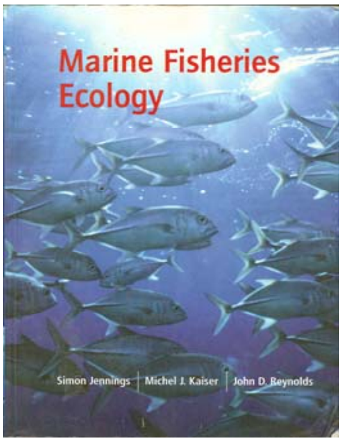
11, 12. Resource economics

The handout for this lecture is a photocopy of chapter 11 from the book by : S. Jennings, M.J. Kaiser and J.D. Reynolds (2001). Marine Fisheries Ecology. Blackwell Science, 417 pp.



and picturesque is not necessarily very productive and that turning fisheries into living museums will not be a solution to global overcapacity and inefficiency in the industry. Many who observe fisheries may feel that small is beautiful and would prefer to see many poor fishers in small boats trolling for tuna rather than modern and sophisticated purse seiners searching for entire shoals with helicopters. Managers may also prefer fisheries based on small boats with limited catching power because it is easier to implement effort controls. But Hannesson considers that economically inefficient fisheries, at least in developed countries, can have undesirable economic effects. This is because society as a whole has to bear the costs of reduced efficiency and productivity in the fisheries sector, and thus resources that could be better used elsewhere (to run hospitals and schools, for example) are needed by fishers.

In other industries, technical improvement leads, in the longer term, to the transfer of the workforce to other parts of the economy where they can be more productive. Witness the development of telecommunications, computing and service industries in the developed world as the extraction of natural resources and manufacturing were increasingly automated. In general, preserving a museum culture within the fishing industry will mean that its inefficiency has to be subsidized and that people working in other industries will have to pay for this through increased taxation or loss of services.

These arguments may be persuasive in the developed world, although many fishers will obviously prefer to carry on fishing rather than move to cities and work in telecommunications or computing. However, in the developing world, many countries have weak economies and fishers have few, if any, alternate sources of food, income and protein. These people cannot leave the fishery without financial support. Unfortunately, such support is rarely available.

Summary

- Most stocks are fished for economic gain and fishing provides employment for millions of fishers and workers in associated industries.
- In most large and economically developed nations, fisheries make a minor contribution to national economic activity. However, fisheries may support large sectors of the economy in small island and developing nations and their contribution to Gross Domestic Product can exceed 10%.
- On a global scale, marine fisheries are heavily subsidized and economically inefficient.
- Bioeconomic models help to explain why fisheries are overexploited and predict their response to different management measures.
- An unregulated fishery expands until revenue equals the cost of fishing. If costs are low, then the stock is likely to be fished beyond its biological limits. Fishers compete in unregulated fisheries because anything left in the sea could be caught by someone else.
- If the future value of fish is perceived to be less than the money that could be made by fishing now, selling the catch and investing the money, then there is an economic incentive to overfish.
- Uncertainty can be incorporated into static bioeconomic models by replacing uncertain variables with random variables that have specified probability distributions. This assumes that probability distributions from historical data can be used to estimate probabilities in the future.
- An alternative approach for making decisions in the presence of uncertainty is decision analysis, where uncertainty is recognized and accepted at the outset.

Further reading

Hannesson (1993) provides a clearly written and accessible introduction to the bioeconomic analysis of fisheries, and gives many examples of bioeconomic models in action. Clark (1985) is a more advanced treatment and is packed with interesting examples and ideas.

Box 11.1
Optimal harvesting with risk of extinction .

Fossil and historical evidence shows that stocks eventually become extinct, and yet the risk of extinction has scarcely been considered in most fisheries and bioeconomic models. How should we harvest when extinction is possible? Lande *et al.* (1994) incorporated risk of extinction in a stochastic model to predict strategies that maximise the expected present value (PV) of cumulative harvest before extinction. They predicted that a stock should not be harvested unless it was above its equilibrium population size in the absence of harvesting. This was an unexpected and unsettling result because it entails a complete halt to fishing except when random processes push the population above the so-called carrying capacity. This is a far cry from the classical goals of maintaining lower populations so that productivity is increased (Chapter 7). Whittle and Horwood (1995) confirmed this result, but reconciled it with classical theory by also considering a different objective: maximising rate of return per unit time (before extinction). These papers are important because they force managers to consider the likelihood of extinction, rather than assuming that stocks can automatically bounce back from low levels.

tion provided a good description of the probability of different quotas being set from 1970 to 1985 (see Fig. 11.6), but in the next 3 years the quota was reduced to nil, a pattern that was not in accordance with that suggested by the log-normal distribution. This should not surprise us when we look at the long-term dynamics of other stocks (Chapter 4), for many stocks undergo periodic cycles of collapse and recovery as their environment changes.

We need to realize that probabilities are uncertain in many areas of fishery science. Moreover, an approach to dealing with uncertainty that is based on replacing model parameters with probability distributions may not help with making management decisions. Confidence limits around parameters may indicate expected uncertainty but they do not provide management guidance. Thus, fishery scientists tend to say that quotas should be reduced in the face of uncertainty while the fishing industry takes the opposite view! (Clark, 1985).

An alternative approach for making decisions in the presence of uncertainty is decision analysis. Here, uncertainty is recognized and accepted at the outset using a prior distribution (Bayesian analysis, section 7.9.1). This distribution is subjective, based on the scientist's experience and any existing data. Since scientists have studied many fisheries, it is usually possible to make an educated guess about the form of the prior distribution. This may be as simple as setting minimum and maximum values for a variable and assuming a uniform distribution between them. Often, we can do much better.

As an example of an application of decision analysis we can consider how we might estimate optimal investment in a developing fishery (Clark, 1985). In most developing fisheries, little is known of the abundance or productivity of the newly exploited stock. Usually, fishery development will be driven by fishers and investors who see an opportunity to make profit, and overcapacity quickly develops. By the time scientific assessment has taken place, and regulations are imposed, the fishing industry suffers economically because they have invested non-malleable capital. Clearly, it would be better to impose regulation at the outset, to keep the stock biologically productive and the fishing industry economically efficient. How can we determine whether investment should be limited at the outset, and to what extent, when the future is uncertain?

Let us assume that, in the developing fishery, year-to-year fluctuations in recruitment are correlated with year-to-year fluctuations in production. If recruitment has been observed for a few years, or we have observed the dynamics of a similar stock elsewhere, we can get a prior distribution. This could, for example, be a log-normal distribution. This prior distribution can then be used to estimate the optimal investment. After a few years, we have more recruitment data, so we know more about the levels of uncertainty, and update the distribution to recalculate the optimal investment. The approach is conceptually simple, and Clark (1985) shows how it can be addressed mathematically. The outputs from his model show that uncertainty about long-term investment prospects calls for a conservative initial investment, since upward adjustments can be made later. This makes intuitive sense, since if the initial investment were too high, subsequent downward adjustment would cause economic hardship.

11.4 Economic vs. social management objectives

11.4.1 Subsidies

We have already shown that marine fisheries, when viewed on a global scale, are not profitable. Unprofitable industries usually collapse, but a large fishing industry persists because it subsidized by direct and indirect payments from governments. The main objectives of governments are to maintain employment levels and to ensure the fishers receive a reasonable income.

Global economic analyses of fisheries are notoriously difficult because a large proportion of fishing activity is not reported to the Food and Agriculture Organization of the United Nations (FAO) that collate these data. However, in 1993 the FAO (1993a) produced an analysis of costs and revenues for the global fishing fleet using data from 1989. The vessels they included were mostly those greater than 100 GRT (gross registered tonnage) in size, and so the reported values should be regarded as minimum estimates. Some of the results are shown in Table 11.7.

It is clear from Table 11.7 that the costs of operating the fleet exceeded revenue by $US54.1 billion in 1989. The fishing industry was overcapitalized and economically inefficient for the reasons we outlined in general terms in section 11.3.1. Notably, access to many fishing grounds was not restricted, and the best way to catch more fish was to invest in more fishing power. In addition, when prices were high or fish were abundant, more vessels were built, but these could not be used outside the fishery when prices are poor and fish were scarce. The investment of such non-malleable capital in vessels means that vessels often had to continue fishing, even when it is unprofitable, simply to cover some of their fixed costs.

There is no doubt that subsidies maintain an economically inefficient industry and increase the probability that fished stocks will be exploited beyond their biological limits. However, they do maintain employment in the fisheries sector and prevent the collapse of fishing communities. The fishing industry is subsidized in various ways. These can include artificial price control for catches, subsidies for fuel or gear purchase, low-cost loans or grants for boat and capital equipment purchase and the provision of ports and marketing facilities. In 1989, the Japanese fishing industry was subsidized by $US19 billion, and high levels of subsidy were also provided for Russian and East European fleets. The European Community paid the fishing industry $US0.6 billion and individual governments within the EC provided further subsidies to their own fleets. As we will see in Chapter 17, many of the current attempts to improve fisheries management are based on plans for reducing subsidy and improving economic efficiency.

Table 11.7 Operating costs and revenue for the global fishing fleet in 1989. From FAO (1993a).

Costs	$US billion	%
Cost of capital	31.9	25.7
Maintenance	30.2	24.3
Labour	22.6	18.2
Gear and supplies	18.5	14.9
Fuel	13.7	11.0
Insurance	7.2	5.8
Total	124.1	
Less revenue	70.0	
Deficit	54.1	

11.4.2 The case for economic efficiency

Economic efficiency is just one possible aim of fishery management (section 1.5). In many cases, one large vessel fishing in areas where effort is strictly controlled to maximize biological yields may be more economically efficient than many small boats in an open-access fishery. Economic efficiency, as in many industries, may improve with increased mechanization and fewer employees. Since fishing has traditionally employed many people in coastal communities it is sensible to ask whether economic efficiency is a more or less desirable goal of management than high employment.

Hannesson (1996) provides an interesting perspective on this problem. He suggests that what is traditional

Table 11.6 Inputs used to assess the optimum investment in the Norwegian capelin fleet.

Input	Value	Units
Price of capelin	80	$\$ t^{-1}$
Operating cost	40	$\$ t^{-1}$
Vessel cost	7×10^6	$
Amount caught per unit capital (k_1)	0.00357	$t \$^{-1}$
Maintenance and depreciation (m)	0.05	y^{-1}
Discount rate (δ)	0.05 (& variable)	y^{-1}

$\log_e$-transformed values of Q. These are 7.392 and 0.318, respectively. We have plotted the log-normal probability density function onto the frequency distribution of quota values in Fig. 11.6.

Having described the probability density function for Q we can add the other parameters to the model. Values for these parameters are given in Table 11.6.

Equation 11.8 is used to estimate K_{opt}. We set both the discount rate and maintenance and depreciation at 5% (0.05) such that $(\delta + m) = 0.10$. Maintenance and depreciation consists of the expected costs of maintaining the fishing vessel and capital equipment plus the depreciation rate. The depreciation rate is the inverse of the lifetime of the fishing vessel and capital equipment. Thus, a vessel and capital equipment with an expected lifetime of 25 years would have a depreciation rate of 0.04.

The term $(pk_1 - c)$ is the net value of the landed quota, where p and c represent the total value realized from selling the catch and the total cost of making that catch, respectively. k_1 is the amount of capelin caught by one unit of capital invested. If the price of capelin is $\$80\ t^{-1}$ and the operating costs per unit caught (c_y) are $\$40\ t^{-1}$, then the net price is also $\$40\ t^{-1}$. A large purse seiner can catch some 25 000 tonnes of capelin each year and costs around \$7 million. With this information we can calculate k_1, the amount caught per unit capital invested as $25 \times 10^3/7 \times 10^6 = 0.00357\ t\ \$^{-1}$. Thus the term $(pK_1 - c)$ is equal to $0.00357 \times 40 = 0.1428$ and the right-hand side of equation 11.8 is 0.700.

On the left-hand side of equation 11.8, $F(k_1K_{opt})$ is the probability that the quota will be less than the catch capacity of the fleet. Since Hannesson has shown that $k_1K_{opt} = Q^*$, where Q^* is the limit to fleet capacity, the right-hand side can be expressed as $1 - F(Q^*)$. Since we

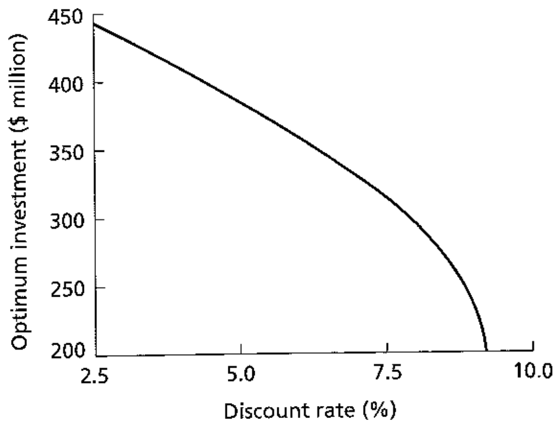


Fig. 11.7 Relationship between discount rate and optimum investment in the Norwegian capelin fishery.

have assumed that quotas are log-normally distributed, the probability that the quota will be less than Q^* can be determined from statistical tables. For the input values given in Table 11.6 we get an optimal Q of 1372 000 tonnes. The optimum investment (K_{opt}) to achieve this quota can be obtained by dividing the quota by k_1, the catch of capelin produced for every \$ invested. This is \$384 million. Note that the optimal investment is less than that needed to catch the full quota every year, so some quota would be left uncaught.

The model can be used to show how changes in discount rates affect optimum investment. As discount rates increase from 2.5 to 7.5% (maintenance and depreciation costs were kept at 5%), there is a rapid fall in optimal investment (Fig. 11.7). When discount rates exceed 10%, any investment is unlikely to be worthwhile, and the fishery may have to be subsidized if past quota variation reflects future variation.

Changes in quota variability also affect optimal investment strategy (Fig. 11.8). Not surprisingly, with no variation in quota, the optimal investment provides enough boats to catch the whole mean (but constant) quota each year. As variance around the mean increases however, the optimum investment falls.

