Harvesting regulation under quota management systems for ocean fisheries

Decision making in the face of natural variability, weak information, risks and conflicting incentives

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Minus sæ pecces si scias quid nescias
(You will go wrong less often if you know what you do not know)
Publilius Syrus

Decisions about harvest levels are the most crucial responsibilities of fisheries managers, but the outcomes are always more or less uncertain. The risk depends largely on the information available. Fisheries biologists, trained to assess the probabilities of outcomes from management decisions, are too often also expected to decide what risks should be taken. Emerging fisheries management regimes based on individual fishermen's quotas, best exemplified by New Zealand's quota management system, redirect the incentives of those with harvesting rights to cooperate in improved management, including improved information-gathering. Under these regimes, most management decisions can be made by quota-holders themselves, although safeguards are needed to protect the broader public interest in resource management.

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The most critical task of fisheries managers is to determine the appropriate level of harvest. Harvest regulation is not an exact science, however, and the prescription must often take account of a variety of biological and economic considerations. Harvesting strategies generally depend heavily on estimates of the size of the stock and its productivity, but the information available to estimate these is never perfect; to a widely varying degree it is incomplete, inconsistent and contradictory. In consequence, the harvest levels fixed by resource managers in fishing nations around the world are subjects of debate and controversy.

Disputes over harvest regulation are aggravated considerably by the conflicting interests in stake. Traditionally, the task of fixing harvest levels falls on governmental managers who see their primary responsibility as protecting the resource from overexploitation. Typically they attempt to specify a harvest that can be sustained, but in the face of uncertainties about the stocks and the effects of fishing they tend to be conservative. In particular, they resist making decisions that run risks of stock depletion or collapse.[1]

However, the brunt of these decisions about harvest levels falls on fishermen, whose main concern is to earn income. Fishermen are more sensitive than the regulators to economic pressures, and to the cost of foregone opportunities when harvests are constrained at a lower level than is necessary. Their readiness to take risks is legendary.

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Not surprisingly, disputes between regulators and the regulated are often heated. Significantly, disagreements are not usually over long-term objectives, but rather over the appropriate response to the uncertainties that plague stock assessment and prediction. Everyone usually agrees that the stocks should be sustained; the arguments are about how much can be harvested without causing depletion.

Aggravating these disagreements, though rarely articulated clearly, is the pervasive problem of uncertain information, and limited understanding of the resource and its response to fishing. A good fisheries scientist, asked by a minister of fisheries to specify the maximum catch that can be harvested from any stock with absolute safety, would have to answer 'zero'. Even with the best of information, he knows he cannot prescribe an absolutely safe harvest policy, because there is no such thing; accidents of natural variation can drive any biological population to extinction whether it is harvested or not, and harvesting can provoke such an occurrence. Nevertheless, fisheries scientists are frequently asked this question. They know that 'zero' is not the answer that ministers seek. In effect, they know that ministers don't really insist on absolute safety, because that is unrealistic.

Consequently, fisheries scientists grapple with uncertainty. They routinely make *personal* and *subjective* judgements about how far to stray from absolute safety in search of some allowable catch greater than zero. They balance the pressure for more fish against risk to the stocks, and specify a harvest that is not absolutely safe but is reasonably safe. The trouble is, what is 'reasonable' in this? Why should biologists be burdened with making these decisions? If not biologists, then who should decide, and how should the decision-making process be restructured?

The whole issue of harvest regulation, and especially the predictability of harvests over time, has recently taken on much greater importance as fishing nations have begun to adopt individual fishermen's quotas as their instruments of regulation. Successful experience so far with this new approach to fisheries management makes it likely that quota systems will be relied upon increasingly in future. This system of regulation puts a heavier onus on harvest specification. Where individual quotas are denominated in tonnes of fish, the prescribed total allowable catch (TAC) is the figure which determines the amount of quota that can be issued; and whether quotas are defined in tonnes or as a percentage of the total allowable catch, the level and expected variability of the harvest determine the value of the harvesting rights.

This article suggests that typical fisheries management systems, in developed countries at least, are not well structured for decision-making about harvesting levels. This applies to traditional management regimes, but it is a much more serious issue under quota management systems. The next section contains a depiction of the harvest level decision, emphasizing the need to allow for variation over time and the uncertainty about outcomes. The decision-making process is then analysed and a distinction is drawn between assessing risks and making judgements about what risks should be taken; it is suggested that too often biologists, trained to deal with the former, are burdened as well with the latter. However, the uncertainty and risk surrounding management decisions depends on the information available. This leads into an exploration of how the new quota management systems redirect the incentives of fishermen to support improved management, and how

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[1]The conservatism of fisheries scientists around the world is observable in their tendency to support the lowest estimates of safe harvest levels that can be justified by the available data. To evaluate the impact of a higher harvest rate, they typically project a fixed and progressively more dangerous loss to the stock, ignoring how future adaptive management responses could prevent such continuing deterioration. To define an acceptable probability, or risk, of stock collapse, scientists tend to choose both a very low probability (eg 10%) and a conservative definition of collapse (eg to less than 20% of the stock's virgin biomass). C.J. Walters, *Adaptive Management of Renewable Resources*, McGraw-Hill, New York, 1986.

institutional arrangements can be restructured to protect the public interest while allowing those with rights to the resources to assume management responsibilities, including decision-making about harvest levels.

Among the quota management systems adopted by fishing nations so far, undoubtedly that of New Zealand is the most advanced. Accordingly, we draw heavily on New Zealand's experience to illustrate the implications of this approach to fisheries management.

Allowable catch: fixed and variable components

To maximize the long-term biological and economic yield from a fish stock, it is usually necessary to vary the catch from one year to the next. This is because the size of the stock varies over time as a result of fluctuations in environmental conditions such as ocean currents and temperatures, predators, and other natural factors.[2] Adjustments over time may also be dictated by new information, market conditions and a variety of other considerations.

