FISHERIES MANAGEMENT

economic efficiency and the concept of 'maximum economic yield'

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- **Given the problems with open access resources, as well as the effectiveness of modern fishing technology, there are few fisheries, if any, that will not be both overexploited and unprofitable unless they are managed effectively. For a fishery to be economically efficient requires that management targets be set correctly, enforced effectively and delivered in a least cost and incentive compatible manner.**

- **An efficient outcome is important not only because it protects fish stocks and guarantees sustainability, but also because it assures that resources will be allocated to the fishery correctly and in a way that maximises the returns from fishing. Inefficient fisheries are plagued by low profits and excessive boat capital or fishing capacity, with the all too familiar outcome of 'too many boats chasing too few fish'.**

The traditional 'command and control' approaches to fisheries management — ones that focus on input restrictions and total catch limits — fail to provide the incentives for those who fish to do so efficiently and in a manner that gives industry a long term stake in the future of the fishery. These approaches often result in considerable effort creep and excessive and wasteful competition, with both inappropriate levels and combinations of inputs used to catch fish. Maximising economic yield requires not only setting catch and effort levels appropriately, it also requires that industry has an effective property right to the harvest, one that removes the incentive for a wasteful and inefficient 'race to fish'. For most fisheries, a system of individual transferable quota (ITQ) is the best instrument to ensure this outcome.

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Economic efficiency in a fishery

From the economist's point of view, the definition of economic efficiency in a fishery is straightforward. Concentrating on sustainable yields alone, economic efficiency occurs when the sustainable catch or effort level for the fishery as a whole maximises profits, or creates the largest difference between total revenues and the total costs of fishing. This point is referred to as 'maximum economic yield' (MEY). For profits to be maximised it must also be the case that the fishery applies a level of boat capital and other resources in combinations that minimise the costs of harvest at the MEY catch level. The fishery, in other words, cannot be overcapitalized and vessels must use the right combinations of such inputs as gear, engine power, fuel, hull size, and crew to minimise the cost of a given harvest.

There are several things to note about MEY at the outset. First, for most practical discount rates and costs, MEY will imply that the equilibrium stock of fish is larger than that associated with 'maximum sustainable yield' (MSY), as shown in the following section. In this sense the economic objective of MEY is more 'conservationist' than MSY and should in principle help protect the fishery from unforseen or negative environmental shocks that may diminish the fish population.

Second, the catch and effort levels associated with MEY will vary, as will profits, with a change in the price of fish or the cost of fishing. This is as it should be. If the price of fish increases it pays to exploit the fishery more intensively, albeit at yields still less than MSY. If the cost of fishing rises, it is preferable to have larger stocks of fish and thus less effort and catch.

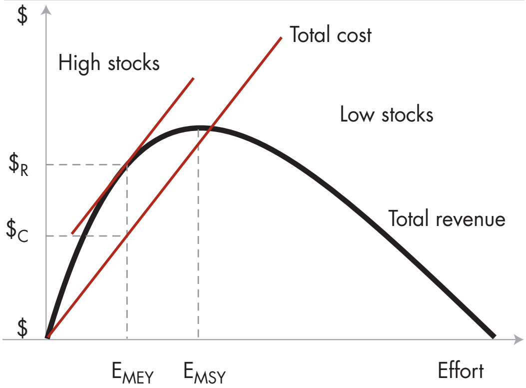
Finally, as long as the cost of fishing increases with days fished, as it generally will, MEY as a target will always be preferred to MSY and of course to any catch or effort level that corresponds to stocks that are smaller than those associated with MSY. The reason is simple. Regardless of what happens to prices and costs, targeting catch and effort at MEY will always ensure that profits are maximised. Profits may be relatively low when the price of fish is low and the cost of fishing is high, but profits will still be maximised. With a biological target of MSY alone, however, it is quite possible that profits will be very small or even zero. The fishery would thus be sustainable at MSY but not commercial, much less efficient. A target where profits from fishing are zero cannot be a good target.

Illustrating MEY

The management structure, stock level and nature and extent of fishing effort that generates MEY depends on a combination of biological and economic factors. In particular, it depends on the relationships between harvest, stocks and recruitment and on the way in which fishing behavior, revenue and costs relate to those factors. A simplified representation of these relationships is given in figure A, where it is assumed that there is no uncertainty about the state of nature (more complete descriptions of bioeconomic models can be found in Grafton et al. 2004 and Hannesson 1993).