Equation 11.8 suggests that it is never optimal to invest in a fleet that can always take the quota unless the cost of capital is zero. Higher costs lower the amount of fish caught per unit of money invested and thus optimum capacity falls. These conclusions are similar to those of Charles (1983). He developed a general model that related optimal investment in fleet capacity to

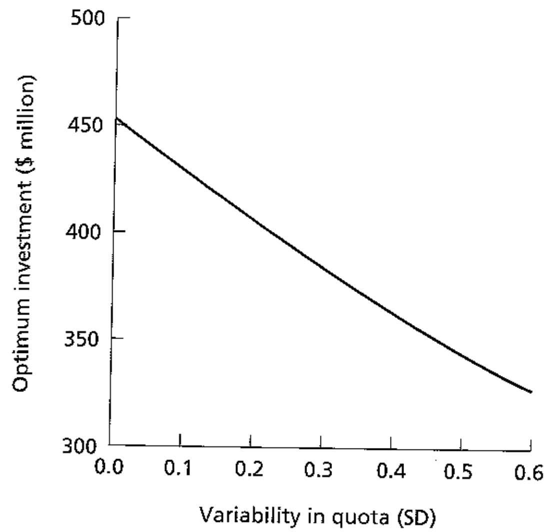


Fig. 11.8 Relationship between predicted variability in the quota and optimum investment in the Norwegian capelin fishery.

uncertainty. His model showed that it would only be worth investing more in fleet capacity when the future was uncertain if vessel capital was very malleable and the intrinsic rate of population increase for the resource was high. In the case of the Norwegian capelin fishery, like most other fisheries, vessel capital is non-malleable and it is economically desirable to invest less under uncertainty.

The choice of optimal capacity can be explained by considering two opposing effects: the **downside risk** of suffering idle excess capacity in bad years and the **upside risk** of lacking sufficient capacity to take full advantage of the resource in good years. Depreciation rates play a key role in the response. If there is no depreciation, then capital is infinitely long lived and the recurrent cost of capital is low. Thus, the downside risk of an increased investment is relatively small. As the rate of depreciation increases, so annual costs rise and the effective life of a unit of invested capital will fall. This causes the upside benefits of an extra unit of capital to be lower, because there are likely to be fewer years in which the fishery could take advantage of higher capacity. In general terms, the lower the depreciation rate the more likely it is that there will be higher investment under uncertainty.

The models we have considered are for single-species fisheries. If fishers can target several stocks, then they may be able to use their fishing capacity elsewhere during bad years. This reduces downside risk and would be expected to increase the optimal investment. Indeed, most fisheries are opportunistic to some extent, often targeting different species in different seasons.

In presenting this example of a model for the Norwegian capelin fishery we have based the output on catch quotas that were set from 1970 to 1985. In fact, Hannesson (1993) also presents data for the years 1986–90. In 1986 catches fell dramatically, and from 1987 to 1990 catches were zero. This demonstrates an important point, that past fluctuations in fish stocks are not necessarily a good guide to those that will occur in the future and may not be consistent with a fixed probability density function. There is always uncertainty about the future, e.g. Box 11.1.

When the future and present are uncertain

Horwood and Whittle (1986) provide another means of finding the optimal effort when there are both random fluctuations in recruitment, and when the size of the stock at age is only known with only some degree of error. Solutions can be found that take the form of a control law that regulates the fishing by each fleet, so that an optimal return can be obtained in the face of recruitment and measurement uncertainty. The actual values are updated as stock sizes change.

11.3.3 Bayesian methods

We have seen that one of the easiest, and still most widely used, approaches to dealing with uncertainty is to take a static model and to replace variables with random variables having specified probability distributions. In adopting this approach, we assume that a probability distribution obtained from models of historical data can reasonably be applied to estimating the probability of events in the future. This is true for card games, coin tossing and in other cases where the range of outcomes is limited and there is complete knowledge of the probabilities. However, this does not strictly apply to fisheries problems where distributions cannot be correctly determined from theory, and the empirical data used to compile distributions are estimated rather than known values (Clark, 1985).

Our capelin model in the previous section was a rather good example of this. The log-normal distribu-

Table 11.4 Parameters used in the Hannesson (1993) model to predict optimal investment in a fishing fleet when potential catches vary from year to year.

Parameter	Meaning
R	Revenue (net of operating costs)
ER	Expected revenue (net of operating costs)
Q	Quota (total allowable catch)
δ	Discount rate
m	Maintenance and depreciation
p	Total value from selling catch
c_y	Costs per unit caught
c	Total operating costs of making catch
K	Fleet capacity represented by amount of money invested in fleet
K_{opt}	Optimal fleet capacity (investment) to maximize ER
Q^*	Limit to fleets catching capacity

they can, processors or markets may not be able to deal with all these fish. Bioeconomic models can describe the uncertainty in stock fluctuations and use this as a basis for optimizing investment.

We will now look at a model developed by Hannesson (1993). This shows how optimum fleet capacity might be estimated in a fishery where catch quotas are essentially random. We consider an application of this model to the Norwegian capelin *Mallotus villosus* fishery. Capelin are fished just before spawning by a modern purse seine fleet. The fishery targets only one or two mature age classes, and like many salmonid fishes, the capelin die after spawning. The aim of management has been to ensure that a minimum biomass escapes each year to contribute to subsequent recruitment. Given the great variability in year-class strength this means that the catch quota (Q) set each year is also very variable. We have adapted and simplified the model for the purposes of this example. So please do not use it for fishery management!

To formulate the model, Hannesson needed: (i) a probability density function for the quotas; (ii) a model for determining optimum fleet capacity; (iii) a description of the relationship between catching capacity and quota; and (iv) a description of the relationship between revenue, price and cost for a range of quotas. These relationships were synthesized to develop an overall model for estimating optimum capacity. The notation needed for these analyses is summarized in Table 11.4. Note that economists routinely use notation that is used for other purposes by stock assessment scientists.

To predict the probability that any given quota will be set in the future, the frequency distribution of past quotas was described using a probability distribution. In a fishery based on one or two age classes, quotas reflect recruitment variability, and there is reasonable evidence to suggest that errors around a spawner–recruit relationship are log-normally distributed (section 4.2.1). In reality, the probability distribution will vary with time and the quotas set from year to year are not independent of one another. However, for the purposes of the model the time dependence and autocorrelation were ignored and the probability distribution of Q was treated as time invariant.

Hannesson assumed that fishing effort was proportional to the number of boats in the fishery, that vessels were identical and that the cost of a boat was constant and independent of the number built. Because we are interested in determining fleet size, and fleet size is equivalent to optimal investment, fleet size is represented by the amount of money invested in the fleet (K).

When the fleet is operational, the profit per year will be $R - mK$, where R is revenue net of operating costs and m is the maintenance and depreciation cost of capital invested in the fleet. Maximization of the present value of profits can then be expressed as:

$$\text{maximize} \sum_{t=0}^{\infty}[ER(K) - mK]/(1+\delta)^t - K \quad (11.4)$$

where ER is the expected revenue net of operating costs and δ is the discount rate. Note that the upper and lower limits of t have been set as 0 and ∞ for analytical purposes.

Hannesson shows that equation 11.4 can be solved and multiplied by δ to give:

$$\max ER(K) = (\delta + m)K \quad (11.5)$$

In written terms we are now maximizing expected annual revenue from the fishery net of all costs. $(\delta + m)K$ is the annual capital cost which consists of the alternative cost of capital (δK) and maintenance and depreciation (m). The optimal solution of equation 11.5 is obtained by differentiation with respect to K:

$$ER'(K) = \delta + m \quad (11.6)$$

where ER' is the first derivative of revenue net of operating costs. The term $ER'(K)$ gives the annual expected

revenue from investing in an additional unit of fish production (i.e. boats!) and $\delta + m$ gives the annual cost of a unit of capital. Thus, it pays to invest in boats until the expected annual revenue from an additional boat is equal to the annual cost of an additional boat.

We will skip much of the mathematics that is concerned with deriving an expression for $ER(K)$, but this was described in full by Hannesson (1993). In brief, expected revenue is calculated as the product of all possible catch values (from 0 to ∞) and the probabilities that they occur (0–1: as defined by the log-normal distribution function for Q) summed over all possible catch values. Since catch is treated as a continuous variable the solution is calculated by integration. In words, we can express the solution as:

$ER(K)$ = (Revenue when quota is less than fleet capacity, i.e. actual catch equals quota) + (Revenue when quota is greater than fleet capacity, i.e. actual catch equals fleet capacity)

Because we want to know the size of the fleet at which the maximum revenue is expected, it is necessary to calculate the mean increase in catch value when fishing capacity is increased by a small amount. This is given by the first derivative of ER which, if price and catch rate are constant in relation to stock size, can be simplified to give:

$$ER'(K) = [1 - F(k_1K_{opt})](pk_1 - c) \quad (11.7)$$

where k_1 is the amount caught per unit capital invested and $F(k_1K_{opt})$ is the probability that the quota will be less than the catch capacity of the fleet (F is used here to denote a function). If we now refer to equation 11.6, the equation we previously derived for expected revenue, this can be substituted into equation 11.7 and the equation rearranged to give:

$$[1 - F(k_1K_{opt})] = (\delta + m)/(pk_1 - c) \quad (11.8)$$

where K_{opt} is the optimal catching capacity (or investment) to maximize the expected revenue. We can now apply this equation to estimate K_{opt} in the Norwegian Barents Sea capelin fishery, and see how changes in various parameters affect K_{opt}.

First we have to develop a function to describe variation in the quotas. The data we use to do this are those presented by Hannesson for quotas (as catches) in the period 1970–85 (Table 11.5).

We have seen that the errors around a mean spawner–recruit relationship are often log-normally distributed (section 4.2.1), and since the fishable biomass of capelin is based on only one or two year classes then a log-normal distribution may be appropriate for describing the variation in Q. This is shown when a log-normal probability density function is plotted with the frequency distribution of quota values (Fig. 11.6). To describe the probability density function for Q, we determine the mean (μ) and standard deviation (σ) of the

Table 11.5 Capelin quotas (Q) 1970–85. Data from Hannesson (1993).

Year	Q (1000 t)	$\log_e Q$
1970	1131	7.031
1971	1393	7.239
1972	1592	7.373
1973	1336	7.197
1974	1149	7.047
1975	1417	7.256
1976	2545	7.842
1977	2940	7.986
1978	1894	7.546
1979	1783	7.486
1980	1648	7.407
1981	2006	7.604
1982	1760	7.473
1983	2304	7.742
1984	1461	7.287
1985	851	6.746

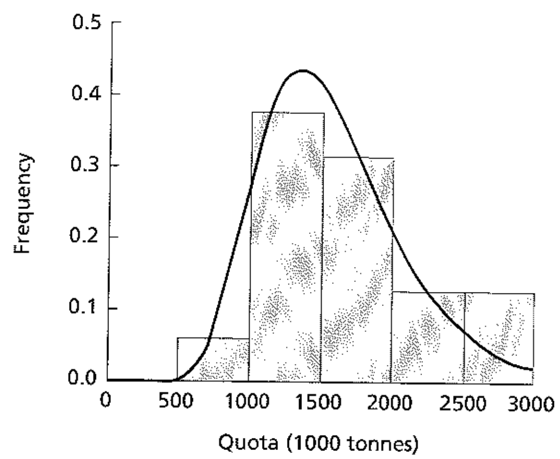


Fig. 11.6 Frequency distribution of quotas in the Norwegian capelin fishery and a fitted log-normal probability density function. After Hannesson (1993).

they will compete and both deplete the resource for fear of making nothing. So begins a race to fish.

In a more realistic situation with more users the payoff for conserving is $Y^*/\delta N$ where N is number of users. If anyone can flout the regulations then they can get B^*—a much greater share than if they participate in the conservation strategy. In these circumstances, the game is likely to degenerate such that the best strategy is to deplete regardless of what the others do. Unless all users can agree to conserve, and trust each other, they will inevitably deplete the resource. The solution deplete–deplete is seen as inferior to the cooperative solution conserve–conserve, but competition seems to force the inferior solution.

We can use a simple model such as this to look at the benefits of management strategies. An example would be restricted entry where the number of users is reduced. In fact, unless the number of users is reduced to one and the user is a monopolist, the results described above will always apply. Access restriction will not encourage conservation because there is still no incentive to conserve. Indeed, under access restriction, future benefits come to users in proportion to their fishing power. This is why real-world access restrictions have to be accompanied by catch or effort control (section 17.2).

Clark's game helps us to understand the basis for overfishing, but it is a 'one shot' game. Fishing in real oceans is a game that continues indefinitely and, in these circumstances, a few users with similar catching power may well cooperate (Hannesson, 1995a, b, 1997).

11.3.2 Optimal fishing strategies

For a single cohort

Most fisheries target fish of many ages from many cohorts, and these cohorts differ in abundance at the time they recruit to the fishery. Bioeconomic models can predict when these cohorts should be fished in order to optimize the value of the catch, and the ways in which factors such as discounting affect the time at which unregulated fishers will exploit them. There is much interest in economic optimization of fishing strategies, but we need to remember that the economically optimal strategy is not necessarily the most desirable strategy for policy-makers of fishers because other social, political and biological constraints may have more bearing on the management process.

As an introduction to bioeconomic models, we describe the approach of Clark *et al.* (1973) and Clark (1985) to determining the optimal fishing strategy for a single cohort. We will look at a single cohort as it passes through a fishery and see how the discount rate affects the time at which it should be exploited in order to give the greatest economic yield.

We have seen in Box 7.2 that the change in the number (N) of fish alive in a cohort with time can be expressed as a function of natural mortality (M) and fishing mortality (F). Since fishing mortality is a function of catchability (q) and fishing effort (f), equation 2 in Box 7.2 can be written:

$$\frac{dN}{dt} = -(M + qf)N \qquad (11.2)$$

The present value (PV) of profits from fishing such a cohort will be given by the expression (Clark *et al.*, 1973):

$$PV = \int_0^\infty e^{-\delta t} f_t (pqN_tW_t - c)\,dt \qquad (11.3)$$

where δ is the discount rate, f_t is fishing effort at time t, p is price, q is catchability, N_t is numbers at time t, W_t is mean individual weight at time t and c is fishing costs. For simplicity, Clark *et al.* assumed that the cohort recruited to the fishery at $t = 0$, that price was fixed and that fishing costs were proportional to effort.

