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34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
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ADAPTIVE MANAGEMENT OF DEVELOPING FISHERIES

R. HILBORN

University of Washington

Seattle, USA

Adaptive management of developing fisheries

Ray Hilborn and John Sibert

Developing fisheries will almost always experience declining catch rates, non-sustainable levels of catch and the need to reduce fishing mortality after the initial growth in catch and fishing effort. The equilibrium-oriented view of the gradual increase to an optimum level of catch is rarely if ever achieved in real fisheries. Flexibility in fishing pressure is essential for good management of fisheries. Mechanisms for maintenance of flexibility might include the allocation of some catch to distant water fishing nations during development; taxation on landings or effort during the development phase which could be relaxed as catch rates decline; or if transferable quotas are assigned to vessels or firms, some quotes should be retained for annual allocation.

Ray Hilborn is Professor in the Fisheries Research Institute at the University of Washington, Seattle, WA 98195, USA and, at the time of writing, John Sibert was Programme Coordinator, Tuna and Billfish Assessment Programme, South Pacific Commission, Noumea, New Caledonia.

Many nations around the world look to the development of new fisheries as a mechanism to increase employment, production of domestic protein, or foreign exchange. This is especially true in the Pacific, where the fisheries resources are often the major potential resource and the ocean area under national jurisdiction may be dozens or hundreds of times the land area of the country.

The scenario these countries imagine is one of increasing catch, increasing fishing effort and an expanding fishing fleet up to some biologically and economically sustainable level. Fisheries science provides a convenient paradigm to guide fisheries development in the form of Figure 1[1] – catch is thought to increase as fishing effort increases. This paradigm leads to the obvious questions for a country developing its fishery, what is the level of sustainable yield and how much fishing effort is required to achieve that catch?

These questions are the focus of much biological work in developing fisheries and fisheries scientists are frequently asked for estimates of the sustainable yield, even at very early stages in the development of the fishery.

A prescription for disaster

The acceptance of the paradigm in Figure 1 sets the agenda for the relevant questions government officials ought to ask, and sets the scene for a disastrous development scenario. Rather than a gradual development of catch up to a sustainable level, the nearly inevitable development path will be excess fishing effort, declining catch rates, and economic collapse of the fishery.

There are two reasons for such a bleak scenario. First, one cannot predict optimum fishing effort, or the sustainable catch, until the fishery has exceeded its optimum size and sustainable catch. Thus, the development scenario can never be a gradual approach to an optimum, but must instead always overshoot the optimum and undergo a period of reduced catches. Secondly, the catch rates, which determine the economic performance of the vessels, will drop as the fishery develops, and at its sustainable level the catch rates will be well below the catch rates during development. Thus a fishery that looks promising and profitable during development will often prove to be unprofitable once sustainable levels are reached.

[1]J. Gulland, *Fish Stock Assessment: A Manual of Basic Methods*, John Wiley, Chichester, UK, 1983, pp 223.

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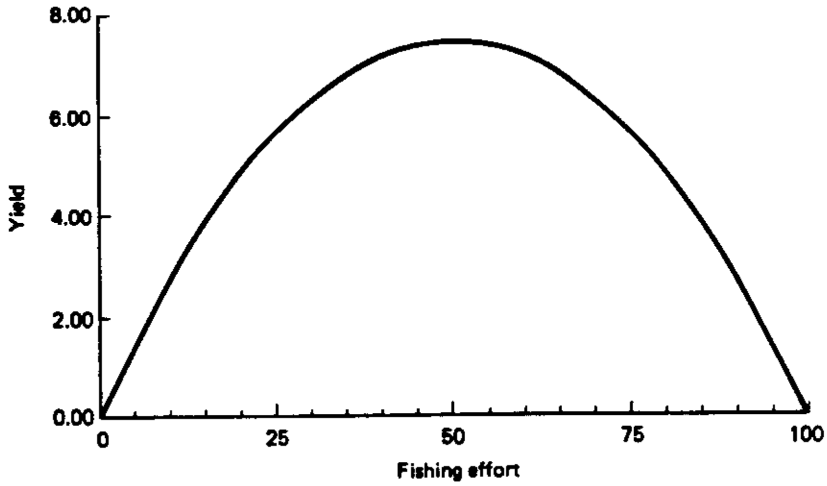


Figure 1. The equilibrium relationship between fishing effort and catch – the basis of the traditional paradigm.