In light of this variation over time, it is helpful to distinguish between two components of the customary TAC. One is the maximum catch that can safely be taken every year. This maximum safe catch can alternatively be described as the lowest TAC within the range of expected fluctuations over time, under a regime designed to maintain the long-term productivity of the stock. This *fixed quota*, sometimes referred to as the maximum constant yield, has important implications for the management of an industrial fishery, because it is the harvest that can be counted on every year. It will generally need to be adjusted, gradually over the years, as more information is gathered about the long-term productivity of the stock.

The second component is the catch in addition to the fixed quota that can be harvested in any particular year. This *variable quota* represents the short-term catch opportunity. It varies because of changing biological and environmental conditions. It may also be adjusted in light of improved information, or as a result of a deliberate policy of fishing down a virgin stock or building up a depressed stock.

Both the fixed and variable components usually account for a significant part of the TAC. If the harvest level is chosen to maximize the total long-term catch, and if the stock's productivity is known with certainty, the variable quota for most stocks can be expected to be between one-third and two-thirds of the total.[3] It follows that if the harvest in a fishery is constrained to a level that can be taken every year – the fixed quota only – the total catch over time will be considerably less than if a variable quota is taken in addition.

For purposes of the present discussion it is important to note that the fixed quota component of the TAC is constrained by two factors. One is the inherent biological variability of the resource. Different species of fish differ enormously in the stability and productivity of their populations, and the greater the natural variability the greater will be the share of the variable component of the average TAC over time. The other factor is the state of knowledge about the stock. The less known about it, the smaller will be the catch that can be predicted to be available with certainty. Improved information not only enables more accurate estimates of the harvestable surplus and hence improved yields, but also

[2] R. Hilborn and C.J. Walters, *Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty*, Chapman and Hall, New York, 1991.

[3] For estimates on New Zealand stocks see J.H. Annala, ed, 'Report from the Fishery Assessment Plenary, April–May 1990: stock assessments and yield estimates', unpublished report, New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Centre, Box 297, Wellington, New Zealand, 1990.

tends to boost the fixed quota component, as uncertainties about the stock's size, productivity, and variability are reduced.

Three conclusions important to the remainder of this article can be drawn from this. First, to obtain the maximum benefit from a fishery, the catch must be altered more or less continuously, in light of changes in the resource itself and changes in the available information about it. Second, the extent to which fisheries managers can reliably make these adjustments, and prescribe harvests that will yield the maximum volume or value over time, depends on the scientific information available to them. Better results can be achieved with more, and more reliable, information about the stock. Third, the outcomes of their decisions are always more or less uncertain, and there is always some risk of stock depletion, collapse or other unwanted result.

We now turn to the processes of deciding harvest levels in the face of uncertain information. The discussion thus focuses on the treatment of uncertainty surrounding the variable component of the allowable catch.

Role of scientists: risk assessment

The recent but now substantial literature on decision making under uncertainty distinguishes two basic components of the decision process: *risk assessment* and *risk management*.[4] Risk assessment deals with methods of assessing the probability of possible outcomes of decisions, while risk management deals with ways of responding to the uncertainty about outcomes.

Risk assessment and management in fisheries have attracted some specific attention,[5] but while this literature says much about the need to define objectively and to account for risks, it says very little about the appropriate role of scientists in making the essential value judgements associated with risk management.

Fisheries scientists are trained in stock assessment methods, which now may involve sophisticated statistical analysis and modelling techniques. They are well equipped to make probabilistic statements about the consequences of policy choices – the risk assessment part of the decision process. Thus, if asked to predict the effect of an annual harvest of, say 5 000 tonnes of fish from a particular stock, scientists can respond with probabilistic statements such as: 'There is a 15% chance that the stock will be reduced below 20% of its virgin size within eight years'.[6]

Probability statements about possible outcomes of policy choices are a much more helpful way of recognizing uncertainty than simply ascribing ranges or confidence limits to expected outcomes. They provide more information from the available data about degrees of risk, and they can be structured in ways that permit formal ranking and evaluation of policy alternatives, as we discuss below.

There is, inevitably, debate among scientists about how historical fisheries data should be used in probability calculations. The issues range from fundamental statistical approaches (such as Bayesian versus frequentist methods) to computational tactics and procedures. These esoteric debates are generally open and constructive. Experts usually scrutinize them, and the stock assessments resulting from them, objectively and with healthy effect. Such debates also stimulate the search for ways to resolve the arguments through data gathering and improved methodologies.

[4] R.L. Keeney, 'Structuring objectives for problems of public interest', *Operations Research*, Vol 36, 1988, pp 396–405; R.L. Keeney, D. Von Winterfeldt and T. Eppel, 'Eliciting public values for complex policy decisions', *Management Science*, Vol 36, pp 1011–1030; W. Edwards and D. Von Winterfeldt, 'Public values in risk debates', *Risk Analysis*, Vol 7, 1987, pp 141–158.

[5] E. Linder, G.P. Patil and D.S. Vaughan, 'Application of event tree risk analysis to fisheries management', *Ecological Modelling*, Vol 36, 1987, pp 15–28; R. Mendelssohn, 'Determining the best trade-off between expected economic return and the risk of undesirable events when managing a randomly varying population', *Journal of Fisheries Research Board of Canada*, Vol 36, 1979, pp 939–947; R.M. Peterman, 'Statistical power analysis can improve fisheries research and management', *Canadian Journal of Fisheries and Aquatic Science*, No 47, 1990, pp 2–15; S. Peterson and L.J. Smith, 'Risk reduction in fisheries management', *Ocean Management*, Vol 8, 1982, pp 65–79.

[6] Particularly good illustrations of this kind of probabilistic assessment, along with an exposition of how the process is applied, can be found in R.I.C.C. Francis's analysis of New Zealand's Chatham Rise orange roughy fishery (R.I.C.C. Francis, 'An assessment by risk analysis of management strategies for the orange roughy (*Hoplostethus atlanticus*) fishery on the Chatham Rise, New Zealand', working paper, New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Centre, Box 297, Wellington, New Zealand).