Figure A illustrates a typical production-surplus model for the fishery as a whole, expressed in terms of the relevant economic relationships. The vertical axis is simply dollar amounts and the horizontal measures effort as nominal days fished. The total revenue curve is drawn from a biological stock–recruitment relationship, translated into effort units, showing the relationship between effort and yield in dollar amounts. The larger is effort the smaller is stock size. Every point along this curve represents an effort and yield combination that is sustainable, with effort at MSY generating the largest total revenue. The total cost curve is taken as the total cost of fishing, assumed to be increasing and linear in effort, for convenience.

A Maximum economic yield



Maximum economic yield (MEY) is the difference between the dollar amounts of revenue and costs at the optimal effort level, or $\$_R$ less $\$_C$. Note that MEY occurs at effort levels less than effort at maximum sustainable yield and thus at stock levels that are larger than those associated with MSY.

MEY in figure A occurs at the effort level E_{MEY} and corresponding value of catch $\$_R$ that creates the largest difference between the total revenue and total cost of fishing, thus maximising profits, given by the difference between $\$_R$ and $\$_C$. The value of E_{MEY} will change given a change in the price of fish, which shifts the total revenue curve up or down, or the cost of fishing, which rotates the total cost curve.

Given prices and costs, figure A illustrates a point made above, namely that targeting MSY will in this case generate very small profits. With a small increase in the cost of fishing, these could easily go to zero — if so, this would replicate a common property or open access equilibrium even though a management regime was in place and operating.

Note as well that a profit maximising movement away from effort at MSY toward effort at

MEY implies a smaller value of harvest. This is often the case with overexploited fisheries — maximising profits requires less effort and smaller catches. The reason of course is that decreases in effort, which also increases the stock of fish in the future, decrease the cost of fishing more than the corresponding fall in revenue.

Nothing has been said until now about boat numbers. Indeed, the graph basically assumes that all boats are the same and there is a rough correspondence between boats and nominal days fished. In this context it is natural to assume that a move from MSY to MEY would imply a decrease in boat numbers, with catch per unit of boat increasing. It is also the nature of an optimal result that those that lose from a reduction in boat numbers can be more than compensated for by the increased profits that MEY generates, at least in principle. In any case, it is easy to see that efficiency requires that at MEY the measure of effort corresponds with a total boat capital in the fishery that is just sufficient to obtain the required catch at minimum cost. Thousands of boats each fishing a day could generate E_{MEY} but clearly that excess capacity would be inefficient.

Why MEY?

It has already been shown that MEY generates maximum profits and that this outcome is guaranteed regardless of the price of fish or the cost of fishing. Also, MEY is 'conservationist' in the sense that stocks will be larger than at MSY, and this in itself can confer enormous benefits to the fishery and its ecosystem. It would also protect the fishery against large negative shocks to the fish population, since larger stock levels generally imply greater resilience in the face of these shocks.

But there is another, equally compelling, reason for pursuing MEY: resource allocation. Effort levels larger than E_{MEY} would imply more boats, days at sea, gear, crew, bait and all of the other inputs used in fishing — resources that could be used instead in alternative employment. This is what economists mean by efficiency in general terms — for the economy as a whole.

If too many resources are being expended in fishing, too few are being used elsewhere. Moreover, as long as the right instruments to facilitate adjustment are in place — instruments that allow for trade in secure and specific property rights, such as the right to a share of harvest — it follows that decreasing the size of an overexploited fishery will make no one worse off and many better off by compensating those that leave the fishery for their lost income, while providing more profit for those that remain in the fishery. That is the nature of an optimal position given by MEY.

Attempts to extend resource use and particularly employment well beyond MEY are common, and often disastrous. Experience in Canada's Atlantic fisheries provides a striking example. Subsidies provided by the Canadian Government — with a specific mandate to maximise employment levels in the industry — greatly extended the amount of resources applied to these fisheries. Indeed, even as early as 1970 it was 'estimated that Canada's commercial catch in 1970 could be harvested by 40 per cent of the boats, half as much gear and half the number of fishers' (*Atlantic Groundfish Fisheries* 1997, pp. 14–15).

