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Economics, Property Rights and Fishery Management

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Lyndhurst Falkiner Giblin was an extraordinary person: son of a Premier of Tasmania, graduate of Kings College, Cambridge, rugby internationalist (representing England), gold prospector in the Klondike, a voyageur with the Hudson Bay Company, ocean yachtsman, member of the Federal Parliament, a soldier on the Western Front (thrice wounded and twice decorated for bravery), and, according to one source, the first European to climb Mt Anne, to name a few of the parts he played. He also had a pivotal role in developing the discipline of economics at the University and making Tasmania the centre of economic studies in Australia prior to the Second World War. He was for a time Professor of Economics at the University of Melbourne, an associate of John Maynard Keynes, and an analyst of the Great Depression who anticipated some of the important developments of economic theory that have contributed significantly to the management of modern economies.

Giblin's professional life was marked by meticulous attention to the measurement of economic variables, establishing their relationships and testing these against the predictions of economic theory. He was preoccupied with statistics, and the methods that he used to interpret them were what we now describe as applied econometrics. One of the many roles he assumed during his life was that of Statistician to the Government of Tasmania, and I think it is appropriate that I begin this lecture commemorating his life and work with some statistics.

My topic is the role of property rights in marine capture fisheries, but given the awareness in Tasmania of the importance of aquaculture I will start with some figures on the relative importance of these two sectors of the fishing industry. World annual marine and inland aquaculture production has been steadily increasing to around 40 million mt, whereas annual production from marine capture fisheries seems to have hit a plateau (for the present) at 80 million mt, with a further 10 million mt coming from capture fisheries in inland lakes. The statistics on production of capture fisheries refer to landings, rather than catches – they omit the further 30 million mt of discarded by-catch. Of the landings of capture fisheries about one-third is used as feed for aquaculture species (10 million mt) or farm animals (20 million mt). In other words, of the fish we eat directly, 40% is farmed and 60% comes from capture of wild fish. Of the wild fish we catch we eat half directly, use a quarter as feed in farming, and throw a quarter away. I now turn to consideration of the world's marine capture fisheries.

Here are some statistics which would surely have caught Giblin's eye. In 1992 the United Nations Food and Agriculture Organization, the FAO, published some information about the economic health of the world's marine capture fisheries. While the annual catch was estimated to be worth $70 billion, this figure was matched by annual operating costs – the costs of maintenance, repairs, insurance, supplies, gear and fuel – of approximately $70 billion, with capital and labour costs totaling another $55 billion. The total cost of $125 billion should be interpreted as an opportunity cost – the value of the goods and services these resources would have produced had they been allocated to other industries. While there are many problems associated with estimates of this type, particularly in relation to the mobility of labour and capital and the conditions of production in other industries, taken at face value these shocking statistics suggest that mankind was annually giving up $125 billion dollars worth of other goods (including food) in order to catch $70 billion dollars worth of fish. In other words, they suggest we could have been better off by $55 billion dollars worth of goods and services per annum by leaving the fish alone. And the fish would have been better off too!

While the amount of waste suggested by these figures is not comparable with the waste associated with the Great Depression, I believe it is the kind of problem that would have attracted Giblin's attention: a significant public policy issue, capable of quantitative economic analysis, with implications for Tasmania with its own fishing industry, and impacting disproportionately on the less well-off.

When I say that over-fishing disproportionately affects the poorer members of the community I am referring to the generally observed relationship between traditional fishing communities and poverty. This association became the subject of controversy in Canada in relation to the relatively low standard of living of the inhabitants of Newfoundland – an island referred to affectionately by its locals as "The Rock", in recognition of the fact that any topsoil it once had was stripped away during the last ice age. Put simply, the question was: "Are they poor because they fish, or do they fish because they are poor?" A consideration of opportunity cost suggests that it is the latter – they fish because they are poor. With adverse conditions of production on shore it is natural for people to turn to the sea – you could say in Newfoundland's case that they are just following the land! Specifically, it makes sense for an to individual to devote extra effort to the fishery as long as the value of the average catch per unit of effort is as high as the value of the goods that could be produced by devoting the extra effort to agriculture instead. This, however, does not make sense from a community point of view, as the marginal return to fishing effort is less than the average return and, hence, is driven below the marginal return in agriculture or other industries.