Stock assessments also involve assumptions about data and population dynamics. Scientists always have to make some judgements that cannot readily be stated in probabilistic terms. For example, faced with evidence that a stock is declining but the rate of recruitment is not, a scientist usually has no objective basis for predicting how much more the stock can be reduced before recruitment effects are felt. As noted elsewhere in this paper, biologists tend to use conservative assumptions in such cases. Again, the problem can be minimized by independent expert review and open debate.

Beyond providing probabilistic statements about stock responses to particular harvest levels, scientists can specify how harvests can be varied over time, in response to unpredictable variations in the stock, in order to achieve a specific management objective such as the maximum average annual catch.[7] One of the simplest of these 'optimum feedback rules' is to harvest a constant fraction of the stock each year (the so-called F 0.1 rule). However, scientists should select a feedback rule appropriate to the management objective which, in the case of most fisheries, is not simple or even well-defined.

Moreover, these rules have value judgements buried within them, so that if the scientist is left to specify the feedback rule he also imposes his value system. The F 0.1 rule, for example, is not just about biological variability; it implies a policy objective of reducing exposure to risk in a particular way which, though convenient to calculate, is unlikely to have much practical relevance to the complicated management challenges most fisheries managers face.[8]

Fisheries science has not yet reached the stage at which a particular methodology for stock assessment can be prescribed for all cases, but whatever method is used, it is only reasonable and prudent to express the results in probabilistic terms. Preferably, the assessment process will be based on a regularly updated 'computational engine', based perhaps on microcomputer software, capable of doing the probability calculations for each stock, for a range of policy options. The results of such scientific risk assessments can then properly be used by others in an entirely separate process of value-laden risk management and decision making.

Risk management

Fisheries scientists are often called upon not only to assess the risks associated with harvest decisions but also to manage the risk. The two parts of the decision process become blurred and confused, and the failure to distinguish these separate tasks and to allocate them to those best placed to dispatch them undoubtedly leads to poor decisions. If an aeronautical engineer advises a traveller to fly in a certain aircraft because it has only a 2% probability of crashing, he strays beyond his competence. We should defer to him about the probability of a crash, but not about his conclusion that the risk to the hapless traveller is worth taking. Similarly, biologists, whom we must depend upon to predict the effects of harvesting stocks, have no business deciding how much risk we should take, or indeed how we should balance the various benefits and costs of resource management decisions.

New Zealand's fishing industry has emphasized the conflict arising from this overlap of responsibilities in recent stock assessments, where governmental scientists were perceived to suffer from:

[7] C.W. Clark, *Bioeconomic Modelling and Fisheries Management*, Wiley, New York, 1985; M. Mangel, *Decision and Control in Uncertain Resource Systems*, Academic Press, New York, 1985.

[8] Technicaly (and arcanely) the F 0.1 rule aims at reducing exposure to risk by maximizing a risk averse, logarithmic utility function (R. Deriso, 'Risk averse harvesting strategies' in M. Mangel, ed, *Resource Management: Lecture Notes in Biomathematics*, Vol 61, Springer-Verlag, Berlin, 1985, pp 65–73).

> . . . excessive conservatism – due to the absence of alternative approaches in the decision-making process. The point that is germane here is that a failure to incorporate appropriate levels of risk analysis, including economic risk (in effect taking a broader view than a straight bias towards conservatism) results in a lack of balance with only the one conservative view prevailing.[9]

Given a range of possible decisions about allowable harvest levels or fishing rates, and probabilistic assessments of the outcome of each, several methods can be used to compare formally the alternatives and to select the best course of action. A brief sketch of three of these strategies for choosing among alternative harvest regions helps to illuminate the problem of decision making with uncertain information, the public policy issues at stake, and appropriate ways of dealing with them.

Maximizing expected value

Suppose that several alternative possible decisions about the harvest rate from a particular stock have been identified. Each might produce a range of future streams of benefits and costs, of varying probability. In the spirit of the preceding paragraphs, let us assume, also, that fisheries scientists have assigned a probability to each of the possible streams flowing from each of the alternative decisions. To illustrate, one alternative might offer a 10% chance of being able to take an annual harvest of 5 000 tonnes forever; another might offer a 20% chance of being able to take 5 000 tonnes for 10 years, followed by collapse of the stock and subsequent rebuilding to yield 3 000 tonnes per year after 30 years. The simplest measure of relative performance involves calculating the present value of each possible outcome, weighting it by the probability of its occurrence, and ranking performance according to the resulting 'expected values'. Using this method, the best choice is simply the one with the highest expected value.

This method fails to recognize the well-known human trait of aversion to risk taking, which is an important influence on rational behaviour. For example, it does not discriminate between an action that has equal chances of yielding a million dollars or nothing, and one that will yield half a million with certainty. Both have an expected value of $500 000, but they would not be regarded as equally attractive by most people (including most scientists). Overwhelming evidence indicates a normal preference to avoid risk, so the certainty of $500 000 will normally be chosen. Indeed, in preference to the zero-or-a-million gamble, some people might accept a certain return as low as $300 000, which provides an empirical measure of their 'risk aversion'.

This indifference to risk impairs the expected value criterion as a guide to individual behaviour, but it may be more useful for governmental decision making. This is because a governmental decision, such as the choice of harvest rate for a fishery, is one of thousands being made continuously on behalf of the public. In this context, a government would be irresponsible to copy the risk-averse decision of an individual. A prudent person might well choose $300 000 in preference to a 50% chance of winning $1 000 000, to be decided by the toss of a coin. However, if the exercise were to be repeated a thousand times, that would be a foolish choice. The law of averages would ensure a greater return by choosing the gamble.

Thus a case can be made for governments to take a neutral stance towards risk, which implies simply maximizing the expected value to the

[9] David C. Sharp and Paul R. Roberts, 'Task force review of fisheries legislation: original submission prepared for the New Zealand Fishing Industry Board', Wellington, 1991, p 31.

public at large in every decision. Of course, this would sometimes result in failures such as stock collapses, which would dislocate certain groups, such as the fishermen in a particular fishery, and call for mitigation or compensation. Such distributional issues raise quite different policy questions, however.