This is wasteful in itself, but dwindling stocks and the eventual collapse of the Atlantic fisheries — in large part caused by overfishing — even further increased the government's burden to maintain incomes. In 1990, for example self-employed fishers received $1.60 in unemployment insurance benefits for every dollar earned in the fishery, and the 'adjustment programs' associated with the collapse of the fisheries cost the Canadian taxpayers over C$3 billion in the 1990s alone (*Atlantic Groundfish Fisheries* 1997, pp. 14–22).

What is wrong with input controls?

For management of a fishery to be effective in the sense that catch and stocks are maintained at desired levels, there must be either direct or indirect control over catches. Management through output controls involves explicit catch targets and direct enforcement of those targets. Management through input controls also involves some implied catch target. The fact that the catch target is sometimes only vaguely defined is one of the reasons that input management regimes are often not successful.

The real problem, however, is the inability of input controls to control effort in the first place. The moment control of a particular input becomes the policy instrument, operators have an incentive to substitute other inputs in a way that will change the relationship between effort and catch. As well, technological advance and improvements in knowledge provide other background reasons for the relationship to change, constantly.

A manager relying on input controls is in constant competition with the imagination, energy and inventiveness of each operator in the fishery and the full technological backup of a modern economy. Effort creep is inevitable. In terms of figure A, attempting to target E_{MEY} can only be successful in the very short run, with effort creep moving the fishery to the right and thus dissipating profits, or decreasing the distance between total costs and revenues.

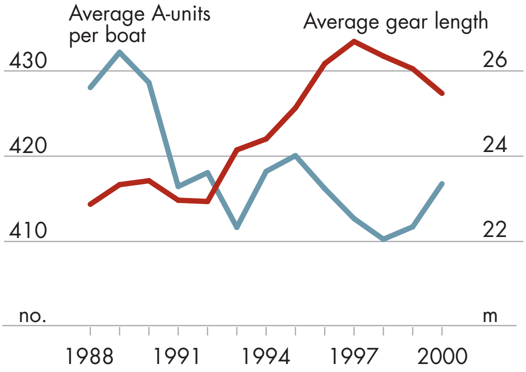
More important to the general lack of success of input management regimes are two characteristics of the incentives that they provide for operators in the fisheries. First, as mentioned, controls on one or more inputs provide an immediate incentive for operators to substitute uncontrolled inputs. Second, input control regimes provide no sense of ownership or stewardship of the fisheries resource. There are no guarantees in any input control management regime except the right of access to the fishery under certain guidelines.

Operators are encouraged by these rules to compete for catch within those guidelines, and if one operator refuses to expand effort, while others do, that operator will be worse off. Unfortunately, if all operators increase effort, all are made worse off through a fall in profits and the fishery remains overexploited — the proverbial ‘tragedy of the commons’. The management response in this environment is to continuously and repeatedly find ways to cut effort (for example, gear reductions, area and seasonal closures, vessel buyback schemes, etc.), ‘winding the fishery down’ over time to a small number of boats or days fished, all making zero (or near zero) profits.

All of this can be nicely illustrated by a look at the Australian northern prawn fishery, providing a good example of how input controls and the resulting ‘race to catch’ can generate very inefficient outcomes. Over the past thirty years the fishery has been managed by a series of input controls, including seasonal closures, a move from quad to twin nets, engine power and hull limits and, most recently, gear reductions and restrictions. In all cases the limits to fishing power have been temporary at best. Indeed, A-unit (a rough measure of hull capacity and engine power) limits in place in the 1990s resulted in a clear substitution toward unregulated inputs, specifically gear. This substitution is illustrated in figure B, where average headrope gear length clearly increased throughout most the 1990s, while A-units fell.

The implication of this countermovement in A-units and gear is twofold. First, restricting A-units in fact did not control effort, since boats simply increased effort by using other inputs, including gear, more intensively. Second, the forced change in input combinations, inducing boat owners to use different proportions of gear to A-units resulted in considerable loss in boat efficiency throughout the fishery (Kompas and Che 2002). In the banana prawn section of this fishery, technical efficiency for the fleet as a whole fell from 75 per cent in 1994 to 68 per cent in 2000 (Kompas, Che and Grafton 2004). For individual operators in the fishery, the aggregate response to input restrictions thus led to

B **Input substitution in the northern prawn fishery**



much lower profits than would otherwise have been realised.