Figure 2 illustrates a much more probable scenario. Both effort and catch increase continually until total catch begins to drop, and then effort is reduced to sustainable level. Note that the catch rate drops continuously during development, so that it is much lower at the sustainable level than it had been initially.

While the above two problems are inevitable features of the exploitation of renewable resources, the fishery's development does not need to be a disaster. To avoid disaster the questions asked, the agenda,

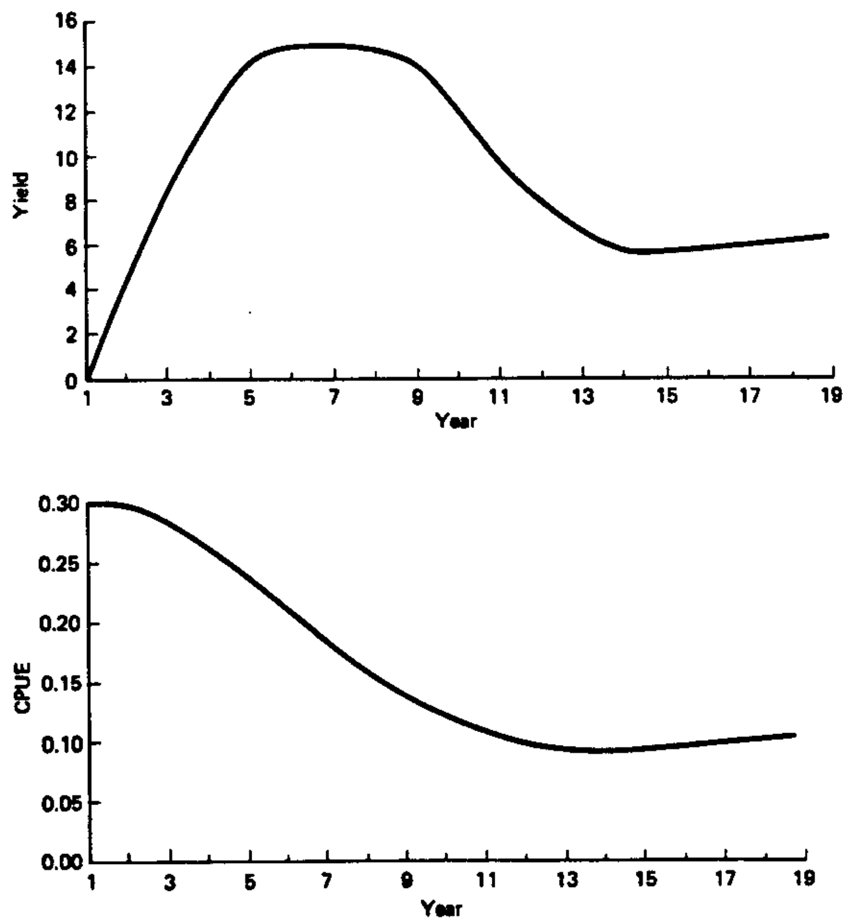


Figure 2. A more realistic scenario of catch and effort during a development path to a sustainable equilibrium.

must be changed. In the sections below we elaborate on the intrinsic economic, statistical and biological characteristics of a developing fishery, and then prescribe a different set of questions that should be asked during development which should help avoid the disastrous scenario described above.

Looking for the mountain top

When we search for the optimum level of fishing effort, we are trying to find the highest point on the hill pictured in Figure 1. If our objective is economic yield, rather than biological, then the hill will be shaped differently, but we will still be looking for the top. Unfortunately the only way we can discover that we are on top of the hill is by going beyond the top and finding that catch (or profit) no longer increases with increased effort. If fisheries dynamics were smooth and predictable, this would not pose a serious problem – a little beyond the optimum we would know we had gone too far. However, fisheries are characterized by highly variable yields, and we never know if a drop in catch one year indicates that we have gone too far, or whether it was just a bad year, with even better catches to be obtained next year with even higher efforts. In almost all real risheries there were significant drops in catch for a year or two long before 'sustainable' catch levels were reached, and in practice one must see catch decrease for several years before one can be assured that the optimum has been exceeded.