The term $f_t\,(pqN_tW_t - c)$ expresses the profit to be made from fishing at time t, while the term $e^{-\delta t}$ reduces the present value of this profit as t or the discount rate rises. Note that the Clark *et al.* (1973) equation is simply a modification of the fundamental yield-per-recruit model (equation 7.26) where the summation sign has been replaced by an integral because time is a continuous variable.

Clark *et al.* (1973) solved equation 11.3 to determine the time at which the cohort should be fished to maximize PV. The solution was sensitive to the discount rate (Fig. 11.5). As the discount rate falls, so the catches are shifted towards the age at which the cohort reaches its maximum biomass (Fig. 11.5a). At high discount rates, growth overfishing, or fishing before the cohort reaches its maximum biomass, is increasingly likely to occur because catches are shifted towards the beginning of the cohort's life span (Fig. 11.5b). Total catch will thus fall as the discount rate increases.

The time at which the cohort should be fished does not depend on the history of fishing the cohort, but on the existing value of the cohort and its potential for future growth in biomass. Once the potential for future growth (and hence value) is less than the existing value then the economically optimal policy will be to catch the fish and sell them as quickly as possible.

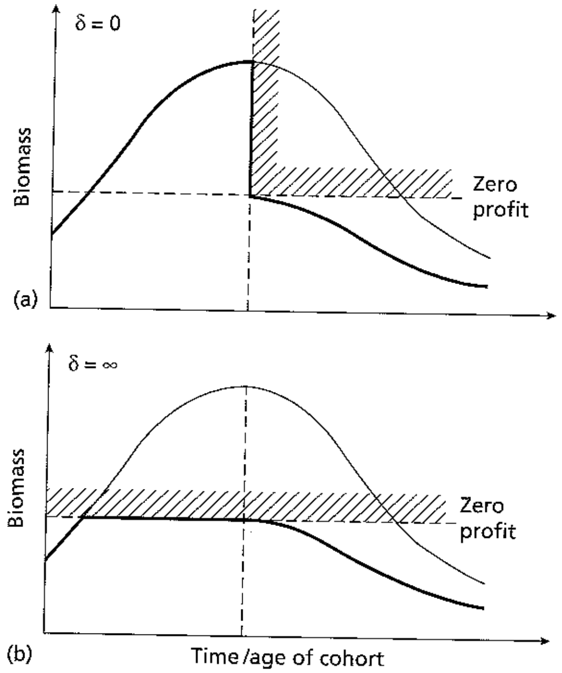


Fig. 11.5 Fishing a single cohort at (a) zero discount rate and (b) infinite discount rate. The fine lines show the natural biomass of the unexploited cohort and the bold lines show the biomass after exploitation. The 'fishing zone' is shaded. We assume that fishing effort is so high that the stock is instantaneously reduced by fishing. Zero profit occurs when $B = c/pq$. After Clark *et al.* (1973).

The single-cohort model suggests that in an unregulated open-access fishery, fish will be caught as soon as there is a profit associated with catching them. High discount rates reduce the optimal age at first capture. As we have seen, fishers tend to work with very high discount rates but managers do not.

Multiple cohorts, species and fisheries

The models of Clark can be extended to more typical fisheries involving simultaneous harvesting of several cohorts or even other species. The optimal equilibrium, where one exists, is still associated with the marginal total productivity equal to the discount rate, but is modified by a marginal stock effect when net rewards are a function of stock size(s). However, the basic models are mathematically and biologically simple. As biological and economic realism increases, and as the models become more non-linear, more complex optimal paths appear, equilibria may not be optimal, and the ability of the mathematics to identify a true optimum becomes more limited.

Optimal results are often criticized as being unrealistic, being of a 'bang–bang' nature—going from where we are now immediately to the optimal solution. But this is unfair. The bang–bang solutions only occur for the simplest of models (often used heuristically), and many optimal solutions are sensibly smooth. Indeed if we put a cost on changing fishing effort from year to year, the solution is likely to be smooth. Horwood and Whittle (1986) and Horwood (1990) show how solutions can be found to more non-linear models, and they provide approximate solutions to multispecies and multifleet problems.

When the future is uncertain

Fluctuations in the environment and recruitment mean that we have little ability to predict long-term changes in the abundance of exploited populations (Chapter 4). As such, the future is uncertain and the investment of capital in boats and equipment is risky. The basic bioeconomic model of Gordon (section 11.3.1) gave valuable insights into the tragedy of the commons and what managers should do in principle, but ignored uncertainty and the biological processes underlying the production curve. For this reason it did not really help us to give quantitative advice that would increase economic efficiency. Predictive models have to deal with uncertainty if they are to provide realistic outputs. The usual approach to incorporating uncertainty is to take a static model and to replace uncertain variables with random variables having specified probability distributions.

Given that fished stocks do vary in abundance over time, one of the most pressing questions that bioeconomic analyses can address is the optimum level of investment in a fishery that targets a fluctuating resource. Stock fluctuations are inconvenient for industry. When stock sizes are low, fishing may be unprofitable and fleet capacity is not used. When stock sizes are high, fishers may not be able to catch all the fish that biological analyses suggest are available and, even if of a fishing industry while a resource rebuilds can have catastrophic economic consequences.

There are many examples of fishers' unwillingness to reduce effort once they have invested non-malleable capital in fishing boats. Munro (1992) gives a good example from the northern cod fishery in Newfoundland and parts of Nova Scotia. In 1977, Canada implemented Extended Fisheries Jurisdiction which meant that the cod stocks, that were once fished by many countries, were brought under Canadian control. The Canadian government decided that fishing mortality had to be reduced to allow the stock to rebuild. The initial reductions in fleet capacity were easy to achieve since foreign vessels had been ejected from the fishery. As the resource grew, the Canadian industry planned to expand, and began to invest in fishing and processing equipment. Such equipment was not useful for other purposes and thus the capital invested was non-malleable. Unfortunately, in 1987 fishery scientists realized that the cod stocks were not rebuilding at the rate predicted, and that the original estimates for stock recovery rates had been too optimistic. They called for drastic reductions in cod catches, but there was a strong adverse reaction from an industry that had invested non-malleable capital on the basis that cod were predicted to be abundant in future years.

Discounting

Even when fishers do not compete for a resource, the decision whether to catch species now or leave them in the sea will depend on their future value. If the value of a fish stock 5 years in the future is perceived to be less than the money that could be made by catching the fish now, selling them and investing the money in a bank for 5 years, then there is an economic incentive to fish.

Discount rates are used to measure the rate at which the perceived value of a resource, such as a fished stock, falls over time. Discount rates reflect the cost of return on alternative investments. Thus, if you 'invest' some money in fish by leaving them in the sea, you require that its value should grow at least as fast as the money you would get from selling the fish you caught and investing the money.

The present value (PV) of income V, occurring t years into the future is:

$$PV(V_t) = \frac{V_t}{(1+\delta)^t} \qquad (11.1)$$

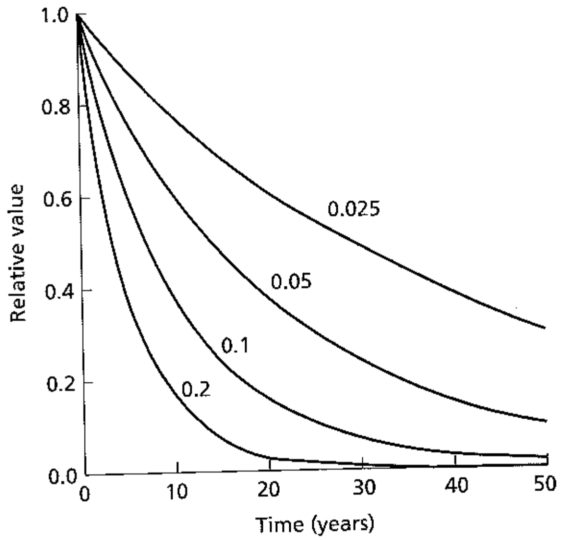


Fig. 11.3 The decline in perceived value of a unit of income at different discount rates.

where δ is the discount rate. The decline in perceived value of a unit of income at different discount rates is shown in Fig. 11.3. A 10–20% (0.1–0.2) discount rate rapidly reduces the perceived value of fish caught and sold in the future.

High discount rates are used by fishers because they reflect risk; fishers are uncertain about reaping the benefits from fishes left in the sea. Fishers' rates are, for example, typically higher than the difference between government interest rates and inflation which guide civil projects such as bridge construction. If fishers had secure rights to fish they might use lower discount rates, but the rates would probably still be higher than the return on other investments because there is always some uncertainty about the growth of fish in the sea.

If fishers use high discount rates they will want to catch fish as soon as possible, particularly if the costs of fishing do not increase rapidly as the stock is depleted. Investment in fish in the sea is less attractive than converting fish to money for investment, because the fish grow at a lower rate than invested capital. The use of high discounting rates explains why species such as whales, with very low growth rates, were 'mined' rather than fished sustainably. In fact, many stocks have growth rates that are lower than fishers' discount rates. The only reasons why these stocks are not routinely 'mined' to depletion are: (i) that the costs of fishing may rise at low levels of abundance and (ii) that some regulations to prevent 'mining' are enforced.

In those fisheries where no attempt is made to control 'mining' then history suggests that mining will occur. Thus, the sea cucumber (*bêche de mer*), trochus and clam fisheries in some Pacific islands have been characterized by short periods of boom-and-bust exploitation, with the fishers removing all the accessible animals and only returning many years or decades later, when stocks have recovered to economically viable levels. For example, a fishery for sea cucumber developed rapidly in the Galápagos Islands during 1992. Fishing was largely unregulated and very intensive because foreign buyers were paying high prices for the sea cucumbers. The economic boom far exceeded anything that had been witnessed in the islands before but, within 5 years, stocks of sea cucumber were so depleted that fishing was no longer profitable (section 1.3.1).

Given that fished species are almost always more valuable if caught today than if left in the sea, why do we bother to conserve fish at all? Is it not better to simply catch and sell fish as quickly as possible and then to invest the money? In purely economic terms this may be true, but we have reached a point at which economic analyses do not address all our concerns about fisheries management. In reality, society as a whole tends to favour the conservation of resources because they feel it is right to conserve them. The reasons include moral and ethical responsibilities to care for life on earth, a desire to preserve fishing communities and lifestyles, and to leave marine ecosystems in an acceptably 'natural' state (Kunin & Lawton, 1996). Clearly, quantifying these benefits is a very complex task, and outside the scope of this book, but the desire to conserve resources for future generations remains an overriding aim of fisheries management.

Clark (1985) has emphasized that a recognized discounting policy is not used when making fishery management decisions. As such, arguments over acceptable levels of catch between the regulators and the fishing industry are effectively an argument over discount rates. Regulators usually want to reduce current catches while fishers want to increase them. The regulator has a long-term view and thus works with a low discount rate while the fishers want to maximize immediate benefits from the fishery and use a much higher discount rate. To the fisher, anything left in water is virtually

		User 1: Conserve	User 1: Deplete
User 2	Conserve	$(Y^*/2\delta, Y^*/2\delta)$	$(0, B^*)$
User 2	Deplete	$(B^*, 0)$	$(B^*/2, B^*/2)$

Fig. 11.4 Payoff matrix for the fishing game. The game is described in the text. After Clark (1985).

worthless. If 0% discount rates were used when planning fisheries development they would encourage the long-term rational exploitation of natural resources. Discounting rates also have critical effects on stock rebuilding initiatives. Thus, if regulators demand that current catches are reduced to boost catches in future, the fishers who used high discount rates would only be expected to support the policy if they expected future catch increases to be very high (Hilborn & Walters, 1992).

Clark's fishing game

Clark (1985) provides a bioeconomic explanation for overfishing in the form of a simple game (Fig. 11.4). This considers whether fishers, acting independently, would be motivated to limit their catches in order to prevent overfishing. He considers two users, which could be individual fishers, boats, fishing companies or nations, with access to a common resource. For simplicity, costs are ignored. Each user has one of two options: to conserve or deplete the resource. We further assume that no restrictions are imposed on fishing activities, that users have equal financial opportunities, and that total profit for both users would be maximized at sustainable biomass (B^*) and sustainable yield (Y^*). δ is the discount rate

The game begins with biomass B^*. When $B^* > Y^*/2\delta$ then depletion is the best strategy for each user regardless of what the other does. So both deplete and obtain a yield of $B^*/2$. When $B^* < Y^*/2\delta$ then a user loses income by the deplete strategy if the other decides to conserve. As such, there is an incentive to cooperate. Both conserve only because it is in their own interest. However, although the depleter loses revenue, if the other user conserves, the conserver will lose more. As a result, if the users do not trust each other it is likely that

Country	Value of Landings ($US million)	Employment (number of people)	Employment (% workforce)
Australia	1 200	–	–
Canada	964	140 000	0.94
EU countries			
Belgium	100	624	0.01
Denmark	438	5 299	0.21
Finland	30	2 948	0.12
France	962	27 598	0.11
Germany	171	4 979	0.01
Greece	5	40 164	0.98
Ireland	189	3 400	0.29
Italy	1 415	45 000	0.20
Netherlands	518	2 834	0.04
Portugal	367	30 937	0.66
Spain	2 080	79 369	0.67
Sweden	136	3 500	0.08
United Kingdom	682	20 751	0.08
Iceland	720	–	–
Japan	21 000	325 000	0.49
Republic of Korea	–	405 000	1.99
Mexico	–	–	–
New Zealand	459	10 000	0.57
Norway	1 034	23 000	1.07
Poland	–	11 500	0.07
Turkey	–	–	–
United States	3 800	300 000	0.23

Table 11.2 Value of landings and employment in fishing (not in related service industries) within OECD member countries. Data for 1993–95. From OECD (1997).