Maximizing expected value with risk constraints

In any event, even fishermen are not likely to be best served by harvest decisions that avoid risk altogether. The problem is to find a way of defining acceptable risks systematically in decision making.

The simplest way to incorporate some risk aversion into decision making is to consider only those options that meet a specific standard of risk avoidance. The rule might be, for example, that fisheries will be managed to generate maximum expected value (or maximum catch, or another objective) without incurring more than a 10% chance of reducing the stock below 20% of its virgin size within the next 10 years. Fisheries scientists in New Zealand have applied constraints of this kind to define a harvest criterion based on 'maximum constant yield'.[10]

The great benefit of such a risk constraint is that it forces decision makers and those affected to grapple with the problem of risk and to be explicit about the degree of risk that is acceptable. People are notoriously unsystematic in thinking about risk; naive notions of 'zero risk' sometimes expounded by interest groups contrast with the receptiveness of some fisheries scientists to take chances deliberately in the interests not only of higher returns but also of enhanced knowledge about the resource.[11] A clear decision rule, coupled with provisions for open review, helps to focus the debate and the implications of avoiding risk, as well as providing clear guidance to fisheries managers.

Maximizing expected utility

Whilst risk constraints help in ruling out unacceptable choices, they do not discriminate among the acceptable alternatives. One way of doing so is to require the decision makers to reveal their preferences for different gambles and the weight they put on different objectives.

A substantial literature on decision making under uncertainty describes how carefully structured questions and related techniques can be used to clarify and quantify decision makers' subjective attitudes about risk and uncertainty, thus forcing them to be precise about management objectives.[12] This information can be used to construct a utility function for outcomes of varying riskiness, which in turn can be used to calculate the expected utility (like an expected value) for each alternative. The alternatives can then be ranked accordingly. This provides a ready technique for revealing preferences among outcomes that are otherwise unclear because they ignore attitudes towards risk taking, such as the earlier choice between a guaranteed \$300 000 and a 50% chance of \$1 000 000.

Formal decision analysis based on utility assessment has much appeal as a way of forcing clarification of attitudes toward risk, but it presents certain practical difficulties. In public decision making as in fisheries management, it is often difficult to identify the decision maker whose attitudes toward risk should be the basis for assessing the utility function. Ministers of fisheries come and go, threatening inconsistency over time; external advisers and bureaucrats raise questions about representativeness and accountability; resource users cannot always be

[10]See Annala, *op cit*, Ref 3.
[11]Walters, *op cit*, Ref 1.
[12]R.L. Keeney, *Siting Energy Facilities*, Academic Press, New York, 1980; R.L. Keeney, *op cit*, Ref 4; R.L. Keeney and H. Raiffa, *Decisions with Multiple Objectives*, John Wiley, New York, 1976; H. Raiffa, *Decision Analysis: Introductory Lectures on Decision Making Under Uncertainty*, Andover Press, Boston, MA, 1968; J. Von Neumann and O. Morganstern, *The Theory of Games and Economic Behavior*, Princeton University Press, Princeton, NJ, 1947.

relied upon to represent the broader public interest in long-term conservation. Moreover, these techniques are not so well developed and standardized that they can be routinely applied and readily understood. Nor are the results easily interpreted and evaluated in the usual arenas of political debate. Consequently, responsibility for the decisions, and the choice of decision criteria, should be assigned, as far as practicable, to those who will incur the benefits and costs, thus ensuring that the relevant economic and political implications are brought to bear on these issues.

The preceding paragraphs can be summarized in three additional conclusions about the decision making involved in harvest regulation. The first is that the process consists of two distinct procedures, risk assessment and risk management. The second is that scientists are competent to handle only the risk assessment part, and can do so most helpfully by expressing the outcomes of alternative harvesting regimes in terms of their probabilities.

The third is that the risk management function, which involves deciding on the course of action to be taken in light of the risks it entails, calls for a decision making body which can represent those whose interests are at stake. This means that decisions about harvest levels must include fishermen, and to a greater or lesser extent it must include representatives of the broader public interest as well. Before turning to the institutional arrangements needed to accommodate these functions and interests, we want to draw attention to the implications of the new management regimes based on individual fishermen's quotas.

Implications of quota management systems

The idea of regulating commercial fishing by means of quotas for individual fishermen is new, having appeared in academic literature in the 1970s.[13]

In the 1980s it was adopted, in various forms, by major fishing nations including Iceland, New Zealand, Australia and Canada, and is now being tried experimentally or partially in many others.[14] Undoubtedly the most comprehensive and sophisticated quota management system implemented so far is that of New Zealand. Fisheries policy in New Zealand, with quota management as its centrepiece, evolved remarkably rapidly during the decade following extension of coastal jurisdiction, and the momentum of change and improvement continues today.[15]

The quota management system was originally conceived and adopted as a means of facilitating the management of fish resources and improving the economic performance of fishing industries.[16] However, it is becoming clear that this system portends profound changes in the relationship between government and fishermen, and in their traditional roles. Under traditional fishing regimes, each fisherman's catch is determined by his own skill and effort in the competition against other fishermen on the fishing grounds, and his preoccupation is understandably with his *share* of the total allowable catch. In fully exploited fisheries, this contest is a zero-sum game, and it leads to the well-known problems of excess fishing effort and excess fleet capacity, dissipated resource rents, and difficulties of conservation and enforcement. Significantly for this discussion, this traditional arrangement depends entirely on governmental regulation to protect the stocks from overfishing. And that, in turn, puts the efforts of public fisheries managers in direct

[13]D.G. Maloney and P.H. Pearse, 'Quantitative rights as an instrument for regulating commercial fisheries', *Journal of Fisheries Reserve Board of Canada*, Vol 36, 1979, pp 859–866.