A second complication in our search for the mountain top is that the top may well be changing. The optimum effort, stock size and catch may vary due to changing weather, predators or competitors. The traditional fisheries view that stocks are governed primarily by their own dynamics is being discarded, and with the growing recognition of the importance of external factors other than fishing, comes the realization that the optimum (whether economic or biological) will be changing. Thus we are searching for a moving mountain top: we may develop our fishery, and then discover that a few years later the optimum fishing effort is larger or smaller.

Caddy and Gulland[2] provide an excellent summary of the dynamics of different classes of fish stocks, and describe four major groups: steady state; cyclical; irregular; and spasmodic. Examples of these four classes are shown in Figure 3. Only the steady state stocks behave as simply as shown in Figure 1 or even Figure 2.

Economic and technological factors may cause the location of the mountain top to change as well. Any increases in individual vessel efficiency will mean that the total optimum fleet size will be smaller. Any changes in the price of fish, or the costs of fishing, will mean that the economically optimum fleet size will also change. Changes in vessel efficiency and the costs of fishing are the most certain events in fisheries management – they happen in nearly every fishery and should be anticipated as the fishery develops.

We must accept that the problem in fisheries development is not to gradually climb up a smooth hill and then rest on top, but rather to track the moving mountain top. The important question then becomes not 'what is the optimum catch?' but rather how to design a measurement and response system both to track the moving mountain top and maintain an economically viable fishery in the process. Managers of developing national fisheries should not be asking their technical

[2]J.F. Caddy and J.A. Gulland, 'Historical patterns of fish stocks', *Marine Policy*, Vol 7, No 4, 1983, pp 267–278.

advisers primarily to estimate the sustainable catch, but rather to determine how to adjust fishing effort to track changes in the stock, and to structure the fishing industry so that it can be viable despite the inevitable variability in catch and catch rates.

Economics and biology of development

A fish population exploited anywhere near its optimum will always be much smaller than its unexploited size, in most cases this will mean that catch rates will drop as the fishery develops and the stock is exploited harder. It also means that the total catch will be higher prior to reaching the sustainable optimum than the sustainable average catch. Thus the sustainable total catch will always be lower than the catch achieved in the development, and the profitability of individual vessels will be higher during development than at a sustainable level.[3]

There are three reasons why catch rates at a sustainable level are lower than those obtained during the development phase. First is the basic biological principle that an unfished stock will in general be one where birth and death are roughly matched due to intraspecific competition for resources. Fishing the stock down reduces the level of intraspecific competition, thus providing surplus production that can be taken as harvest. The standard default assumption in fisheries is that the stock size for maximum biological yield will be about 50% of the unfished stock size.

The second reason for dropping catch rates is that the unfished stock will often have many large old individuals that will not be present when the stock is fished near its biological optimum. These individuals will be caught early on in the development phase, and may provide spectacular catches both in terms of weight and value. In many fisheries the large fish are disproportionately valuable.