Country	Fish production (1000 $US y^{-1})		
	Subsistence	Commercial	Total
Federated States of Micronesia	11.24	1.48	12.72
Fiji	45.77	18.34	64.11
French Polynesia	14.47	14.37	28.84
Kiribati	13.37	4.77	18.14
Papua New Guinea	41.17	22.10	63.27
Solomon Islands	8.41	4.34	12.75
Western Samoa	5.07	0.32	5.39

Table 11.3 The value of fish production in some Pacific Island nations. The value of subsistence landings is their replacement value. Data for 1989–94. From Dalzell *et al.* (1996).

wrasse *Cheilinus undulatus* (Labridae) sold to restaurants in Hong Kong fetch $US90 kg^{-1} while sandeels *Ammodytes* spp. caught in the North Sea industrial fishery are worth $US0.1 kg^{-1}. If a product is expensive, then producers try to increase supply and make more profit. However, increasing the supply usually incurs greater costs and, because price is usually inversely related to supply (the law of supply and demand), this may cause prices to fall. When costs exceed revenue, profit cannot be made and it is no longer worth fishing.

11.3.1 Descriptive bioeconomics

Gordon model

Gordon (1954) made one of the first attempts to produce an economic analysis of a fishery when he tried to explain why Canadian fishers had such low incomes.

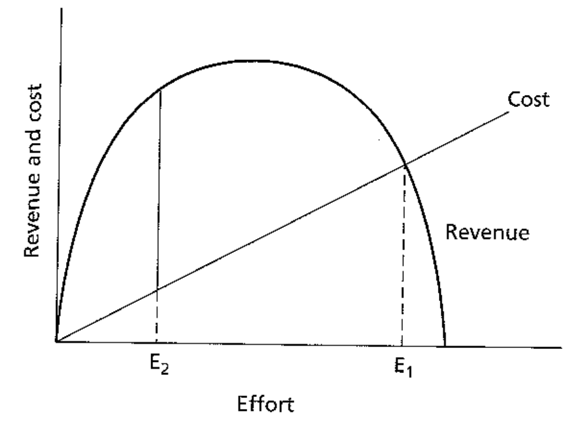


Fig. 11.2 The Gordon (1954) model showing the relationship between fishing effort, revenue and cost. In an unregulated fishery, fishing continues until revenue = cost (E_1) while the greatest profits (difference between revenue and cost) are made at E_2.

He based his model on the classical surplus production curve with all its inherent limitations (Chapter 7), but his analysis was very important because it suggested why an open-access fishery will be overfished and provide poor economic returns for the fishers.

If we assume that yield is proportional to revenue and that the cost of fishing is proportional to fishing effort, then the yield curve described in section 7.3 simply becomes a revenue curve and cost is linearly related to effort (Fig. 11.2). An unregulated fishery would be expected to expand until revenue = cost (point E_1 in Fig. 11.2). This is because fishers would lose money once fishing costs exceeded revenue. The fishery would be most profitable (highest difference between revenue and cost) at E_2. The model suggests that if the costs of entering the fishery and catching fish were low then the fishery would develop well beyond its biological limits and the stock would become depleted. Moreover, the fishery would become economically inefficient because too many fishers would be chasing too few fish.

Gordon thus provided an economic explanation for the low incomes of fishers in an open-access fishery: an open-access fishery would be expected to expand to a greater size than that which gives the highest yield and profitability. However, Gordon's model was not good for prediction. It was a static model, like the surplus production models described in Chapter 7, and suffered from similar weaknesses. Moreover, it did not demonstrate that there are costs associated with moving from E_1 where revenue equals cost to the point E_2 where profits are maximized. These costs exist because stock recovery takes time and revenue falls when effort is first reduced. When reduced effort causes immediate financial loss rather than gain then there is little incentive for fishers to reduce effort. This is especially true in an open access fishery where individual fishers have no control over the whole resource.

Tragedy of the commons

The idea that open-access fisheries will be exploited beyond their biological limits is an example of the tragedy of the commons as formalized by Hardin (1968). Here, competition between people who exploit a common resource depletes the resource beyond its biological limits. Many fisheries are common resources and fishers compete to exploit them. Even with the introduction of Exclusive Economic Zones (EEZ), that gave many countries sole fishing rights within 200 nautical miles of the coast, fisheries often remain open access to fishers within countries (Burke, 1994; section 1.2.1). In many developing nations, the sea is seen as the source of food and livelihood of last resort, from which no-one can be turned away (McManus, 1996). While access to marine resources is essentially free, the action of any fisher does not have a major effect on the dynamics of an exploited stock. There is little to be gained by one fisher trying to conserve fish because fish left in the water will simply be caught by someone else! Thus, it can be argued that a lack of access control, coupled with the common perception that everyone has a right to fish without cost, are the main reasons for the overexploitation of marine resources. In section 17.3.3 we consider management methods that give fishers property rights to their resource and increase the probability that they fish sustainably. As we saw in section 6.4.4, a few such systems have already evolved in some small island states, particularly in the Pacific Ocean.

Non-malleable capital

The capital invested in fishing fleets is said to be **non-malleable** because fishing vessels can rarely be used for other things and can only be sold at considerable capital loss. As such, fishers are unwilling to reduce effort once they have invested in fishing capacity. The non-malleability of capital means that shutting down parts

Fig. 11.1 Fishers selling their catches at a market in the Fijian capital of Suva. Photograph copyright S. Jennings.

11.2.2 Catch values and employment

In 1997, the total first-sale value of fish catches around the world was $US93 329 million of which marine species accounted for $US74 601 million (Table 11.1). The most valuable groups of marine fishes were the redfishes, basses and congers at $US13 687 million and the cods, hakes and haddocks at $US8423 million. Crustaceans were a high-value and low-weight catch accounting in total for 25.1% of value and 6.2% of weight, while fish landed for conversion to fish meal and oils (reduction) were a low value and high weight catch accounting for 3.3% of value but 28.6% of weight. Price differs between species because it reflects the supply of fish available and the demand for them. The maximum price of individual species can reach over $US100 kg^{-1} on resale. Giant grouper *Epinephelus lanceolatus* (Serranidae), favoured by the live fish trade, have sold for over $US10 000 each in Hong Kong. Big-eye tuna *Thunnus obesus* (Scombridae), northern bluefin tuna *Thunnus thynnus* and southern bluefin tuna *Thunnus maccoyii* destined for Japanese sashimi markets also fetch over $US10 000 each.

The relative value of fisheries and the proportion of people employed in fishing depends on many factors, but in general, they are highest in developing coastal and island states. In some of these countries, fishing may be the only source of food and income for many coastal dwellers. The Organization for Economic Co-operation and Development (OECD) collate data on the value of fisheries and fishery-related employment in member states (Table 11.2). In these developed countries, direct employment in fishing is rather low, only exceeding 1% of the workforce in Norway and Korea. This contrasts with employment levels of 10% or more in some developing countries. In the Pacific Island state of Fiji, for example, around 30% of the rural population fish at least once each week. On the largest island of Viti Levu, 37% of males, 48% of females and 5% of children are fishers (Rawlinson *et al.*, 1994).

In many developed nations, the majority of fish landed are sold, and thus their value is a good indicator of the economic significance of fisheries. In rural economies, landings may be eaten by fishers and their families, and thus the social and economic significance of landings may be overlooked by policy makers who base assessments on landed value. To overcome this problem, Dalzell *et al.* (1996) and others have calculated the replacement value for subsistence landings and included them in economic assessments. In the Pacific Islands, the replacement value of subsistence landings consistently exceeds that of landings that are sold (Table 11.3). This emphasizes the significance of fisheries to rural economies, even if they are not always trading in fish.

Although recreational fisheries are not the focus of this book, their value may exceed that of commercial fisheries for species such as European sea bass *Dicentrarchus labrax* in Europe (Dunn *et al.*, 1994). In some cases, this has led to calls for the exclusion of commercial fishers from fisheries.

Table 11.1 Weight, value and prices of fished species landed during 1997. From FAO (1999).

Group	Weight (1000 t)	% of total weight	Price $US t^{-1}	Value ($US million)	% of total value
Fish					
Flounders, halibuts, soles	994	1.2	2 950	2 932	3.9
Cods, hakes, haddocks	8 022	9.6	1 050	8 423	11.3
Redfishes, basses, congers	6 003	7.2	2 280	13 687	18.3
Jacks, mullets, sauries	4 845	5.8	680	3 295	4.4
Herrings, sardines, anchovies	11 674	13.9	240	2 802	3.8
Tunas, bonitos, billfishes	4 851	5.8	1 510	7 325	9.8
Mackerels, snoeks, cutlassfishes	5 263	6.3	315	1 658	2.2
Sharks, rays, chimaeras	790	0.9	840	664	0.9
Fish for reduction	23 986	28.6	103	2 471	3.3
Other fishes	5 328	6.4	510	2 717	3.6
Crustaceans					
Sea spiders, crabs	1 183	1.4	2 900	3 431	4.6
Lobsters, spiny rock lobsters	231	0.3	11 800	2 726	3.7
Shrimps, prawns	2 535	3.0	3 800	9 633	12.9
Other crustaceans	1 258	1.5	2 300	2 893	3.9
Molluscs					
Abalone, winkles, conchs	106	0.1	6 000	636	0.9
Oysters	194	0.2	2 950	572	0.8
Mussels	224	0.3	420	94	0.1
Scallops, pectens	477	0.6	2 200	1 049	1.4
Clams, cockles, arkshells	831	1.0	880	731	1.0
Squid, cuttlefish, octopus	3 321	4.0	1 800	5 978	8.0
Other molluscs	1 648	2.0	450	742	0.9
Echinoderms					
All species	109	0.1	1 300	142	0.2
Totals	83 873			74 601	

11.3 Bioeconomic models

Economic analyses of fisheries are, like the biological analyses we have already described, based on models that abstract aspects of the system and attempt to describe or predict system behaviour. Bioeconomic models help us to understand why fisheries develop as they do and to predict their behaviour under different management regimes. The more advanced models deal explicitly with uncertainty in the parameter estimates.

Before we consider the ways in which economic models can help to explain patterns of exploitation in fisheries, we need to introduce some terminology. **Revenue** is the price of a product multiplied by the amount that is sold. For fishers the product is usually fish! **Costs** are the amounts that need to be spent to produce revenue. They are commonly divided into **variable costs (short-term costs)**, such as fuel for the boat, that can change over periods of a few days, and **long-term costs** or **fixed costs** that do not depend on whether a fisher is actually fishing. Variable costs are likely to be proportional to fishing effort while fixed costs are not. Typical fixed costs would include loan repayments or insurance on boats that still have to be paid when the boat is not at sea. **Profit** is the difference between revenue and cost.

Producers sell products that are bought by **consumers**. It is assumed that producers try to maximize their profits, and they do this by deciding what to sell, how much to sell and when to sell it. Prices reflect the desirability of the product for the consumer. Thus live Maori

Summary *(Continued)*

estimates of mean abundance. However, they are good for mapping boundaries, contouring abundance patterns and making temporal comparisons.

- Depletion and mark–recapture methods are most useful for estimating abundance of fished species in confined habitats such as reefs and estuaries.
- Egg production methods are used to estimate abundance of large stocks that spawn pelagic eggs. The annual egg production method (AEPM) and daily egg production method (DEPM) differ in the way they integrate egg production and fecundity with respect to time.
- The scale and efficiency of commercial fishing activity means that catch and effort data can be collected from large areas over long time scales. The quality of such data are affected by misreporting and differences in fisher skill or behaviour.

Further reading

Seber (1982) and Buckland *et al.* (1993) describe methods for estimating animal abundance. The coverage of Seber (1982) is particularly comprehensive. MacLennan and Simmonds (1992) and Misund (1997) review acoustic methods, and Hunter and Lo (1993) describe egg production methods. Gunderson (1993) provides wide-ranging coverage of methods used to survey fish resources. Chapters in Gulland (1988) and Hilborn and Walters (1992) discuss survey design and collecting data from fisheries.

11 Bioeconomics

11.1 Introduction

Globally, fishing provides employment for millions of fishers and for workers in associated industries such as boat building, net making and retailing. Fishers buy boats and fishing gear, sell catches, spend income, invest profits and often receive subsidies. Given that fishing is the focus of so much economic activity, it is surprising that the roles of economic factors in driving fisheries exploitation are often ignored. To manage fisheries effectively, we need to know how economic factors affect them.

One might expect fishing to be a profitable business. Apart from the costs of boats and gear, access to fishing grounds is often free and fishers reap harvests that grow without being sown. However, in global terms, the fishing industry is highly inefficient and the costs of fishing, supported by government subsidy, have exceeded direct income by more than $US50 billion each year. Economic analyses help us to understand why resources are used as they are, why fisheries are economically inefficient, and how fisheries could be better managed. Moreover, in conjunction with biological data, they can provide a basis for choosing between management options. Bioeconomic analyses, for example, can help to determine optimal fleet sizes, configuration and employment, whether catch limits should be fixed or variable, and how taxation or licence fees would influence fishing effort.

The aim of this chapter is to review the economic significance of fisheries throughout the world and consider the economic reasons why fishers often exploit stocks beyond their biological capacity. We then describe some bioeconomic models and the ways in which they can help to inform management decisions.

11.2 The value of fisheries

11.2.1 Trade in fished species

Most fished stocks are exploited for economic gain. Even when fishers rely on fishing effort to get their own food, they usually sell catches as well as eat them (Fig. 11.1). The total value of fish trade between nations exceeds $US50 billion each year and the trade within nations is worth much more (FAO, 1999). In 1997, 95% of international trade involved only 20 countries. Norway, China, the United States, Denmark, Thailand and Canada were the main exporters, each exporting fish and fish products worth more than $US2000 million. Japan was the main importer, receiving $US15 540 million worth of fish and fish products in 1997. More than $US3000 million worth of imports were also received by the United States, France and Spain (FAO, 1999).

In most large and economically developed nations, fisheries make a relatively minor contribution to national economic activity. Thus, the contribution of fisheries to **Gross Domestic Product** (GDP), the total income of a country before costs, is less than 1% in Europe and the United States. National figures can be misleading, however, because the income from fisheries will often be an important driver of economic activity within coastal communities.

In small islands and developing countries with extensive coastlines, fishing can be a key contributor to national economic activity. In Iceland, where there are major fisheries for cod, herring and capelin, fishing contributes directly to 15% of GDP and to 35–50% of GDP via economic linkages and multiplier effects (OECD, 1997). In the Pacific Island state of Kiribati where there are many artisanal fisheries for reef fishes and tuna, fishing contributes directly to 54% of GDP (Dalzell *et al.*, 1996).

