors in fishing regions to at least increase the employment possibilities [96].

[20]For a general treatment, see [97]. Pindyek notes two important characteristics of most investment expenditures. First expenditures are largely irreversible, so that they are sunk and cannot be recovered. Second, investments can be delayed, giving firms an opportunity to wait for new information to arrive about prices, costs and market conditions before the firm commits to invest.

[21]The slow transition has been observed in [55, 95]. The formal basis of this argument draws from [92].

[22]ITQ auctions, rental charges are discussed in the next section [6] and buyback programs with ITQs are discussed in [32].

potential gains in efficiency will arise. Regulators must specify with great care the characteristics of the property right including its divisibility, transferability, duration and quality of title [98]. Appreciation must also be given to the adjustment period needed to realize efficiency gains, the cooperation among fishers prior to the introduction of ITQs, and the characteristics of the fishery resources [99]. An ITQ program should be designed according to the specific requirements of the multispecies fishery, with minimal restrictions on the property right itself.

Finally, reduced capitalization stemming from ITQs can contribute to improved resource conservation and sustainability. While TAC management in principle limits the total harvest, in practice, pressures are greater in overcapitalized fisheries to set TACs with insufficient regard to risk minimization and the FAO-recommended precautionary approach to TAC setting.[23] Sufficient uncertainty exists in most fishery stock assessments so that a wide range of TACs are consistent with population estimates (other factors also play a role). In overcapitalized fisheries, economic pressures due to excess harvesting capacity and larger numbers of fishers serve to place TACs at the higher ends of the acceptable ranges. In contrast, where overcapitalization is not a significant problem, there may be less pressure to push TACs to higher and higher levels.

Resource rents, rent capture and ITQs

In principle, a significant advantage of an ITQ system is that prices of traded quotas provide information about the value of fish stocks. How useful this information is in developing management policy depends on the structure of the ITQ system, the harvesting technology of fishers, the degree of competition in the ITQ market, the quality and amount of information available to market participants, the costs in trading quotas and the extent to which the market approaches a long-run equilibrium [55, 74].

The annual lease price for quotas may provide a distorted measure of resource rents during the period of adjustment immediately after the introduction of ITQs. Annual lease prices for quotas in a multispecies fishery will also reflect the interaction of price and cost factors, technology, stock availability, option values and TAC settings, and may not accurately reveal marginal valuations on a species-by-species basis. Relative quota lease prices are also likely to fluctuate significantly from year to year and may not be suitable for determining resource rents on an individual species basis. Thus, the value of perpetual quotas may be a better indicator of the capitalized value of the resource rent.

Additional factors limit the usefulness of quota prices as indicators of the resource rent. Quota prices reflect only the expected economic value of a catch and not the actual resource stock itself. The ITQ price does not reflect the complete marginal user cost of the resource because of the remaining stock externality. Hence, the full cost of harvesting the resource is not captured in the ITQ market. Quota prices from markets that are non-competitive (concentrated) or contain infrequent and few trades may not accurately indicate resource rent. Quota prices may be quite unstable over time, raising the question of which quota price is indicative of economic rent. Quota prices may also reflect different types of transactions, ranging

[23] The authors are greatful to William Fox and Michael Tillman for this point.

from those for short time periods as rental or lease arrangements, to others for quota in perpetuity. Quota trades may not be unencumbered, so that quota prices do not simply reflect the economic value of ITQs. For instance, quota trades may also be bundled with vessel sales, confounding the quota price.

In Australia, the federal government's long-term aim is to obtain a return to the community from the exploitation of its commercial fisheries [100]. Current charges levied by the Commonwealth and State governments, however, are aimed mainly at management cost recovery [101, 102]. At present, resource rent charges are not applied on ITQ fisheries or on other fisheries in Australia. In the Greenland shrimp fishery, the initial tax on gross revenue was 11%, but since 1992 it has been 1% [103].[24] Elsewhere, the emphasis has also been on cost recovery. In Canada, revenues from the British Columbia halibut and sablefish ITQ programs fully fund regulatory costs, biological assessment, and monitoring and enforcement. Initially in New Zealand, the rents paid by fishers were determined on the basis of quota values, the expected net returns of fishers and other factors considered important by the regulator [104]. New Zealand has since moved away from this resource rental concept to a cost recovery approach which has been in place for nearly 2 years. Under the cost recovery approach, New Zealand's fishing industry pays most of the costs of the government's management agency, except where the management benefits clearly relate to environmental, traditional or recreational fishing activities. Even though the industry pays well in excess of three-quarters of the total management costs under this approach, which is somewhat contentious, in the long term it is viewed as being more appropriate than a resource rental regime based on some attempt at valuing quotas. Potential ways to capture the rents from fishers include an *ad valorem* royalty, a quota rental charge based on the price of quota, license fees and a profit charge. Although there are a number of theoretical and practical reasons to recommend a quota rental charge or an *ad valorem* royalty, the appropriate method to use will depend on the characteristics of the fishery [105, 106].