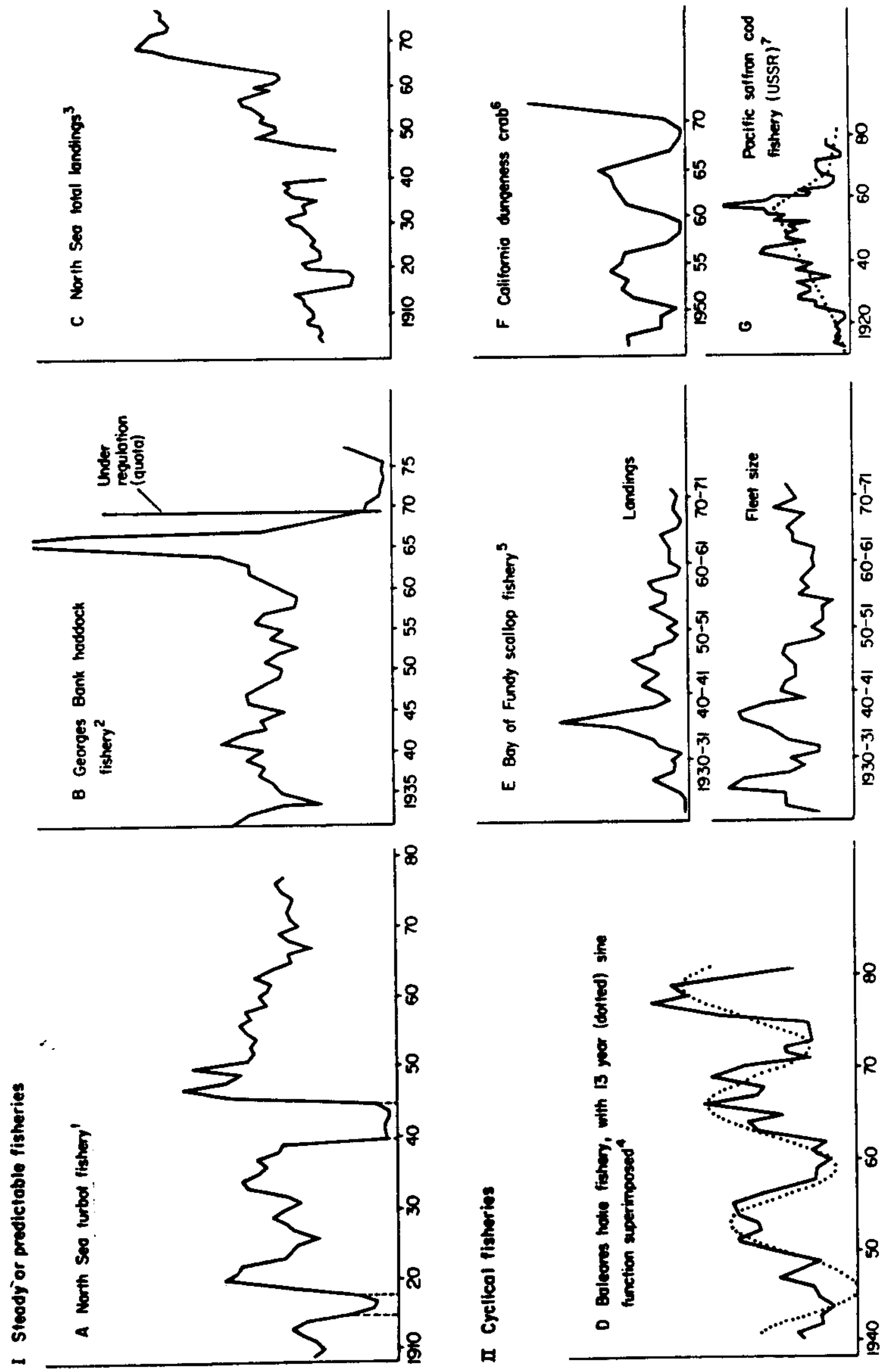
The third mechanism for declining catch rates is biological structure of the fisheries. Many fisheries consist either of mixed species or substocks of fish, where some species or substocks have higher sustainable harvest rates than others.[4] During the development phase the less-productive species or substocks will be severely overexploited, and essentially constitute a non-renewable component to the fishery.