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12 The Economics of Fisheries

RÖGNVALDUR HANNESSON

12.1 INTRODUCTION

The subject matter of economics is the use of scarce resources to satisfy practically unlimited demands. This is particularly true of the subdiscipline of fisheries economics. The productivity of wild fish stocks is limited by nature. What makes fisheries economics particularly relevant is that the rules governing the fishing industry often fail to take due account of nature's limited productivity. Economics offers some guidance for what the appropriate rules are.

The subdiscipline of fisheries biology is a good deal older than fisheries economics. Two classic papers on fisheries economics were published in the 1950s by two Canadian economists, Gordon (1954) and Scott (1955) but there were some contributions before that time (see Smith, Chapter 4, this volume). The subject 'took off' in the late 1960s and the 1970s with contributions by Anderson (1973, 1976), Gould (1972), Plourde (1970, 1971), Smith (1968, 1969), and in particular by Clark (1973a, 1976, 1985). Textbooks dealing with fisheries economics are Anderson (1986), Cunningham et al. (1985), Hannesson (1993), and Clark (1976, 1985). Of these, Clark's books are the most mathematically advanced. On the development of the subject, see Scott (1979). Classic biological reference works, useful for the economist, are Beverton and Holt (1957), Ricker (1975) and Hilborn and Walten (1992).

12.2 THE SURPLUS PRODUCTION MODEL

A natural starting point is the surplus production model, where the rate of growth of a fish stock in excess of what is needed to compensate for natural deaths, or surplus growth (G) for short, depends on the size of the stock (S) (Schnute and Richards, Chapter 6, this volume; Sparre and Hart, Chapter 13, this volume, where biomass is called B). This is, needless to say, a great simplification. The usefulness of this model is that it represents the limited productivity of nature in a simple and transparent way and allows one to demonstrate, simply and clearly, some key concepts and processes. In reality the growth of fish stocks depends on a number of factors, most of which vary over time subject to environmental fluctuations. This has important economic implications which will be discussed later. Schaefer (1957) used the surplus production model in applied analyses, and it is sometimes named after him.

Figure 12.1 shows three possible surplus growth curves. One is based on the logistic equation, another on a modified logistic equation with a critical threshold level of viability, and a third is based on yet another modification of the logistic equation, which shows depensatory growth but no threshold of viability. These differences in shape have implications for the shape of the sustainable yield curve, as will be discussed below, and by Schnute and Richards (Chapter 6, this volume).

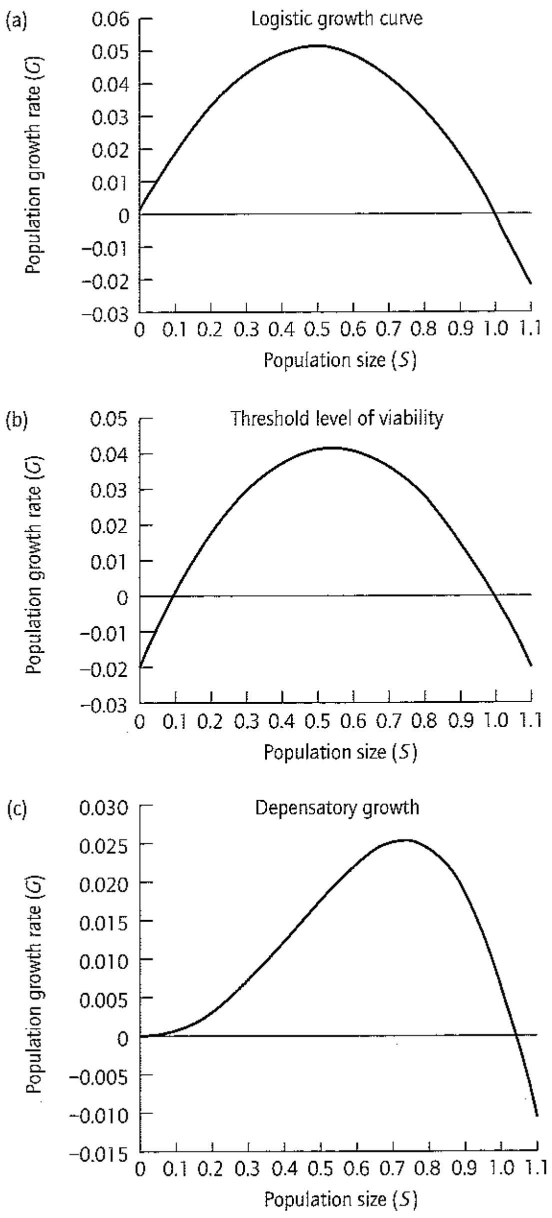

Fig. 12.1 Three examples of a surplus growth function. **(a)** Logistic: $G = aS(1 - S/K)$, with $a = 0.5$ and $K = 1$; **(b)** logistic with a threshold value of viability (A): $G = a(S - A)(1 - S/K)$, where $A = 0.1$ and a and K as before; **(c)** depensatory: $G = aS^{\alpha}(1 - S/K)$, with $\alpha = 2$ and a and K as before. G = rate of growth; S: size of stock; K: maximum stock size (carrying capacity of the environment).

The surplus growth curve shows how much it is possible to fish sustainably. Any quantity between zero and maximum surplus growth is sustainable; if the stock happens to be in equilibrium at some level $S^{\#}$, we can fish the amount $G(S^{\#})$ per unit of time indefinitely, and the stock would remain at $S^{\#}$, because what we are taking away corresponds exactly to the surplus growth. The question is, how much should we take? Should we take the maximum surplus growth or something less? If we take less, we see that we could take that quantity from two different stock levels. Should we take it from a 'small' stock or a 'large' stock?

12.3 FISHING EFFORT AND FISH YIELD

The first step towards answering these questions is to investigate the relationship between the activities of the fishing fleet and the amount of fish it catches. This relationship is in fact highly complex, depending on the technology used and the reaction of a fish stock to continued exploitation and depletion (Misund et al., Chapter 2, this volume).

Fishery biologists early on invented the concept of fishing effort. The purpose was to find an indicator of the abundance of fish stocks, a quantity not easily observed. Fishing effort is a measure of the activity of the fishing fleet directly aimed at catching fish. It can be rigorously defined as the mortality that the fleet causes in a fish stock of a given size and distribution (the importance of these latter two qualifications will become clear presently). Examples of practically measuring effort are hours of trawling (eventually corrected for differences in vessel size), number of hooks lying in the water for a certain number of hours, or days fishing. By definition, fish are caught at a rate equal to the product of instantaneous fishing mortality (F) and stock size:

$$Y = FS \tag{12.1}$$

where Y is the rate at which fish are removed from the stock. If fishing mortality is directly proportional to fishing effort (f), we have

$$F = qf \tag{12.2}$$

where q is a constant (sometimes called availability or the catchability coefficient). Combining (12.1) and (12.2) we get

$$Y/f = qS. \tag{12.3}$$

This means that the catch per unit of effort which is measured over a 'short' period of time, since Y is the rate at which fish are removed, is proportional to the size of the fish stock being exploited and can be used as an index of its size.

The problem with this is that the postulated relationship between fishing effort and fishing mortality depends critically on the assumption that the fish are always evenly distributed over a given area, or that the relative distribution of effort and fish is always the same in a given area. This is not always the case, and perhaps only exceptionally so. If the assumption holds, the density of the fish is directly related to the size of the fish stock; twice as many fish would mean twice as many fish per square kilometre, and twice as many fish would be likely to be dragged up per hour of trawling or to bite the hooks that lie in the water overnight. But consider a different scenario, one where the area over which the fish are distributed shrinks in proportion to the size of the stock. If the size of the stock shrinks by one half, the area where the fish are will also shrink by one half. The density of fish will remain the same as before, in that part of the area where they are located, and if the fishermen know where to find them, as modern technology increasingly allows them to do, the catch per trawl-hour or hook-night would be the same as before, and it would tell us nothing about the size of the stock.

In all probability we have identified two polar cases between which reality is likely to lie. The area over which fish are distributed is likely to shrink somewhat as the stock is depleted, but not in proportion to the depletion. It appears that bottom-dwelling fish like cod (*Gadus morhua* L.) do not contract a great deal as a consequence of depletion, while surface-dwelling stocks that travel in shoals, like herring (*Clupea harengus* L.), do not migrate nearly as widely as the stocks are depleted. But reality departs to a greater or lesser degree from these stylized examples. There are indications that the northern cod stock of Newfoundland became more concentrated as it was depleted (Hutchings and Myers 1994). Hence the catch per unit of effort (CPUE) did not fall as rapidly as the stock abundance, which led Canadian fisheries biologists astray and delayed the necessary cutback in fishing.

We shall in the following stick to these two polar cases, as they are easy to analyse mathematically and to depict graphically. We shall also stick to the definition of effort given previously but note that it is likely to be inadequate for economic purposes. For that we would need a measure of effort that takes into account all activities that give rise to costs. Such a measure would be more comprehensive than 'fishing' effort as defined above. In addition to catching fish, the activities of a fishing fleet involve steaming to and from the fishing ground, searching for concentrations of fish, and handling of the catch and gear. If these activities are always proportional to 'fishing' effort there would not be any problem, but that is not likely; consider, for example, the difference between day-trip boats that always return at night irrespective of whether they have filled up the hold or not and boats that store the catch on board and do not return until the hold has been filled. Because of the obvious problems of generalizing about this we shall leave the matter at that and use the term 'fishing effort' in the sense already defined as a measure of the activity of the fleet and the one that gives rise to costs. In any case it would not be easy to do without the biologist's notion of fishing effort in any applied work, because one would need to relate fish production to the size of the exploited stock and the activity of the fishing fleet.

We thus end up with the following two 'polar' relationships between catch and effort:

$$Y = qfS \tag{12.4a}$$

$$Y = kf. \tag{12.4b}$$

Equation (12.4a) is the case where a stock is always evenly distributed over a given area and where a change in the catch per unit of effort directly reflects a change in the size of the stock. Equation (12.4b) is the case where the area over which the stock is distributed is proportional to the stock size. In that case the density of fish is always constant, and so is the catch per unit of effort, which in equation (12.4b) is equal to k. In order to take into account the intermediate cases, some authors have used the functional form $Y = AfS^{\beta}$, where $0 \le \beta \le 1$. Another way to look at this is to regard the availability coefficient q as being dependent on the stock size; i.e. $q = AS^{\beta-1}$. If the density of the stock is always constant, $\beta = 0$, and the availability would be inversely related to the stock size. For attempts to estimate β for cod and herring, see Hannesson (1983) and Bjørndal (1987, 1988). Empirical evidence of negligible sensitivity of the catch per unit of effort to the stock size can be found in Ulltang (1980) and Butterworth (1981).

12.4 SUSTAINABLE YIELD

We may now combine equation (12.4) with the growth function to derive a relationship between sustainable yield, defined as the catch that is equal to the surplus growth, and fishing effort. Three sustainable yield curves are shown in Fig. 12.2, corresponding to the three growth curves depicted in Fig. 12.1 and the production relationship in equation (12.4a) (equation (12.4b) simply produces a straight line with a slope k, up to a level determined by the maximum surplus growth). The logistic growth equation produces a sustainable yield curve of a similar shape, while the curve with the critical threshold level and the one with depensatory growth give rise to sustainable yield curves that look like loops. Such loop-like curves may also arise if there are 'diminishing returns' to the stock, i.e. if instead of (12.4a) we have the catch equation $Y = AfS^{\beta}$, with $\beta < 1$. (See also Schnute and Richards, Chapter 6, this volume; Sparre and Hart, Chapter 13, this volume.)

Before answering the question what level of sustainable yield we should go for, let us consider what would happen in an unregulated fishery

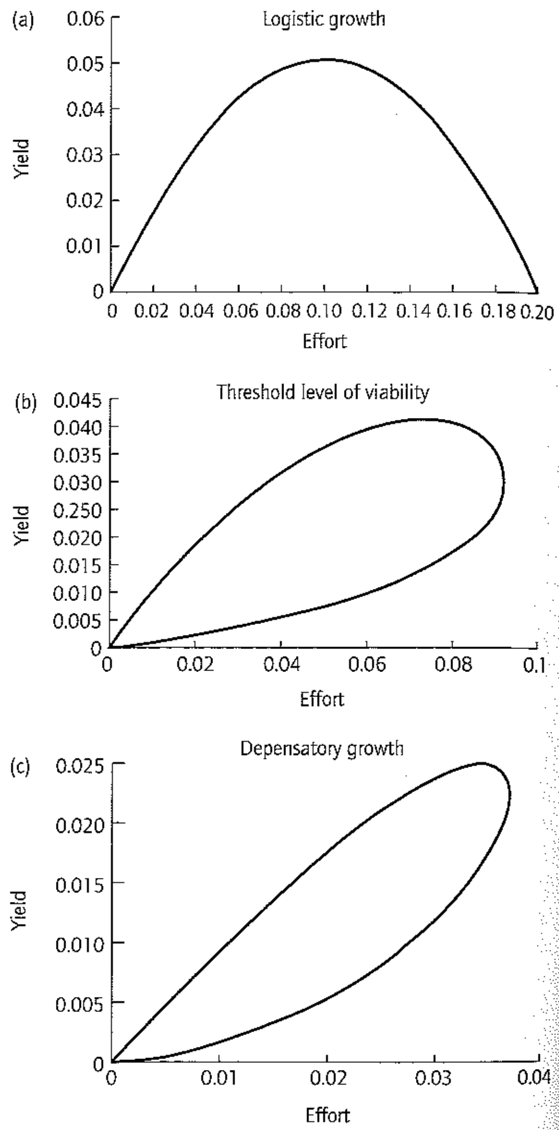

Fig. 12.2 Sustainable yield curves for the growth functions shown in Fig. 12.1 and the catch function $Y = qfS$, with $q = 1$.

where the access to the fish stock is open to all and free of charge. Assume that the price of fish (P) is constant and independent of the volume of landings, and that the cost per unit of fishing effort (C) is also constant. Assume further that all fishing boats are identical in every respect. The value of sustainable yield per unit of effort will then be PY/f and identical for all boats. Sustainable yield will be obtained when the biological system is in equilibrium, which can only happen when the fishing fleet is also in equilibrium, that is, when there is no investment in new boats. What, then, determines the investment in new boats? Presumably, people will invest in new boats if the value of the catch per unit of effort (or catch per boat) is greater than the cost per unit of effort (the cost of each boat). Hence, the system will not be in equilibrium unless the value of the catch per unit of effort is equal to the cost per unit of effort:

$$PY/f = C. \tag{12.5}$$

Combining this with equation (12.4) we get

$$PqS = C \tag{12.6a}$$

$$Pk > C \text{ or } Pk = C \text{ or } Pk < C. \tag{12.6b}$$

In case (12.6a) there will always be some value of S for which an equilibrium exists, provided there is no threshold value of viability for the stock. Figure 12.3 illustrates two possible equilibria for this case. The equilibrium occurs where the sustainable catch value (left-hand side of (12.6a) after multiplying by f) is equal to the total cost (right-hand side of (12.6a) after multiplying by f). The figure uses the logistic surplus growth equation $G = aS(1 - S/K)$ (see also Schnute and Richards, Chapter 6, this volume). Setting this equal to the catch (qfS) gives $S = K(1 - qf/a)$ and a sustainable catch value of $PqfK(1 - qf/a)$. The two equilibria obtain for a 'low' versus 'high' cost of effort, respectively (high versus low price of fish would give the same kind of comparison). For example, if the cost of effort fell, then effort would increase, 'disturb' the equilibrium and drive the stock down to a new and lower equilibrium level.