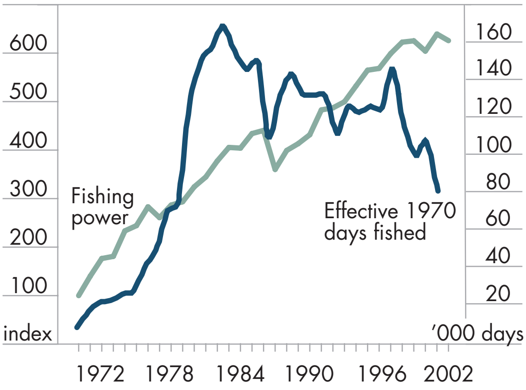
Each of the changes made in the management regime in the northern prawn fishery — seasonal and area closures, A-unit restrictions and most recently gear reductions — was made in recognition that the system it replaced had failed to constrain effective effort and the inevitable effort creep sufficiently to protect prawn stocks. Where effective effort was reduced by management change, the primary reduction was short lived.

This outcome, and one of the primary reasons for it, is illustrated in figure C. Fishing power, measured as the average catching ability of a boat in a day's fishing (compared with a 1970 base — the figures used are those denoted 'basic high' by CSIRO, see Dichmont et al. 2003) has risen rapidly and consistently over time. The rise in fishing power is the result of continuous improvements in technology, input combinations and knowledge.

The acquisition of improved scientific knowledge of the fishery, along with the observation of declining catches has made it increasingly clear over the past few years that prawn stocks are not being conserved and catches and effort are not being controlled.

Although the combination of recent policy changes appears to have temporarily slowed the increase in fishing power as well as contributing to a rapid fall in total days fished, experience suggests that this will only be temporary. It took only four years for effort creep to overcome the initial fall in fishing power in response to the imposed move from quad to twin gear in 1987. The recent removal of A-unit restrictions in favor of gear reductions will logically imply, given the race to fish incentive, that boat owners will now increase the size of their vessels and engine power, spurring more and deeper compensatory cuts in gear (or some other input) in the future. Inevitably the fishery 'winds down'.

C Fishing power and effective effort in the northern prawn fishery



Total days fished in 2002 were already 55 per cent of the 1998 level and far below the fishery peak in days in 1983. Recent estimates show that MEY in the tiger prawn component of the fisheries is roughly 60 per cent and 30 per cent below actual days for 2000 and 2001, respectively, and about 28 per cent below actual days in the 2003 fishery. In other words, even the recent shortening of the season and further large reductions in gear units have not been sufficient to ensure economic efficiency or MEY (Rose and Kompas 2004).

Implementing MEY

If targeting E_{MEY} in figure A with input controls to obtain MEY is not effective or even desirable, the alternative is to target catch at (for example) the value $\$_R$. It is important to recognise, however, that aggregate catch controls can be just as ineffective as input controls, resulting in 'race to fish' behavior. Even if the total amount of catch is fixed, there is still an incentive for boat owners to overinvest in fishing capacity in order to obtain a larger share of the catch, again moving the fishery past E_{MEY}.

With effort creep an inevitable outcome of input controls, in any circumstance, economists thus argue for catch controls combined with an ITQ system to obtain or implement MEY. ITQs confer an individual, transferable, harvesting right so that each vessel is guaranteed a share of the catch. The immediate impact of this, of course, is to remove any 'race to fish' incentive (except where fishing results in stock depletion over the course of the season, implying that even though there is a catch entitlement it will be less costly to catch 'earlier' in the season when stocks are more abundant, or ahead of other vessels. This problem is usually addressed by setting seasonal closures correctly or through quota dated by period — for example, weekly — with a market for trade across periods.)

Where there is no incentive to race to fish, there is no reason for effort to increase beyond E_{MEY}, and MEY can be effectively targeted. The regulator simply needs to set total allowable catch (TAC) correctly.

ITQs have been in place and have worked well for decades in fisheries throughout the world, including New Zealand, Iceland, the United States, Australia and Canada (Hannesson 2004). These schemes have generally established, as in the British Columbia halibut fishery, significant gains, not just in cost savings but also in enhanced revenues (Grafton, Squires and Fox 2000).