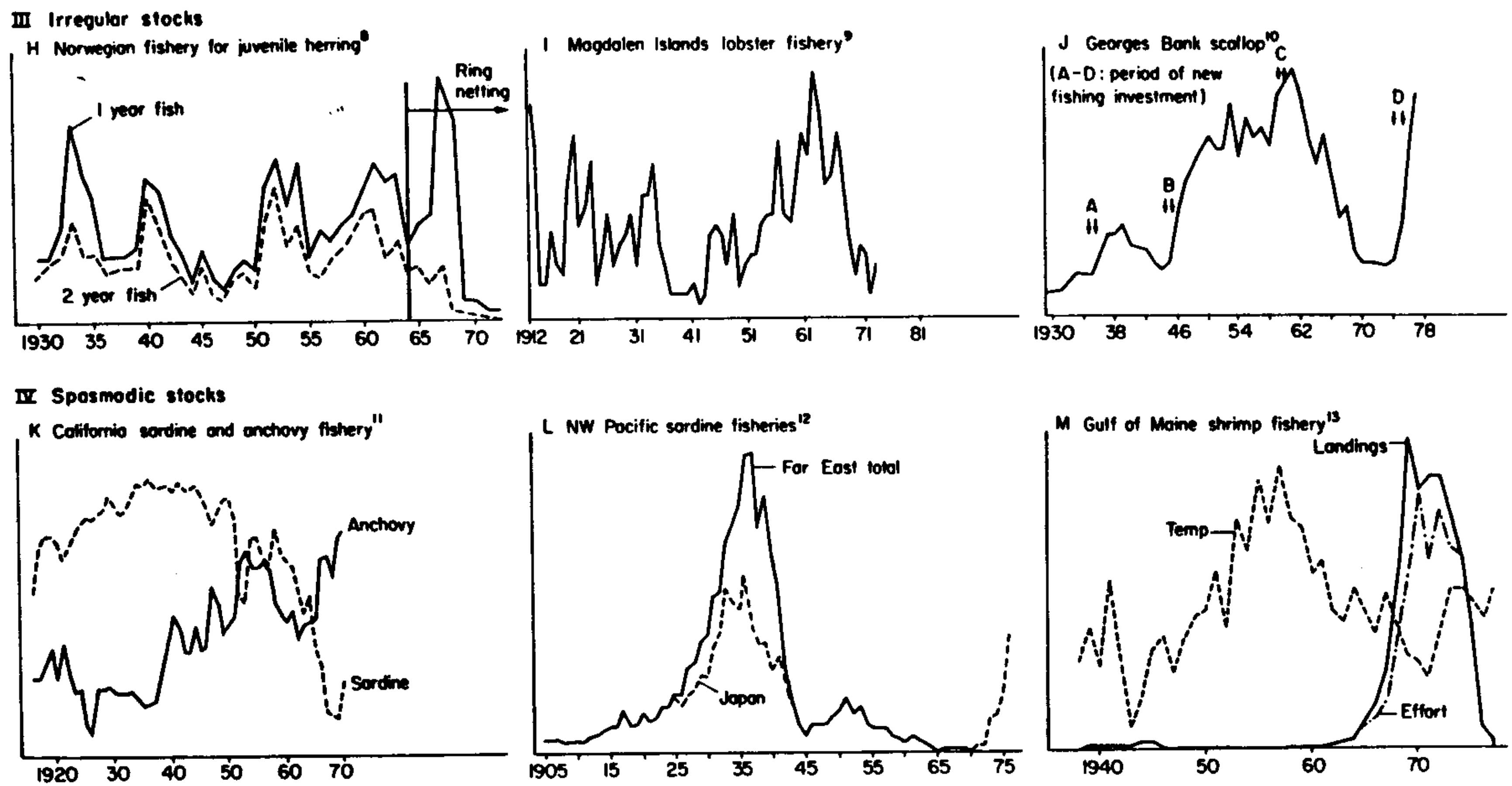
The consequence of these three mechanisms is that catch rates, and therefore profitability, will be lower and possibly much lower once the sustainable harvest regime is reached. Therefore individual vessel operations must be very profitable during development to be economically viable when the fishery is mature. This suggests that if a fishery is not profitable enough to generate its own investment and growth, governments should be wary of trying to encourage further development. If a fishery is to be profitable, it should generate its own economic development.

Adaptive management

An alternative view of the world is one in which we recognize that fisheries management involves tracking the moving target. The term 'adaptive management' refers to the continuous need to adapt to a changing world. An adaptive management system[5] has two elements: a monitoring system to measure efforts and catches and to try to estimate the current status of the stock and its underlying production rela-

[3] W.E. Ricker, 'Two mechanisms that make it impossible to maintain peak-period yields from stocks of Pacific salmon and other fishes', *Journal of the Fisheries Research Board of Canada*, Vol 30, 1973, pp 1275–1286.
[4] Ricker, *ibid*; and R. Hilborn, 'Apparent stock recruitment relationships in mixed stock fisheries', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 42, 1985, pp 718–723.
[5] C.J. Walters and R. Hilborn, 'Adaptive control of fishing systems', *Journal of the Fisheries Research Board of Canada*, Vol 33, 1976, pp 145–159; C.J. Walters and R. Hilborn, 'Ecological optimization and adaptive management', *Annual Review of Ecology and Systematics*, Vol 9, 1978, pp 157–188; R. Hilborn, 'Living with uncertainty in natural resource management', *North American Journal of Fisheries Management*, Vol 7, 1987, pp 1–5; and C.J. Walters, *Adaptive Management of Renewable Resources*, Macmillan, New York, 1986, pp 335.