Note that the equilibrium may be such that excessive effort is used, in the sense that a given sustainable yield is taken with greater effort than necessary. This happens in our example as a result of technological progress: a lower cost of effort induces the industry to apply greater effort, which in the end results in a smaller sustainable yield. This foreshadows the conclusion that open access may not be the most appropriate 'rule of the game' for the fishing industry.

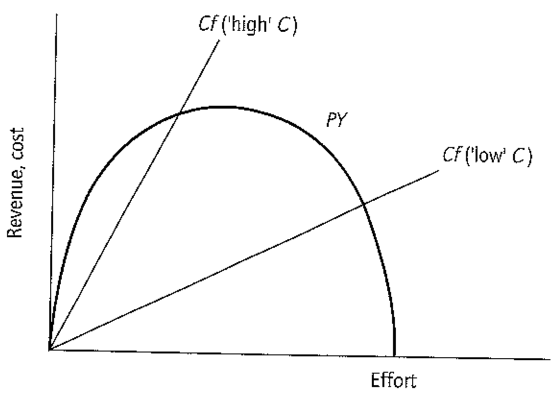

Fig. 12.3 Two bioeconomic equilibria with open access. Equilibrium occurs where the cost line crosses the catch value curve. A lower cost leads to greater effort (f), a smaller stock, and (in this case) a lower sustainable yield. The sustainable catch value is derived using a constant price and the logistic surplus growth function and assuming that the catch per unit of effort is proportional to the stock.

The existence of an equilibrium value of S is, however, no guarantee that it will in fact be attained. The trajectory towards the equilibrium may have the form of a spiral, and it may spin away from the equilibrium rather than approach it. This is what happens for equilibria in the lower part of the loop-shaped sustainable yield curves in Fig. 12.2. Furthermore, if there is a critical threshold value below which the stock cannot reproduce, the equilibrium will not even exist for a high enough price of fish or a low enough cost of effort. Consider again equation (12.6a), which determines the equilibrium level of the stock. From this we see clearly that a lower cost or a higher price implies a lower equilibrium value of S. Figure 12.4 shows two equilibrium values of S, one for a low cost (or high price) and one for a high cost (or low price). The figure also shows the direction of movement of effort and stock when out of equilibrium, and the spiral

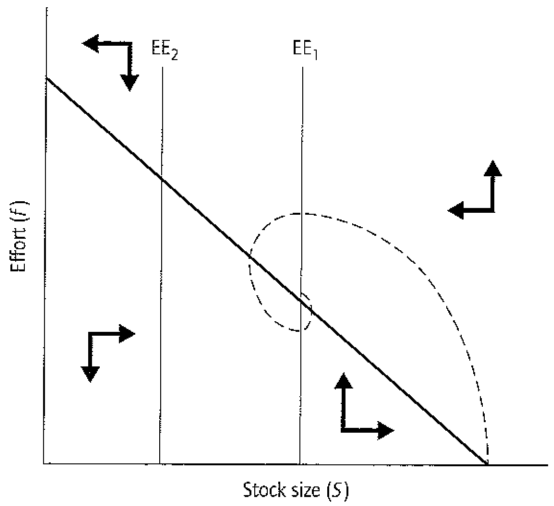

Fig. 12.4 Bioeconomic equilibrium. The downward-sloping line shows all combinations of effort (f) and stock (S) where the yield is sustainable; i.e. where $Y = G$, and $Y = qfS$, and G is given by the logistic equation. The EE-lines show the stock level compatible with economic equilibrium (equation 12.6a), where EE$_1$ implies a low price or a high cost, and EE$_2$ a high price or a low cost. The arrows show movement of variables when out of equilibrium, and the dashed line shows a possible pattern towards equilibrium.

movement towards the equilibrium point (for unstable equilibria we would spiral away). Paths towards equilibrium for real-world fisheries have been analysed by Bjørndal and Conrad (1987) and Conrad (1989).

The risk of extinction as a result of fishing is most dramatic, however, if equation (12.6b) holds. In this case no equilibrium exists except by coincidence; the value of the catch per unit of effort will always be the same, because the density of the fish will always be the same, until the last fish has been taken. This case may come close to describing the situation for the Atlantic herring stocks which nearly collapsed in the late 1960s, due to an increased pressure caused by the introduction of the power block which made it possible to haul purse seines mechanically instead of by hand. This in turn made it possible to use much bigger seines and boats, and led to an enormous increase in fishing capacity over a short time-span. The herring stocks may possibly have been saved by a moratorium that was put in place around 1970. This story alerts us to the fact that nothing except a high cost of catching the last viable animal protects wild animal stocks that are hunted freely from being hunted to extinction, as has in fact happened for certain stocks where the hunting conditions come close to being described by equation (12.6b). A paper by Smith (1975) is a fascinating exposition on why this may explain the extinction of the indigenous American horse (*Equus caballus*) several thousands of years ago. Other examples, such as the Kiwi bird (*Apteryx* spp.) and the American buffalo (*Bison bison*), come to mind. Both these animals were an easy prey to the early settlers in New Zealand and on the North American prairies, respectively.

A special form of open access obtains when the total catch is controlled but everyone is free to participate in the fishery. This typically leads to shorter and shorter fishing seasons, and little or nothing is accomplished from an economic point of view. For a discussion of this, see Homans and Wilen (1997).

12.5 OPTIMAL EXPLOITATION

The stage has now been set for considering economically optimal exploitation of fish stocks. When deriving the optimum sustainable yield of fish stocks it is imperative to keep in mind that fishing is only one of the activities that contribute to our welfare. It need not make sense, for example, to achieve the maximum sustainable yield, as we might be forsaking too much of other goods for that purpose. The fundamental criterion for having achieved optimum sustainable yield is that the last unit of effort expended in the fishery should produce the same value as it would do if used in the best alternative way. If the marginal unit of effort produces a greater value in the fishery than elsewhere, then obviously it makes sense to increase effort in the fishery, and vice versa.

This implies that effort can be used for purposes

other than fishing. In the long term this is certainly true; people employed on fishing boats could be employed somewhere else, and capital to be invested in fishing boats could be invested in something else. In the short term, however, reality may look a bit different. Fishing boats are typically not very useful for other purposes and can only be converted to other uses at some cost, and fishermen may need retraining to be employed in other industries. This implies that the short-term opportunity cost of effort (i.e. the value that the effort could produce in other industries) may be lower than indicated by the wage rate or the capital cost on the firms' books. But in the long run the capital cost and the wage rate are likely to reflect the value that labour and capital are able to produce in their best alternative application, and we shall in our analysis below assume that the cost of effort measures the value that effort could produce elsewhere in the economy.

What, then, is the value that effort produces in the fishery? Below we shall take this as being synonymous with the value of the catch. This presupposes that fish are valuable only in so far as they contribute to our material well-being as a source of food or raw materials and that this is correctly measured by the market price. This is likely to be true or nearly true in a great many cases; fish are sought at considerable inconvenience, and even risk of life and limb, for the purpose of selling them in the marketplace. There are, however, other cases where fishing as such has value, such as in recreational fishing (Cowx, Chapter 17, this volume). Clearly, in such cases it would not be enough to measure the value produced by fishing effort by the value of the fish being caught, and the time spent on this activity would not even be a cost. Lastly fish stocks as such may have value, for reasons of maintaining biodiversity or for viewing as wildlife (Reynolds et al., Chapter 15, this volume).

With these caveats we set out to derive the optimum sustainable yield and the associated fishing effort. In doing so we regard the fishery as being managed by a single owner, a social planner trying to maximize the total value of production derived from all resources at disposal in the economy. The condition for optimality is that the value produced by the last unit of fishing effort applied should be equal to the cost of that unit. In the language of differential calculus this can be expressed as

$$P(dY/df) = C. \qquad (12.7)$$

Figure 12.5 illustrates the solution and compares it with what obtains under open access, for the case described by equation (12.4a) and the logistic surplus growth equation. Clearly it is not worthwhile to take the maximum sustainable yield. Less effort should be used than needed for that purpose, and the fish stock should be kept at a higher level than corresponds to the maximum sustainable yield. Note also that the optimum effort is less and the equilibrium stock greater than what would result under open access. The yield is not necessarily greater, however, than under open access, unless the effort under open access is sufficiently greater than needed to take the maximum sustainable yield. Loop-shaped yield curves, such as shown in Fig. 12.2, would produce revenue functions of a similar shape. This case is not very interesting, however, as equilibria occurring in the lower part of the curve are unstable.

In the case of equation (12.4b) it would always be optimal to take the maximum sustainable yield. This is so because the value of the catch per unit of effort and the cost per unit of effort are both constant in this case; the value of the catch per unit of effort does not decline as the stock is depleted, due to the constant density of the stock.

Note that the optimum sustainable yield was derived by setting the value of the marginal sustainable yield equal to the unit cost of effort. If the unit cost of effort rises with effort, the marginal sustainable revenue should be equal to the marginal cost of effort (i.e. the cost of the last unit). If the unit cost of effort is constant it is equal to the marginal cost. We would have arrived at the same condition if we had maximized the profit in the fishery: i.e. the difference between revenue and cost [$PY(f) - Cf$]. We did not do so, in order to emphasize that maximization of profit is not an obviously legitimate social goal. It would make perfect sense for somebody who owned the resource, but it

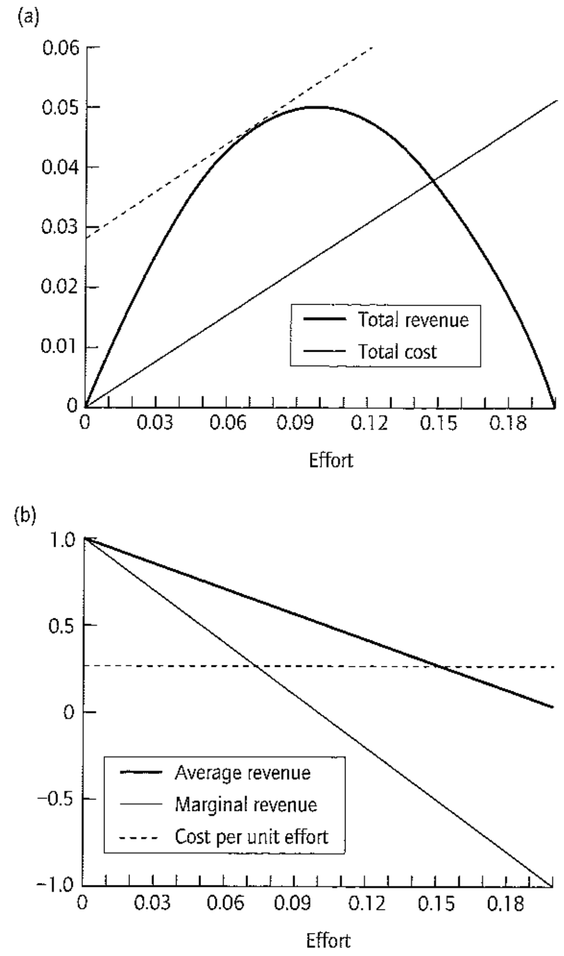

Fig. 12.5 Equilibrium in an open access fishery versus optimum sustainable yield. (a) The curve shows the sustainable revenue (value of the sustainable yield) at a constant price, and the line shows the total cost of effort. Equilibrium with open access occurs where total cost is equal to total revenue, whereas optimum effort occurs where the difference between sustainable revenue and total cost is greatest (i.e., where the dotted line is tangential to the sustainable revenue curve). (b) The downward sloping lines show the sustainable revenue per unit of effort (thin line) and the marginal sustainable revenue ($P(dY/dZ)$, thick line). Equilibrium with open access occurs where the sustainable revenue per unit of effort is equal to the cost per unit of effort (the horizontal dotted line) whereas the optimal effort is where the marginal sustainable revenue is equal to the cost per unit of effort.

would not be a primary goal from a social point of view. What does make sense from a social point of view is to maximize the value produced by the resources at society's disposal. This occurs when the last unit of any productive resource produces the same value irrespective of where it is used. This implies, however, that the profit in the fishery is being maximized. This 'profit' is a bit special, as it is due to the limited productivity of the fish stock and can be seen as a cost of using that productivity. In the economic jargon this goes under the name of resource rent, or fishing rent, due to its analogy with land rent.