Assessing rents on an individual species basis in a multispecies fishery can be extremely difficult. When a species can be perfectly targeted, each species under an ITQ has a separate derived demand curve for its ITQ. When the multispecies harvesting process is non-joint for each species, the total rent in the fishery from all species under ITQs is the sum of the rents for each species. When multispecies harvesting is joint, so that there are not separate harvesting processes for each species, the total rent is represented by the area under one species' market derived demand curve for its ITQ.[25] In multispecies joint production, the rent is conditional on the catch composition, the species covered by ITQs and the total costs of production. It is not feasible to assign costs to individual species and species-specific rents for each species under ITQs are not well defined. In a multispecies fishery, the quota price of a species is generally higher when there is joint harvesting than when there is non-joint harvesting, since the quota price includes economic returns from other species [32, 43, 84].[26] Because of the problem of valuing rents, it is likely that various government agencies may seek only to collect the funds necessary to cover the costs of research and management, i.e. cost recovery.

[24]The tax is based on distributional considerations.

[25]In addition, rent over all species can be calculated as the area under a general equilibrium inverse derived demand curve for any species or for fishing effort (an essential input) [2, 107].

[26]There are, for example, economies of scope from joint harvesting, that is, lower costs from joint harvesting. Higher rents result due to these cost savings.

Monitoring and enforcement

A proper system of monitoring and enforcement is crucial to the success of ITQs. If regulators have little idea about what is being caught, discarded and landed, then the resource may be compromised and the full expected benefits of ITQs will fail to emerge [108–110]. Effective enforcement is also fundamental to well-functioning property rights. When exclusive use is not fully specified and enforced in common-pool resources, such as fisheries, the resource and inputs will not be used efficiently. The need for enforcement is also probably higher with ITQs than with a more complete property rights system [111], because with ITQs the rights are specified on the resource flow (the catch) rather than the resource stock itself [112, 113]. Thus, ITQ owners may not face the full incentives to invest in the future stock by deferring harvests through full compliance, since individual ITQ owners do not bear the full costs of their over-harvest, which is instead borne collectively by all owners of ITQs and the resource stock [114, 115].

Whether or not the cost of enforcement is greater under ITQs than under alternative management options will largely depend on the characteristics of the fishery being managed and the alternatives considered. In the case of offshore fisheries where the return per trip is high, observer programs can provide an effective means of monitoring fisher behavior and have been successfully applied in Atlantic Canada for foreign vessels (for a description of ITQs in Atlantic Canada see [116]). In small inshore fisheries, where the value of landings is very low and there are a large number of fishers, a 100% on-board observer program is not feasible. There are ways, however, to improve on-board monitoring through the use of daily hails or reports to the regulator of what fish were caught and at which locations, coupled with a system of random checks. It may also be possible to install video cameras on board vessels to monitor their fishing activity, along with monitoring by Geographical Position Systems, or to provide information of non-compliance by other fishers through a "whistle blower" system. Even if the risk of apprehension for quota busting and highgrading is low, a sufficiently high cost to the offender would render a sufficiently high expected cost if actually caught, which would tend to inhibit infractions. There should also be a well developed system of dockside monitoring that tracks fish from the time it is landed until it is processed.

The costs of comprehensive observer coverage in some of the larger fisheries may be substantial, but in some instances, the costs of insufficient observer coverage, through discards, may be even higher. Costs savings may be realized in the short term by insufficient observer coverage, but the longer term costs may be even greater as the effects of higher levels of discards eventually accumulate even if they are not immediately apparent. The costs of insufficient observer coverage form the benefits from additional observers, and if these benefits outweigh the direct program costs of observers, then the net benefits are positive, particularly over a sufficiently long time frame.