I Steady or predictable fisheries
A North Sea turbot fishery[1]
1910 20 30 40 50 60 70 80
B Georges Bank haddock fishery[2]
Under regulation (quota)
1935 40 45 50 55 60 65 70 75
C North Sea total landings[3]
1910 20 30 40 50 60 70
II Cyclical fisheries
D Baleares hake fishery, with 13 year (dotted) sine function superimposed[4]
1940 50 60 70 80
E Bay of Fundy scallop fishery[5]
Landings
Fleet size
1930-31 40-41 50-51 60-61 70-71
F California dungeness crab[6]
1950 55 60 65 70
G Pacific saffron cod fishery (USSR)[7]
1920 40 60 80



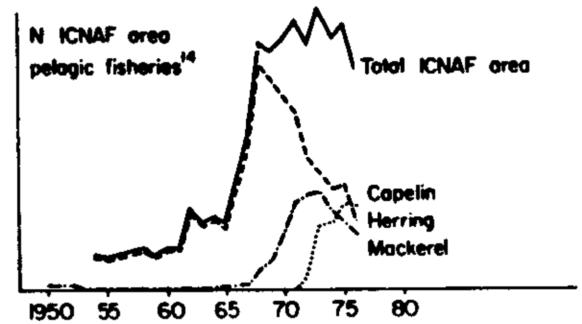


Figure 3. Four types of stock dynamics illustrating that well-behaved sustainable equilibria are often not possible.
Source: After Caddy and Gulland, see text, *op cit*, Ref 2, pp 268–269.

tionships; and a response system that enables us to increase or decrease effort as required to track the moving biological and economic variables.

Monitoring

Once we recognized that fisheries management involves exploring an uncertain world of biological and economic dynamics, it is obvious that we must establish good measurement systems to detect where we are. We must measure the catches, fishing efforts, gear efficiencies, prices, costs and other relevant factors to be able to perform an adequate biological and economic assessment of the potential productivity of the stock, and the desirable fleet size and operational methods. Using the exploration analogy, nothing is worse for an explorer than to be lost, and if we fail to measure the biological and economic conditions of the fishery as it develops, we will effectively lose the knowledge acquired during the development phase.

Although the above advice may seem obvious, in actual practice data are rarely collected intensively as a fishery develops; it is only after there is some type of crisis that the funds are committed to adequate data collection. Data on the logistics of vessel operation which are so vital for understanding changing gear efficiency are not frequently collected even today.

Response

The second essential element of an adaptive management system is the ability to respond to changes as they occur, and this invariably means the ability to either change fishing effort or gear efficiency. As we saw above, even if the stock is perfectly behaved, we will still need to reduce the fishing mortality rate after we have passed the optimum. In the rest of this article we assume that one reduces fishing mortality by reducing effort, although reducing individual vessels' efficiency will have the same biological effect.

Nothing is more difficult for fishery managers than reducing effort, particularly after a period of growing catches. Reducing effort means reduced catches, which in turn means reduced profitability or more likely increases losses by individual fishermen. Once we have detected that the optimum is passed, we need to cut back the effort. This will usually be at a time when catch rates per vessel are at a historic low, and vessel profitability is also poor. Under these circumstances individual fishermen, or national fishing enterprises, are going to resist efforts to reduce their catch. This simple fact of economic life explains the usual long response time between passing of the peak catches to effective reduction of effort.

An economic or biological adviser may clearly recognize that the time has come to reduce effort, but it usually takes several very poor years before individual vessel operators admit that the fishery is in trouble. Since the fisheries in many developing countries are under national control, and the internal politics of reduced fishing effort are likely to be Byzantine, with the officials responsible for the operation of the fishing company opposing reductions in effort proposed by the scientific advisers.

Clearly the most important element in successful fisheries management is the ability to reduce fishing effort when it is required. Precisely because it does not contain this element, the traditional fisheries paradigm of Figure 1 is a prescription for disaster. The traditional paradigm contains effort continuously increasing up to the optimum, with no need to ever reduce it. Obviously, successful management will also need the ability to increase effort on occasion, but this is less of a problem.