One policy response to poverty in the fishery is to provide assistance in the form of subsidies for boatbuilding and income maintenance in fishing communities, but this exacerbates the problem of over-fishing, and contributes to the anomalous result that total cost exceeds total revenue in the world's marine fisheries. Policy needs to address the main cause of the misallocation of resources which is a mismatch between the conditions of production and the institutional framework within which marine fisheries have traditionally operated. The conditions of production are largely competitive and, according to economic theory, a perfectly competitive market will produce an efficient allocation of resources. However efficiency requires that all the conditions for perfect competition are satisfied, including the existence of a complete set of individual property rights to all assets which contribute to economic welfare. In the absence of property rights in the fishery which can be bought and sold, like the ownership of agricultural land, the market mechanism is incapable of regulating access to the fishery and market failure results.

While one consequence of the absence of property rights to the fishery is a misallocation of effort between the fishery and other industries, another consequence of the excessive amount of effort devoted to the fishery is the running down of fish stocks to the extent that, in some cases, the sustainability of the resource may be threatened. From an economic point of view we are depleting capital that would provide a rate of return on investment in excess of other investment opportunities in the economy. Investment in fish capital can be accomplished by reducing harvests to allow stocks to build up.

The notion of fish stocks as a capital asset became generally accepted by economists during the 1950s, following significant advances in fish population modeling by biologists. Biologists established two key characteristics of a fish stock: first, that the rate of growth of the stock declines as the stock increases; and second, that for many important species stock density increases as stock increases. The first of these characteristics is almost self-evident: the growth of a stock must eventually cease if the stock is to establish an equilibrium relationship with other species and the environment. The second characteristic became evident immediately after WWII when trawlers operating in the North Atlantic experienced unusually large catches per unit of effort which were attributed to the increase in fish stocks, relative to the pre-war period, resulting from the enforced moratorium on fishing in the North Atlantic during the war years. A unit of effort – one pass of the trawl through the fish stock – will produce more fish the denser the fish stock. The cost per ton of fish – the ratio of the cost of the trawl to the tonnage of fish caught – is lower the larger (and more dense) the fish stock is. The understanding that larger fish stocks lead to lower catching costs per ton of fish became incorporated in newly developed bioeconomic models – models that combine economics and biology to predict economic outcomes.

We can think of a fish stock as an asset like a bank account. As we have seen the rate of interest on the account (the growth rate of the stock) falls as the size of the balance increases, contrary to normal practice. The cost of making withdrawals (the unit cost of catching fish) falls as the balance increases. How would you manage an account like this? On the one hand, you wouldn't want an increasing balance to drive the rate of return below what you could get from another account, but on the other hand you would want to maintain sufficient funds in the account to keep the withdrawal costs down. In the case of a fish stock, this is the kind of balancing act performed by an optimal harvesting regime identified by a bioeconomic model.

Suppose anyone who wished had access to the bank account, what would be the outcome? Sums would be withdrawn as long as they covered the transaction cost of making the withdrawal. The balance would be driven down to a level at which it no longer paid for anyone to take money out of the account because of the high transaction cost. Any growth in the balance which offered a temporary reduction in transactions cost would immediately be siphoned off. Introducing a subsidy on the transaction cost would result in a further fall in the balance. This is effectively the condition of an open-access fish stock: low stock level and catching cost equal to the value of the catch, or even greater if subsidies are involved.

Why don't those with access to the account agree to let the balance grow to a level at which transactions costs are lower than the amounts withdrawn? Experiments show that cooperation of this kind can be achieved in small groups – say up to 8-12 participants. Those of you who run joint bank accounts might be surprised the number is that high! For industrial processes such as commercial fishing the large number of participants makes negotiation difficult (costly) and the absence of property rights normally precludes the kind of binding commitment that is required from all if it is to be in each participant's interests to cooperate.

In the absence of voluntary cooperation emerging, there are various roles that the state can play to improve the efficiency of the allocation of resources to the fishery. Regulations of one kind or another, including corrective taxes, can be imposed, or property rights of one kind or another can be introduced, allocated and enforced. However before considering these alternatives we need a basis for determining what would be an efficient solution. We get this information from a bioeconomic model – a model of the industry that takes account of both animal behaviour (biology) and human behaviour (economics).