[14]'The individual quotas are variously termed individual transferable quotas (or ITQs in New Zealand), enterprise allocations (Atlantic Canada) fishermen's quotas (Canadian Great Lakes) and other labels. They vary a great deal in their terms and conditions (Philip A. Neher, Ragnar Arnason and Nina Mollett, eds, *Rights Based Fishing*, Kluwer, Dordrecht, 1989).

[15]Christopher M. Dewees, 'Assessment of the implementation of individual transferable quotas in New Zealand's inshore fishery', *North American Journal of Fisheries Management*, Vol 9, 1989, pp 131–139.

[16]Peter H. Pearse (Commissioner), *Turning the Tide: A New Policy for Canada's Pacific Fisheries*, Report of the Commission on Pacific Fisheries Policy. Vancouver Supply and Services Canada Cat No. Fs 23-18/1982E, 1982, 292 pp.

conflict with the efforts of individual fishermen to catch more fish.[17]

In contrast, when fishermen's shares are defined under quotas, these perverse incentives are eliminated and they are replaced by incentives to maximize the value of the product and to reduce the costs of production, as in other spheres of economic activity. Moreover, by giving fishermen rights to defined portions of the catch, quotas give the quota holders in a fishery an incentive to work together to advance their mutual interests.[18]

Under New Zealand's quota management system, a quota gives its owner the right to a specified share of the TAC in a particular fishery, defined by species and area. These rights have, in high degree, the essential characteristics of property, as property is defined in law. They are issued in perpetuity; they are transferable, divisible and combinable with few restrictions; and they are enforceable against third parties.[19]

This system has largely eliminated the traditional and contentious governmental responsibility for allocating the catch among competing commercial interest groups; overexpanded fishing fleets have begun to rationalize; regulations designed to restrict fishing power, fishing effort, and the efficiency of fishing have been removed; the quality and value of catches have increased; and resource management has improved.[20] Notwithstanding many criticisms of the administration, these improvements have resulted in wide support for the quota management system, not only among fishermen but also among public fisheries managers and environmental advocacy groups. They also account for the growing interest in this approach among other fishing nations.

Management by individual quotas also changes the relationship among the fishermen in a fishery. They no longer see one another as rivals, each striving to protect and increase his share of the catch at the expense of the others – racing to the fishing grounds, fishing competitively, and secretively withholding information and knowledge from each other. With their shares in the catch legally defined, their perception of each other switches from one of competitors to joint venturers. They begin to see advantages in cooperation and collective action.

This incentive to cooperate is evident in several of New Zealand's fisheries, where the quota holders have begun to cooperate in catch monitoring, enforcement against outsiders, and improved resource management.[21] In short, fishermen, previously concerned exclusively with catching fish, are now motivated to take a tangible and constructive interest in management.

The incentives of quota holders to contribute to management depend significantly on the characteristics of the quotas themselves. There are many terms and conditions to be considered, but here we want to emphasize two. One is the duration of the rights. The importance of this is obvious: unless the harvesting rights embodied in the quotas extend for at least some years, their holders cannot be expected to make much commitment to long-term conservation and management. In practice, the terms of quotas vary, from one year in some experimental quota regimes to forever in New Zealand's system.[22]

The second feature is the way the quotas are denominated, specifically whether they are expressed quantitatively, as in tonnes of fish, or as percentages of the TAC. Most commonly, quotas are expressed as percentages, but New Zealand has experience with both, having switched from specific tonnages to percentages in the wake of a management

[17]Peter H. Pearse, 'Property rights and the regulation of commercial fisheries', *Journal of Business Administration*, Vol 11, Nos 1 and 2, 1980, pp 185–209.
[18]Anthony Scott, 'Conceptual origins of rights based fishing', in Philip A. Neher, Ragnar Arnason and Nina Mollett, eds, *Rights Based Fishing*, Kluwer, Dordrecht, pp 11–38.
[19]Ian Clark, Philip J. Major and Nina Mollett, 'The development and implementation of New Zealand's ITQ management system', in Philip A. Neher, Ragnar Arnason and Nina Mollett, eds, *ibid*.
[20]Peter H. Pearse, *Building on Progress: Fisheries Policy Development in New Zealand*, a report prepared for the Minister of Fisheries, Wellington, 28 pp, 1991.
[21]Sharp and Roberts, *op cit*, Ref 9; Pearse, *ibid*.
[22]Under a recent agreement with the Maori, the government undertook to issue no new quota rights in perpetuity, pending settlement of their claims. Since then, a new quota system has been introduced for the rock lobster fishery, with quotas carrying terms of 25 years.

crisis in 1989. The importance of this matter arises from the need to vary the total harvest over time, as discussed earlier in this paper. To the extent that quotas deal only with the fixed or constant component of the catch, the choice between quantitative and percentage denomination is inconsequential. However, when they cover the variable component as well, quotas expressed in tonnes must be supplemented or reduced by the management agency to effect the needed changes from one year to the next. In the original New Zealand system, this was accomplished by auctioning more quotas to increase catches and purchasing quotas when reductions were needed, much as a central bank engages in open market operations to adjust the money supply.[23]

Quotas denominated in tonnes of fish are more certain and secure than quotas expressed as a percentage of a global figure which a regulatory agency adjusts unpredictably. They are therefore a more valuable interest. If the adjustments are made through the market in quotas, as in New Zealand's original system, the regulatory agency is also made accountable for its harvest decisions, directly bearing the full financial brunt of any changes.

On the other hand, percentage quotas have two advantages of their own. One is a benefit entirely from the management agency's viewpoint; freedom from having to take financial responsibility for adjustments in harvests. In the eyes of quota holders, who bear the burden of these decisions, this is by no means a virtue and New Zealand's experience is that this split between decision-making responsibility and financial accountability for the decisions generates a great deal of stress, and even litigation, between the two parties.