Like land rent, the fishery rent is a residual that remains after all factors of production (labour, capital and other inputs) have been paid. The rent reflects the differences in productivity between different 'quality' categories of a resource. Inner city plots yield a higher rent than plots in the suburbs, because of a better location for business. Fertile agricultural land can be rented out or sold at a higher price than poorer land. The profits realized by extracting oil from a well in the sands of Arabia are higher than the profits that can be extracted from underneath the North Sea. And the profit obtainable from fishing cod in the Norwegian Sea is higher than fishing the less coveted saithe in the same area, provided both stocks are properly managed. When fisheries are controlled by some fishing rights scheme, such as individual transferable quotas or transferable boat licences, the resource rent becomes capitalized in the form of a value of a fish quota, or a value of a fishing boat with a licence in excess of what the boat is worth for the purposes of fishing only. If such rights are handed out free of charge they end up as windfall gains for those who got these rights initially and who later sell them in the marketplace. Note, however, that it is possible to reduce or perhaps eliminate these gains by imposing a fee on quotas or licences, or by selling them or renting them out.

Maximization of profit in the fishery would, however, under certain circumstances, lead us astray. Suppose that the price of fish from a particular stock depends on the landings from that stock only because, for example, the fish is sold in a local market and there is no other fish that competes with it. We can write the sustainable profit, alias rent (V), in the fishery as

$$V(f) = P[Y(f)]Y(f) - Cf. \quad (12.8)$$

Maximizing this requires that

$$dV/df = [P + (dP/dY)Y](dY/df) - C = 0. \quad (12.9)$$

This would not be the socially optimal solution. The value produced by the last unit of effort is $P(dY/df)$, as this is what the consumers of fish are willing to pay for the fish caught by the last unit of effort. This should be equal to C, the cost of effort. The term dP/dY is negative, because the price will be lower the more fish is being landed. If the fishery were controlled by a single firm, or an industrial association, it would presumably be aware that it would be eroding its own market by selling more, assuming that all fish must be sold at the same price, and it would take this into account when deciding how much to sell. This would be an example of the exercise of monopoly power, which is not in the social interest. This monopoly power should not be confused with sole ownership of scarce resources like fish stocks; although it makes no sense socially to artificially limit the supply of something just to get a higher price in the market, it makes perfect sense to limit fishing to what the productivity of nature can support, with due account taken of the cost of fishing. This is what sole ownership, or privatized use rights, of scarce resources would attain, in contrast to the overexploitation occurring under open access.

Now that we have relaxed the assumption of a constant price of fish we might as well ask: what would this mean for our previous analysis of open access versus optimum exploitation? The answer is: not a great deal; open access would still result in overexploitation. Similarly, relaxing the assumption that the cost per unit of effort is constant does not cause any fundamental change; what happens is that all the fishing rent would not be absorbed by unnecessary costs; all units, except the last one, would obtain some profit over and above their opportunity cost. In everyday life this would translate into profits being obtained by fishermen who are better skilled than others, or have better equipment than others. Such 'skill rents' or 'equipment rents' are often a conspicuous fact of life in real-world fisheries even under open access. The implications of a volume-dependent price have been analysed by Anderson (1973), and the fishing rents by Copes (1972).

12.6 TIME DISCOUNTING

Up to now we have been concerned with sustainable yield. If we put an equal emphasis on what happens in the short and the long run this is all that matters, but if we value any given benefit we get in the future less than if we get it now, it is not enough just to look at sustainable yields.

The systematic 'devaluation' of effects that occur in the future is called discounting. The implications of time discounting have been analysed by Clark (1973a, 1973b, 1976), Clark et al. (1973), and Clark and Munro (1975). The ethical underpinnings of time discounting are often called into question, as it would seem to amount to a systematic discrimination against future generations. There is, however, another argument in favour of discounting. If it is possible to invest profitably in the economy, we should require that all investment opportunities yield the same return at the margin, or else only invest in such opportunities as yield the highest return. By making profitable investments we do in fact leave a richer world to our descendants. Discounting the future stream of benefits from any investment at the same rate of return as we can get in the best alternative opportunity is a method for ascertaining whether that investment is in fact worth while.

To explain this, suppose we can invest our money in the bank so that it will yield $r \times 100\%$ interest every year. Note that this is not a purely financial phenomenon; the rate of interest in the banks may be expected to reflect rates of return on 'real' investments: that is investment in productive capacity. The reason that the banks can charge a certain rate of interest is that somebody is prepared to borrow the money and pay it back with interest, financed out of profits that he expects to make on the investment.

If we deposit the amount K in the bank we would have $K(1 + r)^T$ at the end of T years. Suppose instead that we invest the amount K at time 0 in a project that will provide an income I net of operating cost every year for T years, after which our investment is worthless. At the end of the T years we would have $I[1 + (1 + r) + \ldots (1 + r)^{T-1}] = I[(1 + r)^T - 1]/r$, assuming that we continuously invest our income from the project in the bank as it accrues. Hence, if the project is worth while, we must have

$$I\left[1-(1+r)^{-T}\right]/r > K. \qquad (12.10)$$

The left-hand side of this is the so-called present value of the income stream I over T years, discounted at the rate r. Hence the criterion for a profitable investment is that the income stream from a project, discounted at a rate of interest equal to the return on the alternative investment, be at least equal to the initial outlay for the project.

The relevance of this is that we can regard any fish that we do not catch immediately as an investment. Why should we leave it in the sea? Because a fish left uncaught contributes to the growth of the stock, through individual growth and through reproduction. If fish did not grow, or did not grow fast enough, it would make no sense to leave them in the sea. Hence, if we exploit a fish stock optimally, the return on a fish we leave in the sea must be equal to the return we can get on catching that fish, selling it in the marketplace and investing the money we get for it at the highest return we can obtain.

What about fish stocks that do not grow fast enough to satisfy the required rate of return? On the basis of the above reasoning such stocks should be fished out and converted to other forms of capital that are more productive. Many people undoubtedly find such a recommendation offensive, but implicit in that attitude is that fish stocks are valuable for other purposes than their surplus production, such as for preserving biodiversity or for tourism.

Consider now a stock that is optimally exploited. For easier exposition we use a continuous time model. The term e^{-rt} is the analogue of the discount factor $(1 + r)^{-t}$ in continuous time. If interest accrues n times per year, one unit of money would grow to $(1 + r/n)^{nt}$ over t years. Then consider the expression $[1 + 1/(n/r)]^{(n/r)rt}$. The expression $[1 + 1/(n/r)]^{(n/r)}$ approaches e as n approaches infinity. Hence the present value of exploiting the stock in perpetuity is

$$PV = \int_0^\infty PG(S)e^{-rt}dt = \frac{PG(S)}{r} \qquad (12.11)$$

where r is the discount rate, which equals the rate of return we can earn on an alternative investment project. The immediate gain of increasing fishing by the amount $-\Delta S$ will be equal to $-P\Delta S$ (note that changing the amount fished will cause an opposite change in the stock size). This will change the present value of all future catches by

$$\Delta PV = [P(dG/dS)/r]\Delta S. \qquad (12.12)$$

If ΔS represents a departure from an optimal stock level, to be maintained in perpetuity, the sum of these two changes must be zero: i.e. the short-term gain must be cancelled by the long-term loss. Hence, $P\Delta S - [P(dG/dS)/r]\Delta S = 0$, or

$$dG/dS = r. \qquad (12.13)$$

The solution is illustrated in Fig. 12.6. We see that the optimum equilibrium stock is in fact smaller than that which corresponds to maximum sustainable yield. In other words, a positive discount rate implies that some biological overexploitation would be optimal. The reason for this is that discounting of the future makes it worth while to incur a permanent loss for the sake of a temporary gain. Even if the absolute value of a permanent loss is infinite, its present value when we discount the future is finite; the positive discount rate turns the infinite series of losses into one that converges to a finite value.

Taking fishing costs into account modifies this conclusion, provided the catch per unit of effort depends on the size of the exploited stock. In

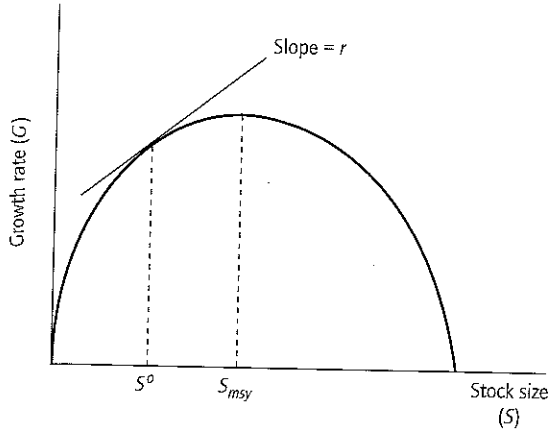

Fig. 12.6 Optimum stock level (S^o) with a positive discount rate when the catch per unit of effort does not depend on the stock level. S_{msy} is the level giving maximum sustainable yield.

that case it is attractive to fish from a large stock rather than a small one, in order to keep down the cost per unit of fish caught. Let the cost per unit of fish caught be denoted by $X(S)$. The immediate gain from increasing the amount fished by $-\Delta S$ is $-(P - X)\Delta S$. The present value of future fishing is now

$$PV = \int_0^\infty [P - X(S)]G(S)e^{-rt}dt = \frac{[P - X(S)]G(S)}{r}. \qquad (12.14)$$

The change in the present value resulting from changing the stock by ΔS is now

$$\Delta PV = \{[(P - X)(dG/dS) - (dX/dS)G]/r\}\Delta S. \qquad (12.15)$$

Letting immediate gains be cancelled by permanent losses now gives

$$r - (dG/dS) + (dX/dS)G/[P - X(S)] = 0. \qquad (12.16)$$

Since $dX/dS < 0$ (fishing from a larger stock reduces the cost per unit of fish landed), it is possible that $dG/dS < 0$ in the optimal solution. This would certainly be true in the absence of discounting ($r = 0$). Thus biological overfishing need not be optimal, even if the future is discounted. But discounting of the future reduces the optimal standing stock; the higher the discount rate (r) is, the greater is dG/dS, and the smaller is the optimal standing stock (see Fig. 12.6).

The implications of discounting could be dramatic. If max $dG/dS < r$ and the unit cost of landed fish is not stock-dependent (X is constant), the implication is that the stock should be fished to extinction; investing in the stock simply would not yield a high enough rate of return to be worth while. The implication is that such stocks should be 'mined', like minerals or oil deposits, which after all are resources with too low a rate of growth (zero or, for oil, negligible) to make exploitation based on surplus growth interesting. There are a number of slow-growing fish and whale stocks that might be in this category. Orange roughy (*Hoplostethus atlanticus*) is a slow-growing fish which matures when it is 30 years old and lives to be 60 to a 100 years old if left unfished. Yields were high in this fishery when it started and the stocks were mined, but the sustainable yields have turned out to be much lower (see, for example, Batstone and Sharp 1999). Given that the stocks of such species are sufficiently valuable as such it would not, of course, be optimal to mine them to extinction, but the point is that if the exploitation of such stocks were a matter to be decided by the industry in its own interest, or by a sole owner, the investment aspect would be likely to prevail. The industry or a sole owner would not attach much value to the stocks as such; these values stem from ethical considerations like preserving species for their own sake, which are not likely to loom large in the profit and loss accounts of private individuals or firms.

Above we have looked at optimal equilibria. Another question is what the adjustment path towards the equilibrium will be like if, say, the fishery starts from a situation with overexploitation. The optimal approach path can be shown to depend on the discount rate and to what extent capital, measured in terms of production equipment, is 'malleable'. The reader is referred to a classic paper by Clark et al. (1979).

12.7 FLUCTUATIONS: SHOULD CATCHES BE STABILIZED?

It was mentioned above that the growth of fish stocks is influenced by fluctuations in the marine environment (Myers, Chapter 6, Volume 1). These fluctuations give rise to variations in the size of fish stocks, even if they are exploited at a rate consistent with long-term sustainability. The fluctuations in stock abundance in turn give rise to fluctuations in catches. Such fluctuations are usually considered an inconvenience by the industry, as fish buyers usually prefer even and secure deliveries. A review of stochastic models in fisheries is provided by Andersen and Sutinen (1984).

One way of responding to the problems caused by fluctuations is to stabilize the catch (Hannesson and Steinshamn 1991). Would this be desirable, from an economic point of view? Consider, first, the revenues from fishing. These are

$$R(Y) = P(Y)Y. \quad (12.17)$$

Now suppose that the fishery is managed by a TAC (total allowable catch) regime where the TAC is set equal to some fraction of the stock available in each period. Suppose, further, that the stock is subject to random fluctuations. Then the TAC will fluctuate as a consequence.

Would a stable catch equal to the expected catch (EY) with a fluctuating TAC provide a larger revenue? It would, if

$$R(\mathrm{E}Y) > \mathrm{E}R(Y) \quad (12.18)$$

where ER is the expected revenue under the fluctuating TACs. This holds if the revenue function is concave, with $dR/dY > 0$, at least for 'low' values of Y, and $d^2R/dY^2 < 0$. This is quite possible. From equation (12.17):

$$dR/dY = P + (dP/dY)Y, \quad (12.19)$$

$$d^2R/dY^2 = 2(dP/dY) + (d^2P/dY^2)Y. \quad (12.20)$$

Because larger landings normally imply a lower price, $dP/dY < 0$. We are not assured that $d^2R/dY^2 < 0$ but it is quite likely.

As an example, consider the demand function

$$P = AY^{-b}. \quad (12.21)$$

The revenue function is

$$R = AY^{1-b}, \quad (12.22)$$

and its derivatives are

$$dR/dY = (1-b)AY^{-b}, \quad (12.23)$$

$$d^2R/dY^2 = -b(1-b)AY^{-b-1}. \quad (12.24)$$

If $0 < b < 1$, $dR/dY > 0$ and $d^2R/dY^2 < 0$ and we have a concave revenue function. The opposite is true if $b > 1$; then we have a convex revenue function, ER > R(EY), and fluctuating catches would in fact yield a higher revenue on the average than a stable catch would do. In this latter case the price is highly sensitive to the quantity being sold, and the revenue becomes greater as the quantity becomes smaller, because the price 'goes through the roof'. This case is known as inelastic demand (the elasticity of demand, $-d\log Y/d\log P$, is equal to $1/b$).

It may be noted that stabilizing the catch would imply stabilizing the effort as well if the density of fish is always constant (equation 12.4b). With a constant unit cost of effort the cost would simply be proportional to the catch and irrelevant for whether or not the catch should be stabilized.