To illustrate how a bioeconomic model is constructed I will use a Tasmanian example. A large stock of orange roughy was discovered in 1989 off the east coast of Tasmania. Called the St Helen’s aggregation it became the subject of intensive study by fishery biologists. Scientists from CSIRO plotted the location, extent and density of the stock and estimated it to be around 100,000 tons. Biologists at CSIRO and the University of Tasmania subjected samples to intensive examination to determine the age structure of the catch. It was found that the fish were very slow growing – not surprising given the great depths at which they live: a 100 year-old fish is around 50 cms in length and 3.5 kilos in weight. The information assembled by these scientists was handed to the population modelers, again at CSIRO, and using this information and standard growth models (developed partly as a result of the post-war North Atlantic experience) a model was developed which predicted recruitment, growth, natural mortality and the response of the stock to various levels of catch. This is the “bio” part of the bioeconomic model and it is the product of a great deal of scientific effort.

It is relatively simple to add the “economic” part of the model. Using the New Zealand experience with fishing for orange roughy, a relationship between catch, stock and effort was established by members of the School of Economics at the University of Tasmania, and the economists and biologists then pooled their efforts to develop a relationship between value of catch, cost of fishing effort and level of fish stock. This model could then be used to work out the level of fishing effort that maximized the use-value of the stock. The term use-value refers to the value of the fish in human consumption and does not include additional values, such as contribution to biodiversity, which should also be taken into account. Implementing the recommendations of the bioeconomic model requires regulating the total level of fishing effort, which in turn requires a degree of control by the management authority.

The bioeconomic model indicated that, because orange roughy are taken from large aggregations or schools, unit harvesting costs were not strongly stock-dependent. It also revealed that, while the rate of growth of the stock would rise to some extent as stock declined, it remained quite low even at low stock levels. The orange roughy stock was like a bank account with a low rate of interest on the marginal dollar invested and with no significant penalties in terms of higher withdrawal costs if the balance was run down. The question to be answered was “Which Bank?” Do we leave the bulk of our assets in an account with a low rate of interest and low withdrawal costs or should we cash in some of the balance and shift it elsewhere? The answer from the bioeconomic model was that biomass would have to be reduced to around 25% of the initial level to get a marginal rate of return similar to that of other capital investments. The annual sustainable catch at that biomass level was low relative to the high catches taken while the stock was being fished down. The outcome in terms of harvests was very similar to that from converting an old-growth forest to a plantation-style “normal forest”. Foresters refer to the “fall-down effect”, which is the drop in yield as harvesting the stock of old-growth is replaced by the annual sustainable yield of a plantation. One clear message conveyed by the bioeconomic model was that in the absence of effort controls the economic incentives facing individual fishermen would lead to commercial extinction of the stock.

Now consider the fate of another orange roughy aggregation located on the Macquarie Rise in the southern ocean. An ABC television documentary titled “Sea of Trouble” featured interviews with Tasmanian fishermen who were confined to port by government regulations designed to protect the orange roughy stock from over-fishing, while foreign boats filled their holds. The effort of local fishers could be controlled but apparently not that of foreign vessels. Part of the problem was a dispute over whether the whole extent of the stock was in Australian waters or whether it was a straddling stock, to use modern parlance. Either the foreign vessels were behaving illegally, or there was a lacuna in the evolving property rights structure under the UN Law of the Sea.

The Law of the Sea is a useful illustration of the process of the development of property rights – the missing ingredient in the unregulated competitive fishery. Ask an economist to explain something and she’ll say “it’s caused by supply and demand”, and the evolution of property rights is no exception. The demand for property rights to fish stocks grows as the scarcity value of these stocks rises due to increased exploitation. Consider for example the case of Iceland which, in response to the urgings of its fishing industry, unilaterally increased its fishing zone in a series of steps to 12, 50 and then 200 miles in the period 1958-75. British trawlers objected to being excluded from Icelandic waters and each extension of the fishing zone was followed by a skirmish referred to as a “Cod War”. The third “Cod War” lasted seven months and saw a few shots fired and some vessels rammed, but the Icelanders had logic on their side and other countries, including Canada in 1977, soon followed their example.

Why was the 3-mile limit originally established and why did it last so long? Three miles was about as far as you could fire a cannonball from the coast and there is no point to a property right which can’t be enforced. This suggests that one of the important determinants of the supply of property rights is technology. With the development of radar, and more recently satellite technology, countries can survey, and to a certain extent control, activity in their waters. The other determinants of the supply of property rights are the legislatures, bureaucracies, police and courts which develop and enforce property law.