The other advantage in expressing quotas in percentage terms has broader implications; providing they have long terms they give their holders a legally defined stake not only in the current productivity of the stock but also in its potential productivity. This, in turn, gives the quota holders in a fishery incentives to cooperate in prudent management, exploration programmes, enhancement measures and other activities to boost yields and thereby increase the value of their rights.

Thus we observe the quota holders in quota-managed fisheries beginning to cooperate not only in organizing and regulating fishing operations, but also in resource management. In New Zealand where quotas are expressed in percentages of the total commercial catch and carry perpetual terms, shellfish quota holders have begun investing in enhancement projects at their own cost; quota holders of deep-sea species have organized expensive programmes of exploration and abundance surveys; and current discussions are likely to lead to management responsibilities being assumed by the quota holders in other fisheries.[24]

These developments illustrate a general rule: when those who have the rights to the harvest in a fishery are circumscribed and legally identified, and their shares are defined, they quickly see benefits in cooperative measures to protect and increase the integrity and value of their rights. Since the value of fishing rights reflects the returns to fishing, and thus measures the efficiency with which fishing and the resources are managed, this is to be encouraged.

In these circumstances, the allocation of responsibilities between governmental regulators and fishermen needs to be reassessed. One area of changed responsibility is in the organization of fishing. The traditional regulatory approach to managing fishing puts the gov-

[23]Clark *et al*, *op cit*, Ref 19.
[24]Sharp and Roberts, *op cit*, Ref 9. In the words of New Zealand's fishing industry: 'Groups of quota-holders will perceive incentives to enhance productivity where the benefits from their joint actions will accrue to group members. There is no dispute over who holds the rights to develop fish stocks. Proportionality gives quota-holders all the potential, as well as current, commercial yields. Group developed enhancement projects have already taken place under the (quota management) regime, for example the Chatham Islands paua enhancement project and the orange roughy exploratory fishing venture (Sharp and Roberts, *op cit*, Ref 9, p 16).

ernmental manager at the centre, organizing fishing times and places, specifying the permitted kinds of vessels, gear and fishing techniques, and monitoring, policing and enforcing. Much of this kind of close regulation of activity is unnecessary under a quota management system. All the traditional regulatory effort aimed at constraining catches becomes redundant, because allowable catches are embodied in quotas. Indeed, since quotas are rights which cannot be unreasonably constrained, any regulations that impinge on the quota holders' freedom to exercise their property rights must pass a much higher legal test. The way fishing is conducted, and the way fishing rights are exercised, can and must be left, for the most part, to the fishermen themselves.

More importantly for the present discussion, fishermen can assume responsibilities for resource management decisions, including information gathering and harvest regulation. The reasons have been alluded to already. One is that quota systems have the effect of redirecting fishermen's incentives from single-minded short-term harvest maximization to long-term maximization of the value of their resource rights, giving them a vested interest in prudent resource management. Another is that the quota holders inescapably bear the brunt of decisions about harvest levels, giving rise to conflict and acrimony when decisions are made by others. A third reason is that fishermen and governmental regulators respond differently to the risks inherent in harvesting decisions and, since the risks fall largely on the holders of resource rights, their willingness to take risks should influence decisions. A fourth is that those who fish are in a much stronger position than governments to efficiently collect information useful in assessing stocks and their productivity. This last brings us back to our earlier point about the contribution of information to decision making in harvest regulation.

For these reasons, the fishing industry of New Zealand has been pressing the government to recognize that the appropriate balance of responsibilities for fisheries management between the government and those with rights to the catch has fundamentally changed. The quota management system, they argue:

> . . . provides a potential for cooperative action between holders of quota rights where productivity gains may be achieved that are of benefit to all of the cooperating quota-holders . . .
>
> However, this potential will not be fully realised while Government . . . remains cast in the role of 'hands-on' fishery manager. Through (outdated legislation) the Ministry is authorised '. . . to conserve, enhance, protect, allocate and manage the fishery resources . . .' All of the decisions . . . remain under the authority of a Government department that bears no commercial or resource risk and is not accountable to those who are affected by its decisions (p.8). . . .
>
> Present rights-based allocations are sufficient from which to construct a legislative framework empowering groups of quota-holders to co-operatively undertake fisheries management.[25]

How much responsibility can safely be transferred to fishermen? Some have suggested that virtually all of it can,[26] but this would depend on unusually well-developed market processes to induce the fishermen to take account of impacts of their decisions on people other than themselves.

It is important to recognize interests in fisheries management extending beyond the quota holders' narrow interest in fish production. The

[25]Sharp and Roberts, *ibid*, p 16.
[26]Peter Ackroyd, Rodney P. Hide and Basil M.H. Sharp, 'New Zealand's ITQ system: prospect for the evolution of sole ownership corporations', report to MAF Fisheries, Wellington, 1990, 86 pp; A. Scott, 'Development of property in the fishery', *Marine Resource Economics*, Vol 5, 1988, pp 289–311.

public needs assurance that the resources will not be exploited recklessly, mistakenly, or deliberately in ways which, though profitable, result in depletion of their stock or the stock of prey or predator species on which other fishermen depend. This suggests that the management authority assigned to quota holders must be constrained.

The concern of quota holders for the health of the stock arises from their interest in its productivity and yield, while that of the public at large arises from a general concern about resource conservation, and a desire to maintain healthy, resilient resources and ecosystems. Thus the public interest can be protected most suitably not by prescribing the harvest that may be taken but rather the minimum stock size that must be maintained. For example, it might be required that a stock be maintained at not less than one-third of its virgin stock size, to be measured in a prescribed fashion.

Reconciling quota management and risk management

The discussion above suggests that a quota management system should, ideally at least, be designed to protect the public interest while achieving certain other operational objectives. In summary it should:

- ensure that related fisheries and the public interest in resource conservation are protected;
- allow for variations in harvests from year to year;
- recognize that part of the allowable catch can be guaranteed with reasonable certainty every year;
- ensure that those who make decisions about variations in the catch from year to year bear the financial burden and the risk associated with their decisions; and
- generate as strong incentives as possible for quota holders to invest in fisheries management and resource development.