Many of the costs of monitoring and enforcement may be stable or fixed regardless of the number of species under ITQs or the comprehensiveness of the monitoring and enforcement. Expanding monitoring and enforcement to existing or additional species may add only minimally to total costs and might well even lower unit costs as the fixed costs are spread over more species. In turn, lower unit costs would make cost recovery through charges or levies more cost effective.

Options for designing ITQs

The key technical factors to be considered when designing an ITQ program for multispecies fisheries are: (1) the total number of species in the fishery, i.e. the number of principal and bycatch species; (2) the stability and abundance levels of the respective resource stocks; and (3) the nature and selectivity of the joint harvesting process. At one extreme, a multispecies fishery with a limited number of species (or only a few economically or biologically important ones) with fairly distinct separation (temporal or spatial) of stable resource stocks harvested by highly selective gear, may provide one of the most favorable settings for ITQs (or any other management system). At the other extreme, a multispecies fishery with numerous but no dominant species, unstable and unpredictable recruitment and resource stocks, highly commingling stocks, and lack of gear selectivity pose a more serious challenge to effective ITQ programs.[27] A limited number of gear types, and in some instances vessel size classes, probably further simplifies management and limits conflicts between user groups, where one group's directed species is another group's bycatch.

Adaptive management approach

An option for multispecies ITQs is a form of adaptive management.[28] This approach does not simultaneously or comprehensively impose TACs and ITQs across all species. Instead, only the most economically or biologically important or vulnerable species might be initially regulated by ITQs. These might also be the species for which there is the greatest amount of management information available. For example, the species might be the one(s) that seems to economically or biologically "drive" the system, or it might be the species with the greatest vulnerability to sustained high rates of harvesting. It might also be the species which induces the strongest economic incentives for disinvestment [32, 84, 93]. Another version would regulate most species in selected species assemblages or only a few key species in different assemblages. If there is only a limited opportunity to change the species mix when harvesting (i.e. limited targeting or substitution possibilities), or if when increasing (decreasing) the harvest of one species the catch of one or more other species also increases (decreases) (i.e. complementarity in joint harvesting), then only this key species needs to be subject to an ITQ. Thus, several species can in these instances be managed by managing only a key species.

Focussing management on only a subset of species poses a number of potential benefits, including a potential for reduced cost of management,[29] reduced micromanagement, lessened program complexity and lower transactions costs, although some precision in control may be sacrificed. In addition, concerns over quota overages at both the vessel and industry levels, constraints on harvesting flexibility and regulatory costs may be eased. One serious disadvantage with placing ITQs on only the most crucial species, however, is that it might generate substantial redirected effort on to species or fisheries without quotas or TACs. Additional harvesting pressure may also be placed on

[27] It is shown in [21] that trip quotas can be effective in protecting a species only when stocks are reasonably well separated. When the species regulated with trip quotas commingle with unregulated species, bycatch and discard of the regulated species is unavoidable.

[28] This can be viewed as a form of an adaptive control problem.

[29] To the extent management and enforcement costs are fixed costs, then costs have the potential to be rather insensitive to the number of species covered by ITQs. There could even be cost savings, especially on a per ton basis, as costs are spread out among a greater volume of fish through a greater quantity of a given species (product-specific scale economics) or a greater quantity as more fish from different species are regulated (scope economies).

species thought to be likely candidates for future ITQs as fishers establish a catch history. There may also be other costs associated with managing only a subset of species if it results in overexploitation of unregulated fish stocks.

Another version of adaptive management can also be viewed as an incremental approach to selecting and adding species for ITQ coverage. An initial core group of principal species is selected to be the centerpiece of the ITQ program. As additional species are selected for ITQs, the incremental benefits with each newly included species (or species assemblage) may well progressively decline due to increasingly limited harvesting flexibility and lower incremental rents, higher discards and problems of matching TACs and harvest rates, and also as species with a lower value are covered. Additional costs of any new population assessments required to set TACs can also be a factor. The incremental benefits of an additional species could even become negative at some point, detracting from rents. Therefore, there may well be serious costs of micromanagement. The point at which the incremental benefits from expanded ITQ coverage are matched by additional costs would yield the economically desired scope of ITQ coverage. Different sequences of species to receive ITQ coverage can be evaluated by considering the incremental net economic and biological benefits under each alternative sequence path and the optimum selected. The choice could also consider uncertainty of resource abundances and TACs and apply the precautionary approach to fishery management. From a strictly economics point of view, this adaptive approach has promise.