When all these factors come together, as in the case of the UN Law of the Sea Conference, an expansion of property rights can occur, and in 1982 countries were granted various rights, including the right to manage fisheries, in waters out to 200 miles from shore. Of course 200 miles is an arbitrary boundary and it was discovered that it cut through some significant fisheries. Such stocks are termed straddling stocks: the Macquarie Rise orange roughy aggregation was claimed to be in this category, and the cod stocks on the Grand Banks of Newfoundland certainly were. Other fish stocks don’t remain in one place but move among Exclusive Economic Zones (EEZs) and the high seas. Such stocks are termed highly migratory and examples, in which Australia has an interest, include the Southern Bluefin tuna (SBT) and the Western and Central Pacific Ocean stocks of skipjack, yellowfin, bigeye and albacore tuna. An important part of the development of the law of the sea is to extend the system of property rights to promote protection and efficient exploitation of species such as these.

I have described the problem of over fishing as one of market failure – the absence of property rights – and have hinted at a direct solution- the establishment and enforcement of property rights. Turn fishermen into ranchers by giving them responsibility for and control over the resource they exploit. However there is another approach which is the traditional approach to economic policy - direct regulation, and indirect regulation through a system of incentives generated by taxes or subsidies. We have already seen that subsidies - on vessel construction and in income support for fishing communities - are in part responsible for the dismal record of economic inefficiency recorded by the FAO. Taxes on the catch or effort of fishermen have been proposed in the past but have been rejected as infeasible, or perhaps downright dangerous to enforce. Direct regulation of catch or effort has been widely used and has contributed to some objectives, such as conservation, but has generally not achieved the objective of economic efficiency.

If fish stocks have been over-exploited, why not introduce regulations that limit catches in order to let stocks build back up again? The simplest measure is a limit on the total catch: when the limit has been reached the fishery is closed for the season. This type of regulation has the unfortunate consequence of encouraging a race for the fish, with each fisherman trying to catch as much as he can before the seasonal closure. The ultimate illustration of the economic waste involved is the British Columbia herring roe fishery which has had a season as short as 15 minutes! Picture the scene: the fishery officer ready to open the season with a blast from his shotgun, dozens of specially constructed punts circling the schools of herring ready to set their nets, the gun fires, the vessels vie with one another to encircle the fish, the gun fires again to close the season and the lucky few secure their catch. Afterwards the herring punts retire to the boatsheds to wait for the following year's season.

Another type of regulation limits the gear which can be used to catch fish – the length of net, the number of lobster pots, or the size of vessel. At first glance this seems a reasonable approach, but what if we were to apply it to other industries? Would anyone take seriously a proposal to conserve old-growth forests by banning the use of chain saws in commercial forestry? While gear limitation might be effective as a temporary measure, legislating for technical or allocative inefficiency should not be part of a long-term solution.

An example of gear limitation which was partially effective was the limit on the total number of pots in the Tasmanian rock lobster fishery. We know this program had some success in economic terms because in the late 1980s the licences were selling for around $4000 per pot. This sum reflected the expected present value of the excess of revenue over cost associated with each pot. Recall that the problem identified by the FAO was an excess of cost over revenue. The profit per pot multiplied by the number of pots measures the annual value-added generated by the stock of fish; it is comparable to the rent generated by farm land. However a study concluded that this approach to management was only partially successful, generating only around half of the potential value from the fishery. It is also subject to erosion over time as fishermen find ways to overcome the gear restrictions; in the case of the lobster fishery this involved measures that increased the fishing power of pots through more precise placement – by means of satellite navigation, colour echo sounders etc. - and by lifting pots more frequently. The struggle between the fishermen and the regulators is an unequal one – the fishermen know the fishery better than the regulators and can usually find ways around the regulations.

I argued earlier that the problem of the fishery lies in the mismatch between the conditions of production and the institutional framework. The fishery tends to be competitive – the sort of industry structure that will generate an efficient outcome if the property rights structure is adequate. In the absence of individual property rights, however, competition leads to over-fishing, depleted stocks and higher costs. It is reasonable to conclude that efficiency can be achieved by creating the sort of individual property rights envisaged by the theoretical model of competition. We have already considered one type of right – the right to fish a lobster pot in accordance with various rules and regulations. This type of property right made a partial contribution to economic efficiency but was not precisely enough defined to achieve the full potential of the fishery or to prevent a slide back towards greater inefficiency.