Building a new paradigm

We are suggesting that the paradigm associated with developing fisheries needs to be changed. Rather than view fisheries development as a steady increase in up to a Utopian optimum, we must begin to think of fisheries development as continual exploration of the economic and biological system which will involve increasing efforts initially, to be inevitably followed by subsequent variation in fishing effort, particularly periodic reductions in effort.

The role of stock assessment

Traditional fisheries stock assessment has an important role in our new 'adaptive' paradigm. The monitoring system must attempt to track the changes in the biological stock and continually predict the consequences of alternative catches. as Caddy and Gulland point out, the existing tools are far better equipped for dealing with 'steady state' stocks than the other, less-tractable types, but considerable progress is being made at understanding cyclical, spasmodic and irregular stocks.

However, traditional stock assessment is not sufficient. The monitoring system must pay equal attention to the harvesting and processing sectors, since the desired management actions will depend as much on economics as biology.

One major change in stock assessment methods that has immediate application to many developing fisheries is the use of basic scientific principles of experimental design. Many fisheries are spatially structured, that is, the fish consist of discrete populations (at least as adults). If some of these spatial areas are deliberately overfished as quickly as possible, and some areas are preserved in a lightly exploited state to act as controls on the effects of fishing, several benefits can be gained. First and most importantly, assessment of how the stock will respond to fishing will be more rapid, because the heavily exploited areas will provide information on what types of yields are sustainable and what symptoms appear as exploitation increases long before most fishing areas are being heavily exploited. This would allow us to approach the potential yield in most fishing areas more gradually and lessen the inevitable need to reduce fishing pressure. Secondly, the lightly fished areas can serve as a reserve, where fishing effort could be directed when fishing pressure needed to be reduced in major fishing areas.

The success of such an experimental design depends on the biology of the fish, as well as the manager's ability to control fishing effort. There will naturally be a tendency for fishermen to fish where catch rates are best, and the lightly fished areas would be a tempting target for illegal fishing. However, we have discussed this concept with officials and fishermen from many developing countries and they do see it as real possibility for their fisheries.

Fisheries regulations

Having identified the need for mechanisms to reduce fishing effort when necessary, how do we actually do it? We have three suggestions. First, many of the opportunities for fisheries development have occurred due to the extension of national jurisdictions to 200 miles. Developing nations seek to expand their domestic fisheries to replace fishing fleets of DWFNs. In some cases, such as tuna in the western Pacific, or pollack in the Bering sea, the DWFNs still constitute the major fishing fleet, and the coastal nations are collecting access fees from the DWFNs. There the coastal nations are in a position to reduce effort by eliminating some of the DWFN effort. It should be far easier to reduce DWFN fishing fleets than the domestic one.[6]

If the developing nation is attempting to replace DWFN fleets with a domestic one, it would be well advised to allocate a substantial portion of the catch to the DWFNs to serve as a buffer for its own fleet. Any required reductions in effort can again be absorbed by the DWFNs. The proportion of total catch allocated to DWFNs would depend on the dynamics of the fishery. For the 'steady state' stocks most of the catch could be allocated to the domestic fishery. For cyclical, spasmodic or irregular stocks the country would presumably want to allocate most of the catch to the DWFNs, while providing a relatively stable but smaller domestic fishery. Some of the bioeconomic implications of allocating some catch to DWFNs are discussed by Garcia, Gulland and Miles – they raise the issue that allocation of any catch to DWFNs will decrease the catch rate of national fishermen and therefore always has major costs.[7]

One potential hidden danger in using DWFNs operating on access agreements as a buffer, is that the country may become dependent on the access fees and government officials may be reluctant to reduce the size of the DWFNs' catch because of implications for the national budget. This will be especially true for small countries where access fees may constitute one of the largest forms of national income.[8]

In many fisheries there are no DWFNs to use as a buffer for the national fleet. Given that the difficulty in reducing effort results from the implied reduced cash flow to fishermen, the best protection is to maintain the fishery at a profitable enough state in which it can absorb a reduction in catch without economic diaster. If we can anticipate the need for a reduction in catch, then we should make sure the fleet size does not develop to a point where each vessel could not be profitable if it were forced to reduce its catch.