Is it possible to design such a system? We believe that these objectives could be substantially met if the management of a fishery were organized in a way which can, with some risk of oversimplification, be seen as a sequence of steps:

(1) The minimum stock size deemed to protect the public interest in conservation of the resource adequately would be specified. This would be a stock size sufficient to maintain its vigour and resilience. It would not guarantee against stock collapse, of course, but the risk of stock collapse would be acceptably low.

(2) The holders of fishing rights would be sanctioned to manage the fishery to their best advantage, as long as they maintained the stock above the prescribed minimum size. Since the prescribed minimum is likely to be well below the most productive stock size, they would be expected to maintain the stock above the minimum in normal circumstances.

(3) The maximum constant yield from the stock would be identified and allocated to fishing enterprises in the form of perpetual, quantitively-specified fixed quotas.

(4) The quota holders would be permitted to harvest, in addition to their fixed quotas, a variable amount each year to be determined by them, acting collectively to assess the capacity of the stock and the risks involved in their decisions. They would also determine

the allocation of this variable quota among themselves, in proportion to their holdings of fixed quota or by some other formula.

(5) Hefty penalties, including forfeiture of fixed quotas, would be imposed on the quota holders, if the stock size fell below the specified minimum.

These arrangements should serve the objectives set out earlier. They would be sufficient to give quota holders the desired incentives to cooperate in fishing, monitoring and enforcement, and in resource management and enhancement. By assigning quota holders the responsibility of varying catches, they would enable the full potential of the stocks to be utilized, while ensuring that the decision makers bear the full benefits, costs and risks of their decisions. The public choice about acceptable risks associated with the minimum stock size would be made separately, through an appropriate political process.

With respect to information gathering, the quota holders would have incentives not only to improve estimates of stock productivity to boost variable catches, but also to increase the proportion of total catches that can be covered by more valuable fixed quotas. This raises intriguing possibilities. The fixed component of harvests, as described here, is analogous to the well understood concept of 'proven reserves' in the mineral and petroleum industries, but since it is measured as a production rate rather than a stock, it can better be considered 'proven production potential'. This proven potential can be increased with improved information on stock sizes and their production rates, of which stock size information usually provides the biggest gains. This in turn offers opportunities and incentives for quota holders to invest profitably in exploratory fishing and stock surveys, just as mining companies invest in exploration.

Institutions

Let us assume, then, that governments adopting quota management systems seek to take advantage of the opportunities and incentives for quota-holders to take on resource management responsibilities in the way suggested above. How can this be organized? Clearly, new institutional arrangements are needed to accommodate the new roles.

First, certain functions should be institutionally separated from the responsibilities for fisheries management. Others have argued the importance of separating the responsibility for allocating fishing rights and the catch among competing fishermen and fishing groups from the responsibility for managing the resource. Fisheries managers can provide better resource management if they are insulated from decisions about who is to participate, and from the endless criticism and importuning that they are subject to when these functions are combined.[27]

A quota management system of the New Zealand type accomplishes this separation of functions by turning over decision making about the allocation of fishing rights to the market. The fisheries management agency no longer concerns itself with the allocation of the catch because that is decided by private trading in quotas; indeed, apart from administering certain general rules about quota holdings and fishing operations, management officials must stand aside and allow quota holders to exercise their rights.

However, someone must maintain a registry of quota holders, keep account of transactions in quotas, and record catches against quota

[27]Anthony Scott and Philip A. Neher, 'The public regulation of commercial fisheries in Canada', a study prepared for the Economic Council of Canada, Ottawa, 1981, 76 pp; Pearse, *op cit*, Ref 16.

holdings. The registry function is akin to the record keeping for automobile licences or the Torrens system of registering land holdings. However, the monitoring of catches and reconciling them with quota holdings, which is inevitably a closely related function, link the important functions of enforcement and raising public revenues from fishing rights. The same body may be best placed to organize a quota exchange. In New Zealand, recent debate on this matter has focused on who can carry out these activities most efficiently – the fisheries agency, a separate governmental agency, a private contractor or fishing organizations.[28] The important point is that this activity be kept separate from resource management. The information it generates should, however, be available to fisheries managers and quota holders alike.

Second, those who are expected to manage must have means to enforce their decisions. Thus, if an organization of the quota holders in a fishery is given responsibility for organizing fishing or powers to enhance the resource, it must be able to ensure the compliance of its members. Voluntary compliance will not do, because some will find it to their advantage not to cooperate. For example, if the organization decides to levy a fee on its members to finance exploratory fishing or enhancement projects which will benefit all its members in proportion to their quota holdings, it must be empowered to compel participation, otherwise some could benefit without contributing (which economists refer to as the 'free rider' problem). Consequently, some measures, potentially advantageous to the group as a whole, would not be undertaken because they would not be sufficiently beneficial to the subgroup that would bear the cost.

Those who hold the rights to the harvest in a fishery must therefore be empowered to organize themselves into a quota-holders' association with authority to make rules, assess levies and enforce its decisions on its members. This implies, of course, that democratic principles are followed in the association's organization and governance.[29]

A third requirement, to complement the second, is a single management regime for each fishery for which separate quota rights are issued. A separate management system for each fishery will ensure that an association of the quota holders can control operations within its fishery, with minimum interference from others and minimum interference in other fisheries. This, of course, increases the importance of carefully defining 'fisheries' for regulatory purposes in the first place.

A fourth requirement is a framework of legally enforceable rules about the minimum acceptable stock size and any other provisions to protect the broader public interest, within which the quota holders in each fishery can organize their activities and exercise their rights to fish. These ground-rules or conservation prescriptions can provide the mechanism for specifying the standards of management that those who use the resources are obliged to achieve, and for holding them accountable for their activities.