Along with creating effective property rights to fish, ITQs confer a number of other related benefits. First, since these rights are tradable, market forces will generally distribute quota among fishers that value the right most highly. Vessels that have lower marginal costs of fishing will thus be willing to pay more for quota, with the resulting transfer of quota from high to low marginal cost producers increasing economic efficiency overall — essentially fishing inputs are distributed to those who use them best.

In other cases, quota trade allows vessels to compensate for catches that are larger or smaller than planned or prior quota holdings. These efficiency gains (or what amount to cost reductions) can be substantial, even in fisheries where the TAC is not binding in aggregate. In the Australian south east trawl fishery, for example, where TAC undoubtedly does not correspond to MEY (Gooday 2004), the cost savings from quota trades are estimated to be 1.8–2.1 cents a kilogram for every 1 per cent increase in the volume of quota traded (Kompas and Che 2005).

Second, instead of investing in boat capacity to catch fish before others do, with a guaranteed harvesting right, boat owners can instead concentrate on investments that lower the per unit costs of fishing. This is a major benefit. With input controls, technological change — new boats, a better engine, more efficient gear, try nets, GPS, etc — is harmful in the sense that the resulting effort creep through increased fishing power lowers fishery profits and endangers stocks. In some cases, input restrictions are in fact designed to prevent the very adoption of such new technologies, that under other circumstances may be beneficial or efficiency enhancing, simply to control effort.

With output controls and ITQs alternatively, boat specific technological change is good, in that it lowers the costs of fishing and increases profits, with no effect on stocks or the cost of fishing of any other vessel in the fleet that does not yet adopt the new technology.

A third benefit of ITQs is that a good number of area and seasonal closures, common to input controlled fisheries, can be done away with. Spawning stocks must naturally be protected and marine reserves can almost always be justified even on economic grounds (Grafton, Kompas and Lindenmayer 2005), but area and seasonal closures used to simply limit effort are unnecessary under an ITQ system and often economically harmful in any case. By eliminating these controls, vessels can fish when the

Box 1: Impact of uncertainty

Setting effort creep aside, it should be noted that in a deterministic world (with no uncertainty) there would be no difference in outcomes between a catch or effort control, as long as the correspondence between input restrictions and effort levels is known exactly and is perfectly enforceable. With uncertainty, and again setting effort creep aside, in cases where there is more variance in the stock–recruitment relationship than in catch per unit of effort (CPUE), effort controls will be preferred. If there is more variance in CPUE relative to the stock–recruitment relationship, then output or catch controls will dominate, generating less variance in profits. For the tiger prawn component of the northern prawn fishery, the latter is the case — output controls are the preferred instrument (Kompas and Che 2004). A clear evaluation of all of the specific, or detailed, alternative fishery management instruments is contained in Gooday (2004).

weather permits and perhaps more importantly match the harvest throughout the year to market conditions, generating the highest price for their catch. In general, unlike with input restrictions, output controls and ITQs allow fishers to choose the right mix of inputs, and the time and manner to fish — all of which is cost reducing and efficient.

A final benefit of ITQs is that they allow for autonomous adjustment of the fishing fleet, with operators voluntarily able to 'cash out' by selling their quota to more profitable vessels. Indeed, if implemented correctly, an output control and ITQ system that targets MEY will generate the largest possible (marketable) asset value for those who have the right to fish, reflected in a high price for each unit of quota. Fishers are thus compensated for exiting the fishery, without the need for government intervention. This is in stark contrast to input controlled and overcapitalised fisheries where fishers lobby heavily for government vessel-buyback schemes, which are costly and often are only temporarily effective at reducing capacity.

For catch controls and ITQs to be successful there must be adequate monitoring and enforcement. This too can be costly, although there is no necessary reason for this cost to be a government responsibility. Under an ITQ system, fishers are keen to protect their secure property rights and it is not uncommon for monitoring to be at least partially funded by industry (Grafton et al. 2005). Even when government pays for monitoring and enforcement, this cost is likely to be comparable to the cost of monitoring and enforcing effort controls, not to mention the cost of any resulting effort creep that goes with input restrictions.