Composite species approach

Under this approach, ITQs would treat all species in a multispecies complex as a composite or aggregate species with removals determined by only considering the most important species from either an economic or biological viewpoint. This approach might be most effective with many species, none of which dominate either biologically or economically. This approach might also be applied to several major groups of species, where species might be grouped by biological characteristics or type of harvesting gear. Some multispecies tropical fisheries or some of the multispecies rockfish fisheries along the Pacific coast of the USA are possible candidates. Multispecies fisheries with harvest rates that are in relatively fixed proportions, such as some gill net fisheries, would also be likely candidates.

Comprehensive approach

In many multispecies fisheries the best approach may be comprehensive ITQ management.[30] Without comprehensive species coverage by ITQs, conditions are set for fishers to establish catch histories for eventual ITQs. Moreover, mixed management systems (only partial ITQ coverage) can be expensive and enforcement can be more difficult, and one person's catch is another's bycatch. Comprehensive ITQs promote widespread reduction of incentives for the race to fish. In addition, and probably most importantly, once any new system is implemented—often no easy task—changes become difficult as new interests coalesce around the new system and industry and regulators become increasingly focused on operating within the system already in place. Hence, from a

[30]We are grateful to Lee Anderson and Paul Hillis for encouraging this approach.

political viewpoint, and to ensure that fisheries are fully committed to, and supportive of, the ITQ program, comprehensive coverage may be the preferred approach. The primary limitation to proper design and implementation of such a program is the extensive information required, which often may not be present.

Mixed strategies approach

Even with widespread ITQ management on all important species, additional measures, such closed areas, may be necessary.[31] These types of regulations can help keep fishers within their quota limits and direct effort on to species which are under less harvesting pressures. Supplemental measures may also be necessary to protect juveniles, such as increased mesh sizes or eliminating gear in which juvenile mortality cannot be controlled.[32] Refuges may also be important in fostering conditions conducive to sustainability [118–121].

More broadly, these supplementary measures can be viewed as mixed strategies [122]. A mixed strategies approach increases the options available to managers for populations subject to uncertainty, giving some control over an ecosystem even when the dynamics of the system are unknown and may never be known. Thus, confronting uncertainty and managing multispecies may not mean using conservative global quotas or acting prior to a full scientific consensus (the precautionary approach to management), but rather using mixed strategies that provide a degree of control whatever the underlying dynamics [122].

Concluding remarks

The complexities and difficulties of managing multispecies fisheries are well known. ITQs can further complicate multispecies management, but in a number of situations they have potential for improving both industry viability and resource sustainability. Applying ITQs to multispecies fisheries, however, is likely to be much more difficult than with so-called single species fisheries, because of complex multispecies interactions, substantial mingling of stocks and limited ability for fishers to target specific species.

The expected economic benefits from ITQs are largely related to decision-making flexibility they afford fishers and resource managers. Placing limitations on ITQ transferability, divisibility or duration reduces the flexibility of fishers' operations and the flexibility of managers in dealing with management issues and, therefore, the potential economic efficiency gains from ITQ management. Such limitations are typically imposed in recognition of equity and distributional interests (e.g. preventing the consolidation of quotas) and the trade-offs between efficiency and equity in multi-objective management.

ITQs will not solve all the problems of managing a multispecies fishery. Regardless of the management system in place, there remain complicating factors related to uncertainty about the resource stocks and species interactions. ITQs retain problems, such as incomplete property rights (albeit in a reduced form) and discards, and are sure to raise new issues dealing with balancing individual quotas with catches, and monitoring and enforcement.

The management challenge is to find a "good" second-best strategy in

[31]We are grateful to Wim Davidse for this insight, who also suggests that days-at-sea regulations on top of the ITQ system may be called for in some instances (see also [117]).

[32]We are grateful to Ran Meyers for this point.

an imperfect world. The key issue is not that ITQs fail to give the best outcome, but whether in a particular case they lead to an improvement over current fishery management practices, or possible alternatives. Whatever the benefits and costs of ITQs and their suitability in different fisheries, the management of multispecies fisheries is likely to remain a formidable and ultimately an imperfect task.

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