The provisions of these conservation prescriptions can be expected to vary greatly among fisheries. The critical criterion in designing them should be identifiable adverse impacts on people other than those who hold the rights to the catch, and the need to control these. While we are especially concerned here with the minimum stock size, there are likely to be other needed prescriptions. For example, if some users of the resource do not hold quotas, as may be the case for subsistence or

[28]Sealord Products Limited, 'Initial submission to the Task Force for Review of Fisheries Legislation', Nelson, New Zealand, 1991, 14 pp.

[29]These requirements to enable quota holders in a fishery to organize themselves and manage their affairs can be provided through legislation like New Zealand's 1990 Commodity Levies Act, which authorizes producers of agricultural products to organize themselves in this way, subject to the approval of a sufficient majority of the producers. There may be a case for special provisions in the constitution of such associations to protect minority interests among quota holders in some fisheries (Pearse, *op cit*, Ref 20).

recreational fishermen, their interests might need protection through constraints on quota holders. Most fisheries call for standards to protect other, ecologically interdependent stocks; other resources such as mammals and birds that are vulnerable to fishing gear, seabed habits, aesthetic values affected by fishing; and so on. The prescriptions can be expressed as objectives to be achieved (in contrast to traditional fishing plans that specify how operations are to be conducted) leaving as much scope as possible for quota holders to organize their operations.

The specified standards of performance must, of course, be measurable and enforceable, with appropriate provisions for monitoring and information gathering, and buttressed with suitable penalties. They should constitute a stable set of rules and standards, revised only rarely so that quota holders can plan their operations over time with maximum certainty.

The process of defining the conservation prescriptions affords an opportunity to bring the full range of environmental and other special public interests to bear on fisheries management. This suggests a well-organized consultation process to accommodate public participation and to channel advice.

The task of designing conservation prescriptions is partly technical, involving scientific information and professional interpretation, but it also involves subjective value judgements and compromises among conflicting values. The relevant minister should therefore be responsible for resolving otherwise unreconcilable issues and for officially approving the standards. Since they must have the force of law, they should be given the status of regulations supplementary to the appropriate fisheries statute.

Finally, this structure puts a heavy burden on measurements of stocks and methods of estimating their productivity. It calls for well-defined and standardized techniques for sampling, assessing the efficiency of survey gear and calculating potential yields. This does not necessarily imply heavy additional government commitments, however. With the incentives of quota holders directed toward improving management information, advantage can be taken of the enormous sampling power of fishing fleets in order to conduct surveys according to approved methods.[30] The important role for governmental authorities is to specify the scientific standards to be met and techniques to be followed to 'prove-up' the production potential of stocks.

With all these arrangements in place, the quota holders in a fishery could be expected to form an association to advance their mutual interests, controlling it much like shareholders in a corporation or members of a cooperative.[31] They would then be in a position to organize fishing for the benefit of their members, gather information in support of improved management and higher catches, undertake research, exploratory fishing and enhancement to improve harvests, all within the parameters of the conservation prescriptions. In particular, they may find it advantageous to adopt more stringent catch limits than those specified in conservation prescriptions, in order to build up stocks and future catches or to reduce fishing costs.

Focusing incentives and allocating risk

Preceding sections of this article have explored the nature of decision making under uncertainty with special reference to harvest decisions in

[30] C.J. Walters and J.S. Collie, 'An experimental strategy for groundfish management in the face of large uncertainty about stock size and production', in R.J. Beamish and G.A. McFarlane, eds, *Effects of Ocean Variability on Recruitment and an Evaluation of Parameters Used in Stock Assessment Models*, Can Spec Publ Fish Aquat Sci, Vol 108, 1989, pp 13–15.

[31] At least one major quota-holder in New Zealand suggests that these groups should operate as limited liability companies (Sealord, *op cit*, Ref 28).

fisheries. The article has been particularly concerned about the allocation of responsibility for deciding harvest levels and other management decisions in fisheries regulated under individual quota systems. Its purpose is to illuminate the opportunities for realigning responsibilities consistently with the realignment of incentives that results from the switch, in common property fisheries, from undefined to defined shares of the catch. The article has sought to emphasize that, in order to take full advantage of these opportunities, the reassignment of roles and responsibilities must ensure that those who make decisions about resource management are accountable, as far as possible, for the costs, benefits and risks that flow from their decisions.

Thus a set of institutional arrangements and structures which could take maximum advantage of the incentives of quota holders to cooperate in the efficient management of the fishery were outlined. The quota holders' associations described above, or some similar authoritative organization of users, provide the mechanism for collective action on the part of those who hold rights to the resources. The conservation prescriptions, and ministerial responsibility for them, provide the needed protection for the broader public and special interests, and set the limits within which quota holders can use and manage the resources.

In approaching decisions about stocks and yields, this structure enables a much more appropriate allocation of responsibilities. Professional and scientific data and expertise can be called upon to advise on probable outcomes of alternative courses of action in the context of broad consultation leading to the formulation of conservation prescriptions. If the process of participation and consultation is well structured, the decisions about minimum stock sizes will be properly taken by a broadly representative body and endorsed by overtly political authority.

Quota holders, also, will want the benefit of scientific guidance in organizing their harvest plans within the limits of conservation prescriptions. Indeed, they are likely to call for even more demanding estimates of the probable effects on stocks of alternative harvest strategies. However, the decisions will rest, legally and unequivocally, with the quota holders themselves. They will also bear the full benefits and costs of their decisions, the full risk of unfulfilled catch expectations in the event of mistakes, and the risk of penalties for failure to maintain the prescribed conservation standards. This should eliminate the disagreements arising from differences in attitudes toward risk-taking noted above.

Finally, the article has sought to direct the incentives of quota holders towards gathering information useful in assessing alternative decisions about harvest levels, reducing uncertainty about their outcomes, and identifying new possibilities. Under the arrangements outlined here, the costs of such information gathering would be distributed among quota holders in accordance with the distribution of benefits. The end result of this redistribution of responsibilities, costs and benefits would probably be far better 'scientific' management, as well as economic management of fisheries, than can be observed anywhere in the world today.