Economically unregulated fisheries will be particularly difficult to control, since they will naturally tend to develop to a point where few vessels are profitable. In practice, unregulated fisheries tend to develop even further to the stage where all vessels are unprofitable. The dynamics of fisheries development, with higher total catches and catch rates during development than are sustainable, are undoubtedly partially responsible for this problem. The fact that most fish stocks are not 'steady state' producers, but cyclical, irregular, or spasmodic makes things even worse.

Economists have considered the problem of excess fishing capacity and methods in preventing overcapitalization. The most commonly proposed techniques[9] include taxation of landings, taxation on effort, limited entry, and individual transferable quotas. Limited entry is a direct mechanism for reducing fishing effort, but has proved extremely

[6] G.R. Munro, 'Coastal states, distant water fleets and EFJ: Some long-run considerations', *Marine Policy*, Vol 9, No 1, 1985, pp 2–15.

[7] S. Garcia, J.A. Gulland and E. Miles, 'The new Law of the Sea and the access to surplus fish resources', *Marine Policy*, Vol 10, No 3, 1986, pp 192–200.

[8] The agreement between the Republic of Kiribati and the USSR for 1986 provided for US $2 million a year which is approximately 20% of the national budget for Kiribati.

[9] H.S. Gordon, 'The economic theory of a common property resource: the fishery', *Journal of Political Economy*, 1954, pp 124–142; J.A. Crutchfield, 'Economic and social implications of the main policy alternatives for controlling fishing effort', *Journal of the Fisheries Research Board of Canada*, Vol 36, 1979, pp 742–752; and C.W. Clark, 'Towards a predictive model for the economic regulation of commercial fisheries', *Canadian Journal of Fisheries and Aquatic Sciences*, Vol 37, 1980, pp 1111–1129.

difficult to implement in the real world. The social and political implications of removing fishermen often make such direct control impractical.

The second mechanism for maintaining flexibility in fishing effort we see as potentially useful is taxation on landings or effort. While taxation has not found favour with policy makers, we believe this is primarily due to the fact that it cannot be introduced after overcapitalization has taken place. Once the fishery is overdeveloped, fishermen are losing money and are not in a position to pay additional taxes. We see taxation during the profitability periods of a fishery as a potential buffer. When catches need to be reduced, the taxes can be eliminated or reduced and fishermen can catch fewer fish without loss in income.

The third mechanism is the use of individual transferable quotas, a regulatory mechanism that is recommended by many economists and now being widely applied in Australia and New Zealand, with some conspicuous successes. If the management agency reserves some of the catch quotas for annual allocation, this could act as a reserve which could not be allocated at times when catches need to be reduced.

Allocation of the entire catch, either on a tonnage or a percentage of an allowable quota basis would be, we believe, quite dangerous. If individual quota licences were granted during a developing fishery, it is certain that the licences would be valued largely based on historical profitability and not on the expected profitability after the fishery came to equilibrium. Thus, the likely scenario would be many individuals paying large sums for the licences, suddenly finding their quotas reduced, their catch rates dropping, and exerting the same type of political pressure against declining quotas that we find in unregulated fisheries. One could argue that these are just bad investors who should suffer the consequences of their poor investment. However, fisheries history teaches us that when fishermen are in trouble, the government pays.

Licence limitation has certainly taught us that the licence value tends to reflect past catches much more than potential future catches. Effort will be just as hard to reduce under vessel quotas or licence limitation as it is in unregulated fisheries.

Conclusions

Shifting to a new paradigm is primarily a problem in perception. Technical advisers to developing nations must be sure to emphasize the inevitable ups and downs of catches and catch rates as well as the interaction between catch and catch rate. Most government officials are looking for simple answers to simple questions. When asked to estimate the sustainable yield or the optimum fleet size, advisers must explain the changing nature of these quantities. Rather than perform some mystical number crunching, technical advisers must help developing nations design their monitoring and response systems.

The agenda determines the questions. So long as the agenda for developing fisheries is the traditional prescription of Figure 1, the questions will concern the sustainable yield and optimum fleet size. The agenda needs to be changed to Figure 3. We must change the worldview of those in charge of developing fisheries so they begin to ask the right questions.