Similar arguments can be made about problems with highgrading and variations in stock abundance. Highgrading will most likely occur in long lived or fast growing species where the price differential between high and low grade fish is relatively large. With highgrading, a key difference between input and output controls is in the relationship between the policy instrument and the policy objective. For output controls, the possibility of highgrading means that the policy instrument (TAC) may not always match the policy objective (a given level of mortality from fishing). However, highgrading occurs in only some circumstances. Those circumstances are often predictable. As well, provided that highgrading can be estimated, the TAC can be matched with desired mortality. Unless the relationship between fishing costs and the price differential between grades changes substantially, the match will be valid over time.

There can be no doubt that waste occurs through highgrading, but that is simply a cost of management to be assessed against the other costs of management, as well as the benefits — and compared to the costs and benefits of other management instruments. More importantly, the level of highgrading enters the management decision once only. Since the incentive to highgrade is a function of the cost of fishing and the price differential between grades, it is not something that increases over time in a way that erodes the practical meaning of a catch quota, or in the way in which effort creep subverts input controls (Rose and Kompas 2004).

When considering variations in stock abundance, the traditional arguments against catch controls (and with it ITQs) are clear. With output controls, managers face a problem in setting the TAC when abundance varies between seasons and is unknown at the beginning of the season. By setting the TAC too high the manager runs the risk that fishing pressure on stocks will be excessive if a low abundance season occurs. By setting the TAC more conservatively, the manager guarantees the loss of potential profits if the season is one of high abundance. Indeed, not only is the problem well recognised, it is often cited as a primary reason for preferring input controls.

What is not so well recognised, however, is that essentially the same problem affects the setting of input controls. To set effort at the optimal level, the manager needs information on abundance, catch per unit effort, the value of catch and the cost of effort. Setting input controls too tightly leads to loss of potential profits in seasons of high abundance. Setting input controls too generously leads to excessive investment and effort and excessive catch. The long term consequences are pressure on future stocks and dissipation of potential profit.

In principle, the type of information needed to make an efficient choice using input controls does not vary much from that needed to make the choice using output controls. There is really no argument for input controls on this basis. Careful assessments of stock abundance, including where needed, fishery independent surveys and pre-season and in-season sampling, are mandatory under any management regime. If the cost of obtaining this information does vary under different regimes, or with different management instruments, a case has to be made in terms of a comparison of these costs, against all the other costs and benefits of alternative management systems.

Concluding remarks

Economic efficiency in a fishery, or pursuing MEY, is important. It not only helps protect the fish population, by ensuring that stock levels are larger than those associated with the traditional MSY target, it also guarantees that resources will be allocated to the fishery correctly and in a manner that maximises profit. Management regimes that attempt to extend the amount of resources devoted to the fishery beyond MEY only generate a system with excess boat capital and lower returns from fishing.

In many cases — especially those where input restrictions fail to prevent effort creep — the fishery simply 'winds down' to a state where total fishing days are severely limited and asset values and profits are low, with industry repeatedly calling for government assistance or some sort of vessel buyback scheme to restore profitability.

Implementing MEY requires that a system of effective property rights to harvest be established. Aggregate input or output controls alone are not sufficient to prevent a 'race to fish'. Given the inevitable problem with effort creep in input controlled fisheries, ITQs combined with a TAC set by management to target MEY is the best option for most fisheries. With a secure property right to catch, there is no longer a 'race to fish' incentive, since catch is assured, and thus no tendency toward overcapitalisation in the fishery.

Under such a system, technological change lowers the cost of fishing, rather than endangering stocks through increased fishing power. In addition, by providing a secure and easily transferable property right, ITQs result in increased capital values to fishing entitlements. Quota passes from high to low marginal cost producers, increasing efficiency, and maximising fishery profit generates the largest possible asset value for quota holders. Lowering the TAC when conditions warrant also results in relatively seamless and autonomous fishery adjustment through the exchange of quota holdings, generally passed to more efficient vessels that can afford to pay relatively more for each unit of quota.

In some cases, ITQs can be more costly to administer and enforce than other schemes and highgrading will always be a concern. However, the establishment of private property rights with ITQs, and the desire to protect them, also generates incentives for self policing and conservation. The cost of an ITQ system must also be compared with the costs associated with alternative management regimes. The cost of effort creep under an input-restricted management regime (in addition to the cost of monitoring and enforcement), for example, can be far more excessive than the cost of any comparable rights based fishery.

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