A more precisely defined right is the right to catch a certain tonnage of fish. In 1985 each licensed diver in the Tasmanian abalone fishery was allocated 28 units of quota, with each unit providing a right to take 1/3500 of the total allowable catch (TAC). This system rapidly became a victim of its own success with the market value of quota rising to $30,000 per unit by 1991. In response to demands for greater security of tenure and more flexibility the commercial abalone licence was split into two parts- the diving licence and the abalone quota unit – and both these rights became transferable in 1993. In 1994 increased security was provided for quota holders by a deed of agreement. By 2000 quota was trading for $280,000 per unit.

In the Tasmanian commercial rock lobster fishery the right to fish a pot was converted, in 1998, to a transferable right to take 1/10507 of the annual TAC. This change gave the Department of Primary Industries, Water and Environment control over the TAC and gave fishermen flexibility in organizing and conducting their business. The introduction of individual transferable quotas (ITQs) has been judged a success on sustainability grounds, with lobster biomass increasing, and on economic efficiency grounds with catch rates going up and quota units doubling in value. The only perceived drawback is the loss of employment in the fishery. While this is of concern from a social point of view, it is, in fact, another measure of the success of the scheme. The problem identified by the FAO was excessive effort directed to the world's fisheries: the solution to this problem is to transfer effort to productive uses elsewhere.

The success of ITQ schemes depends critically on the enforcement of the rights: only rights holders should participate in the fishery and they should limit their catch to their quota holding. If the right is the sole method of management it may need to be quite complicated – specifying, in addition to weight of fish caught, where it can be caught, when, and what size of fish. The more complicated the right the more costly it is to enforce. Thus ITQ schemes are often supplemented by regulations; for example, size limits in the rock lobster and abalone fisheries, and seasonal and area closures in other fisheries to protect breeding stocks. Economic research on enforcement suggests that "naming and shaming" offenders and swiftly imposed penalties are the best deterrents to criminal behaviour in the fishery - justice swift and sure, and seen to be done!

If property rights are to be created they have to be distributed in some way. Economists are fond of saying that the method of distribution is irrelevant and that dropping them from a helicopter is as good a method as any. Ben Bernanke, the Chairman of the Federal Reserve, recently used this analogy to random distribution to suggest a way out of the current liquidity crisis. The reasoning behind this view is that, irrespective of the initial distribution, in the long-run resale of the assets will result in them ending up in the right hands from the viewpoint of economic efficiency.

Fishermen don't seem to be as relaxed as economists when it comes to the distribution of property rights. While it was generally agreed that ITQs should be established in Tasmania's rock lobster fishery it took two years of intense political lobbying before a scheme was finally passed by Parliament. I don't have time to discuss other examples in detail – the 1400 out of a total of 1800 eligible fishermen who appealed against their quota allocation in New Zealand's deep sea fisheries, or the court case against the orange roughy quota allocation in Australia's South East fishery on the grounds that the average of a vessel's annual shares of total catch was not the same as its average share of catch over the relevant period; the court agreed, finding that the management authority had committed "a statistical fallacy that produces an irrational result". One wonders what the judge would have said about the helicopter method! I cite these examples as a reminder to economists that, in the words of the old saying "There is many a slip twixt cup and lip". It is one thing to prescribe property rights as the solution to the problem of over-fishing and another to implement it.

I now turn to an important fishery which I have been working on recently and which illustrates many of the issues we have been discussing - the Southern Bluefin Tuna (SBT) fishery. SBT is a highly migratory species which is harvested mainly in the high seas areas of the Southern Ocean and in waters off Australia and New Zealand. SBT were heavily fished in the past with the reported annual catch reaching 80,000 tons in the early 1960s, but since then trending downwards to around 14,000 tons per annum in 1990, and leveling out at that level. Before 1961 Australia and Japan were the only two countries reporting catches. In more recent years New Zealand, Taiwan, Korea, Indonesia, The Philippines and South Africa have also participated in the fishery.

In 1982 Australia and Japan were still the main countries harvesting SBT, with New Zealand and Taiwan having a very minor involvement. In that year the UN Law of the Sea gave coastal states the right to manage fishery resources within the 200-mile limit. Australia and New Zealand's newly acquired property rights to the valuable SBT fisheries in their waters could perhaps be used as bargaining chip. The Japanese long-line fleet could fish as much as it liked in the high seas but craved access to the productive Australian and New Zealand waters. For their part, Australian fishers needed access to the lucrative Japanese sashimi market if they were to get full value for their catch. The stage was set for negotiation.

Perhaps coincidentally with the Law of the Sea coming into force, a meeting providing an opportunity for an exchange of views between fishery biologists, fishery managers and industry representatives from Australia, Japan and New Zealand took place in Wellington in 1982. There followed a series of annual trilateral meetings at which biologists from the three countries exchanged views about the status of the stock. Basic biological research conducted at the CSIRO in Hobart on the size and structure of the SBT stock suggested that by 1980 the spawning stock biomass (SSB) had been reduced to around 50% of the virgin level and that the 1980 catch level of 45,000 tons was not sustainable. A system of annual catch quotas for the three countries grew out of these trilateral meetings, and ITQs became adopted as a way of distributing Australia's quota.

We have already argued that the more precisely defined the property right is, the more closely will the market solution approach the efficient outcome. However, as we have noted, there is an obvious trade-off here as the more finely defined the property right is, the more difficult (costly in economists' language) it is to enforce. The country SBT quotas and the ITQs were denominated in tons of fish, but catching a ton of juveniles has a different impact on the stock than catching a ton of adults. Early research suggested that total yield would be maximized by postponing capture until the fish were at least 4-5 years old, a prescription which would have virtually eliminated the Australian fishery which was based on purse-seine harvesting of the juvenile stock. Concerns about the impact on the stock of harvesting juveniles led to Japan agreeing to purchase and freeze (ie. not catch) 3000 tons of Australian quota for three years starting in 1987. Australia's willingness to enter into this arrangement reflects the fact that its fishery was barely economically viable at the low prices being obtained per ton of juvenile fish, as compared with the sashimi quality adult fish taken by the long-liners.

In 1994 the voluntary management arrangements agreed on at the trilateral meetings were formalized when the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) came into force. By the 1990s the SSB of SBT was estimated to have fallen below 20% of its unexploited level. The CCSBT adopted the goal of stock recovery, setting a target level of 50% of unexploited SSB to be achieved by 2020. The CCSBT continued the system of member country catch quotas and encouraged other nations participating in the fishery to become members.

Our bioeconomic model of the SBT fishery takes account of the size and structure of the fish stock and the different impact of long-line and purse-seine gear. The model tracks the survival and growth of each cohort as it progresses to sexual maturity at age 11 and then for a further 10 years as part of the SSB. The impacts of purse-seine gear on juvenile cohorts and long-line gear on adult cohorts are represented by a series of coefficients relating catch to fishing effort and stock level. The estimated catches corresponding to the chosen levels of fishing effort are then used to revise the biomass of each cohort and the SSB as a whole. The level of the SSB then determines the recruitment to the stock in the following year. Using this model it was determined that the management regime in place in 2001, involving Australia, New Zealand and Japan as CCSBT members and Korea, Indonesia and Taiwan as fringe players, was generating close to 100% of the potential economic value of the fishery, and likely to achieve the conservation objective of 50% of SSB by 2020.

This outcome perhaps illustrates the point that cooperation can be achieved when a small number of players is involved. Alternatively it may indicate that when countries negotiate and each country pursues its own interests, taking account of the likely response of the others, the outcome of a non-cooperative game with a small number of players is similar to the cooperative outcome. Furthermore there is a lingering doubt about whether catches were reduced over the period 1982-2000 because of the quotas, or whether the quotas were reduced in tacit recognition that the over-exploited state of the stock meant that catches were bound to decline anyway.

The development of tuna farming restored the viability of the Australian fishery, resulting in significant value being added as juveniles were grown in cages to the quality and size demanded by the market. However Japanese representatives at the CCSBT expressed continuing concerns about harvesting juveniles on both economic efficiency and resource sustainability grounds. The bioeconomic model was used to conduct an experiment to test this claim. Suppose that instead of farming, Australia took its quota by means of long-liners following Japanese fishing practices. What would be the implications for stock conservation and economic efficiency? The answer is that it makes virtually no difference: if Australia switched to long-lining the value of the fishery would decline slightly, and the biomass level would marginally increase.

Some significant changes have occurred in the management and modeling of the SBT fishery since the results I have just described were obtained. On the management side, Korea and Taiwan joined the CCSBT as cooperating members in 2001 and 2002, and have been allocated catch quotas. The Philippines, South Africa and the European Community became cooperating non-members, a transitional stage to full membership, in the period 2004-6, and Indonesia has indicated that it intends to apply for cooperating membership in the near future.

Recent experience of one or two years of reduced catches of small fish in the Japanese and Korean long-line fleets suggested lower recruitment to the stock than that predicted by the bioeconomic model. This could simply reflect the variability of year to year recruitment or changes in the performance of fishing gear, but it creates uncertainty about the parameters in the stock recruitment function. Revised stock assessments prepared by CSIRO have tended to be more pessimistic than earlier results, particularly in terms of the recruitment of juveniles to the SSB. The revised stock recruitment functions suggest that the productivity of the stock is lower than was previously thought and this is reflected in lower economic values at all effort levels. When the revised bioeconomic model was used to re-evaluate the performance of the management regime in the light of these changed circumstances a gloomy picture emerged. The net present value of the fishery was halved as compared with the earlier results and the model predicted that continuation of the 2005 CCSBT regime would eventually threaten the commercial viability of the stock.

The revised model suggested that, to further both economic and conservation objectives, the combined CCSBT annual catch quota needed to be cut from its 2005 level of around 15,000 tons to a level well below 10,000 tons per annum. This is consistent with the recommendation recently made by the CCSBT on conservation grounds that:

> "the global SBT catch should be reduced to 9,930t for 2006, which corresponds to a 5,000 tonne reduction in the assumed global catch of 14,930t for 2004 and 2005. This level of catch reduction was chosen so that, when coupled with the implementation of a management plan, it would provide an estimated 50% probability that the spawning stock biomass in 2014 (when a minimum is forecast) would be no lower than 2004 spawning stock biomass which is currently the lowest estimated." (CCSBT (2005), excerpt from paragraph 37)

Compounding the uncertainty about recruitment is uncertainty about the relationship between reported catches (which are the data used in the stock assessment models) and actual catches which some Australian industry sources had claimed might be higher by a factor of three. An audit of the Japanese market, using sales data to estimate landings, indicated that Japan's 2005 SBT quota had been over-fished by 25%. Further investigation suggested a pattern of over-fishing going back several years. This revelation will require a substantial revision of the stock recruitment component of the bioeconomic model, which was estimated on the basis of reported catches, and the preparation of a new set of predictions about the future of the fishery. It is too early to say, but, paradoxically, the new predictions may be more optimistic since the revised catch history tends to suggest that the stock has been more productive than previous models suggested. On the other hand, the episode casts doubt on the prospects for international cooperation.

Responding to the over-fishing scandal the CCSBT was able to cut the TAC to just under 12,000 tons. The bulk of the cut was borne by Japan which saw its SBT quota reduced to 3000 tons for the years 2007-2011. In addition Korea and Taiwan agreed to keep their catches below their quota allocations. The 12,000 ton TAC is still higher than that recommended by the current version of our bioeconomic model, and by the CCSBT's own assessment, but we have yet to see what the revised bioeconomic model will predict for the future of the Southern Bluefin Tuna stock.

In conclusion, the world's fisheries face unprecedented challenges. Demand for fish will continue to increase with increases in population and incomes, and as agricultural production is disrupted by climate change. The total catch of marine capture fisheries is unlikely to increase and may decline, placing more pressure on aquaculture. In turn the demands of increased aquaculture production involving carnivorous species that are fed on wild-caught fish will place more pressure on marine stocks. High demand encourages illegal fishing which continues despite the efforts of national and international management frameworks, and under-reporting of catches frustrates efforts to model fish populations. On the supply side, technical change has increased the catching power of fishing fleets but, except in high-profile cases such as turtles and dolphins, there is little incentive to avoid by-catch and wasteful discarding continues. The interactions between wild and aquaculture stocks are still imperfectly understood. Finally, climate change is leading to increasing acidification of the world's oceans with so far incalculable consequences for the marine food chain.

Can we meet these challenges? We have many of the necessary tools: fishery biologists are adept at modeling fish populations and the economics of the industry is reasonably well understood. Many management options have been developed, of which property rights with individual catch quotas are just one. Many of the necessary management institutions already exist at state, federal and international levels, and we have shown an ability to develop new institutions in response to special cases such as straddling stocks and highly migratory species. We have the wherewithal to take the necessary actions, but will we take them quickly enough? The debate about fishery conservation and management eerily resembles that surrounding climate change: how do we balance the claims of poorer developing nations against those of the richer established fishing nations? How do we balance the claims of the current generation against the needs of future generations? Can we find the political will to resolve these issues before we do irreparable harm to the earth's stock of natural capital?

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