Things turn out differently if the cost of landed fish depends on the size of the exploited stock. Let us proceed on the basis of equation (12.4a), where the catch per unit of effort is proportional to the size of the stock. We normalize effort such that $Y = fS$. Setting the TAC equal to a certain fraction of the stock amounts to fixing the effort at the level f^* which, because of the normalization, is equal to the desired fraction to be caught from the stock. Under this catch policy the total cost of fishing will in fact be constant and equal to Cf^*. If, on the

other hand, the catch is held stable at a level equal to the expected catch under the said TAC policy ($Y^* = \mathrm{E}Y$), we would have to vary effort according to equation (12.4a):

$$f = Y^*/S. \quad (12.25)$$

The expected effort would be

$$\mathrm{E}f = Y^*\mathrm{E}(1/S). \quad (12.26)$$

Using $Y^* = f^*\mathrm{E}S$, we can write this as

$$\mathrm{E}f = f^*\mathrm{E}S\mathrm{E}(1/S). \quad (12.27)$$

Since $1/S$ is a convex function of S, $\mathrm{E}(1/S) > 1/\mathrm{E}S$, so that $\mathrm{E}S\mathrm{E}(1/S) > 1$. Hence, $\mathrm{E}f > f^*$, which means that stabilizing the catch will be more costly than letting it vary with the stock. What the stabilization policy amounts to is telling the industry to fish with great intensity when the stock is small and the catch per unit of effort is low but to hold back when the stock is plentiful and the catch per unit of effort is high. Hence, even if a stable catch were attractive for marketing and for the processing industry, it would be less attractive, and perhaps decidedly unattractive, for the catching industry, if the catch per unit of effort depends on the abundance of the stock. Hence there is no clear economic argument for stabilizing catches; on the revenue side there are likely to be arguments pulling in that direction but on the cost side the argument is likely to point the other way.

Note, finally, that stabilizing the catch is likely to be a risky option. It amounts to fishing intensively when the stock is low and less intensively when it is plentiful. This may jeopardize the growth of the stock, particularly if there is a threshold level of viability or if low stock levels are somehow inimical to growth as occurs when there is depensation. Some stocks fluctuate so wildly that the TAC is set equal to zero in some years; capelin (*Mallotus villosus*) is an example. Stabilizing the catch at a biologically safe level might in a case like that imply the ridiculously low level of zero. Given that stabilizing the catch is risky or impossible, and in any case not a clearly superior option economically, we turn to the case of fluctuating catches.

12.8 OPTIMUM FLEET CAPACITY FOR FLUCTUATING STOCKS

If fish stocks fluctuate in part for random reasons and the management regime sets a TAC that is somehow related to stock abundance, such as a given fraction of the stock or everything in excess of some target escapement, the optimum fleet capacity will not depend solely on the deterministic stock–growth relationship element that influences the development of the stock; the nature of the random fluctuations will also be a determinant of optimum capacity. In this case optimal management involves determining the capacity of the fishing fleet and its use at any particular time. In 'bad' years the capacity of even an optimal fleet will be too great and its activities must be somehow restricted. These decisions are interrelated: that is, the use of an existing fleet, or the optimum TAC in any particular year, depends on the optimal size of the fleet, provided the stock size is not entirely random but depends as well on a deterministic stock–growth relationship. This latter issue is discussed in Hannesson (1993) but here we shall, for simplicity, ignore the deterministic stock–growth relationship and assume that the growth of the stock is entirely random.

Another simplification we shall make is that the catch per unit of effort is constant and that effort is simply proportional to the number of identical vessels in the fleet. The value of the catch each year will then be

$$R = \min(PQ, PaK) \quad (12.28)$$

where Q is the total allowable catch, K is the size of the fishing fleet, measured as capital investment, and a is the amount one unit of money invested in the fleet can catch if the fleet is used to its full capacity. Here P is the price net of operating costs, which would include fuel, ice, fishing gear, and other expendable equipment.

As explained above, we can find the optimal policy by maximizing the present value of the rent in the fishery. We make the further simplification that we start without any fleet and that the boats we build have no alternative use. The best policy will then be to invest in an optimal fleet at time zero and maintain it forever by setting aside the fraction δK of revenues to cover depreciation of the fleet ($\delta = 1/T$, T being the lifetime of a fishing vessel). The present value of rents is then

$$V = -K + \sum_{t=1}^{\infty} \frac{ER_t - \delta K}{(1+r)^t}. \qquad (12.29)$$

If the probability distribution of the stock (and the TAC) is time-invariant, ER will be the same year after year. Then the sum in the above expression will be a convergent geometric series and we get

$$V = -K + (ER - \delta K)/r. \qquad (12.30)$$

We get a more intuitive interpretation of this if we multiply on both sides by r (the maximum of V will occur for the same value of K if we multiply V by a scalar). Then we get

$$V^* = ER - (r + \delta)K. \qquad (12.31)$$

What we are in fact maximizing is the rent per year, calculated as the revenue net of operating cost less capital cost. The capital cost consists of two elements, the depreciation of capital, δ, and the opportunity cost, r, of tying up capital in a fishing fleet rather than investing in something else giving the return r. The condition for maximum rent is

$$E(dR/dK) = r + \delta. \qquad (12.32)$$

What, then, is $E(dR/dK)$? From equation (12.28) we see that $dR/dK > 0$ only when $aK < Q$, i.e. when the total allowable catch is greater than the capacity of the fleet; only then will another vessel make any contribution to the total catch. Define $F(Q)$ as the probability that the total allowable catch is less than or equal to Q. Then we have

$$[1 - F(aK)] = (r + \delta)/Pa. \qquad (12.33)$$

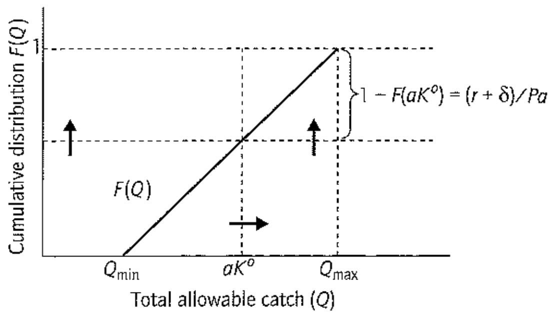

Fig. 12.7 Optimal fleet capacity (K^0) for a total allowable catch (Q) that fluctuates randomly between Q_{min} and Q_{max}. $F(Q)$ is the cumulative distribution function. The linear form of F implies that the probability density is constant. The arrows show the effect of a higher price, lower capital costs, or technological progress (higher a).

Figure 12.7 shows the optimal solution, with arrows indicating how a lower capital cost ($r + \delta$), a higher price net of operating cost (P), or technological progress (greater a) affects the solution. We see that a lower capital cost, a higher price net of operating cost, or technological progress all increase the optimum fleet capacity, as indeed we would expect. We also see that only exceptionally would it be economically sensible to invest in a fleet that is large enough to take the maximum TAC (the Q-value for which $F(Q) = 1$). This would involve investment in boats that most of the time are not needed, contributing to cost all the time but to revenue only infrequently. Only if the cost of capital is exceptionally low would it make sense to have a fleet that could take even the largest TAC.

Note also how a change in the probability distribution affects the optimal fleet capacity. Suppose it is realized that the minimum total allowable catch could be much lower than Q_{min} in Fig. 12.7 but that the probability density of Q remains uniform between Q_{max} and the new Q_{min}. This would rotate the line in Fig. 12.7 clockwise (it is fixed at the point 1, Q_{max}) and thus reduce the optimum fleet capacity.

In this section we have regarded the fleet as being managed by a single owner (the social planner again). Although this approach is useful to derive optimality conditions, from the point of view of the whole economy, this is not how the real-world fishing fleets are run. A pertinent question is: will individual decision makers achieve the optimality? Under open access they certainly will not, but in a market-driven management regime such as individual transferable quotas (ITQs), to be discussed below, they might. There is a presumption, however, that they will in fact overinvest when the crew is remunerated by a share in the catch, but ITQs are likely nevertheless to lead to much less overinvestment than open access. For details of this analysis, see Hannesson (2000).

12.9 MANAGEMENT METHODS

Based on the deterministic, surplus production model it has been concluded that all we need to do to manage fisheries for maximum economic benefit is to tax fishing effort or the landings of fish sufficiently to eliminate all incentives for economic overfishing. The argument is perfectly valid within the framework of the said model, provided that the catch per unit of effort increases with the stock level. For fluctuating stocks there is a case for control by landing fees, provided there is no economic uncertainty and the catch per unit of effort depends on the stock size in a stable and predictable way. Landing fees versus output controls (fish quotas) have been discussed by Weitzman (2002).

We look, first, at the deterministic biomass-growth model. Consider sustainable yield and the production relationship in equation (12.4a), which gives rise to Fig. 12.5. As explained above, the open-access equilibrium occurs where the average sustainable revenue is equal to the cost per unit of effort, while optimal exploitation requires that the cost per unit of effort be equal to the marginal sustainable revenue. We may in fact achieve the optimum solution by moving the line showing cost per unit of effort upwards until it intersects the marginal sustainable revenue line above the optimum level of effort, or by rotating the average sustainable revenue line downwards until it intersects the cost per unit of effort line above the optimum level of effort. These movements would be accomplished by putting a tax equal to t_f on effort, or t_y on the landings of fish, such that

$$P(1 - t_y)Y(f^o)/f^o = P(dY/df)|_{f^o} \qquad (12.34)$$

or

$$C(1 + t_f) = P(dY/df)|_{f^o} \qquad (12.35)$$

where f^o is the optimal level of effort. Either tax would confiscate all rents in the fishery and deter the fishing firms from investing in a bigger fishing fleet than needed to take the optimum sustainable yield.

This solution is neat in theory, but even within the confines of the deterministic model it is not as straightforward to apply as it may seem. Fishing effort is produced by a number of different inputs: manpower, capital, fuel etc. All of these would have to be taxed proportionately in order not to disturb the cost-minimizing combination of inputs. Taxing landings would appear more straightforward, but the optimal tax is determined by the growth characteristics of each stock, so that if many stocks are being fished by the same fleet, the landings from each stock would have to be taxed at a different rate. Finally, there is the case where the density of fish is always constant (equation 12.4b). Here the value of the catch per unit of effort is constant. An optimal tax on landings or on effort would equalize the revenue per unit of effort and the cost per unit of effort for all levels of effort but would fail to identify any particular level of effort.

But the most difficult problems occur when we enter the world of fluctuating stocks and TACs. Note that these fluctuations typically occur on a much shorter time-scale than the lifetime of fishing vessels. We need, therefore, to contract and expand fishing effort over the lifetime of a single boat, perhaps over several cycles. This is not easily accomplished by changing tax rates. Such changes more often than not are time-consuming, unless the management authorities get a mandate to do so swiftly and substantially as the circumstances might require. But even if that mandate existed, the management authority would not know precisely how the industry would react to a change in the tax. It might even react in a direction opposite to what the authority would expect and opposite to what would happen in the long run. A fisherman who has to care for a mortgage or two, a wife, a child, a dog and a car might, in the face of a reduced income due to a higher tax, decide to increase his effort in order to make ends meet in the short run, even if in the long run he could not renew his boat if the high tax were to prevail. Trial and error would presumably teach the authorities how fishermen respond to the tax changes, but that learning process might need a longer time-scale than tolerable to cope with short-term fluctuations in fish stocks.

It is difficult, therefore, to see how one can do without some direct control of the fishing activity, in order to cope with random fluctuations in catches. Two major modes of control are available, a control of fleet capacity and fishing effort, and a control of the catch through catch quotas.

Effort controls

Effort controls only indirectly achieve the short-term objective of keeping the catch of fish within some set limit. These types of control may be very imprecise in this regard; the relationship between effort and catch is seldom precisely known and is likely to depend on the size of the stock and climatic and oceanographic conditions. Fishermen may get around effort controls if all elements of effort are not included: a limited number of fishing days may be made ineffective by using more gear, for example. The only advantage effort controls would seem to have compared to a direct control of the catch is that they may be much easier to monitor; fishing boats can be seen and counted, their trips and even type of activity can be monitored, nowadays by satellite tracking, and the gear and other equipment they use can be inspected. Controlling landings is, on the other hand, often costly or nearly impossible, to say nothing of the throwing away at sea of undersized fish or fish that are not covered by a quota.

Boat licences are related to effort controls. This method can be used for controlling the capacity of the fishing fleet, but it has several limitations. Fishing capacity is a multidimensional variable, and it is difficult to control all of the variables optimally. In order to be effective a boat licence has to specify the size and design of a boat in some detail. Naval architects have been notoriously inventive in circumventing such regulations, packing an impressive amount of fishing capacity into a hull that meets length or tonnage requirements. In some cases such designs have been alleged to reduce the seaworthiness of fishing vessels. Fishing licences therefore are an imprecise method of controlling fleet capacity and one that causes unnecessary costs. Individual transferable catch quotas (ITQs) would appear to do so much more effectively by affecting the incentives to invest, provided they can be effectively implemented.

Individual transferable quotas

Catch quotas have frequently been used for keeping the total catch from a stock within desired limits. As soon as fisheries started to be controlled by TACs it became evident that this caused new problems in fisheries where the capacity of the fishing fleet exceeded that which was necessary to take the permitted catch. Often a fierce competition developed for getting the largest possible share of the TAC. In many cases management responded by dividing the TAC among the boats in the fishery.

From this, ITQs evolved. When the TAC was much less than the catch capacity of the boats, it was clear that cost savings could be achieved by allowing people to trade quotas among themselves rather than having each and every one go out and fish his perhaps very small quota. In that way the owners of active boats could make ends meet, and those who were eligible to participate in the fishery but chose not to got a share of the pie by renting out their quota. Making the quota allocation valid for a long time eliminates the incentives to invest purely for the purpose of getting a share of the rents in the fishery, an activity which in the end is self-defeating; in the long run the rents get absorbed by unnecessary costs, as has already been explained. With a quota allocation that is secure for a period at least as long as the lifetime of a fishing boat the quota holder can predict his future catches, using the best available biological evidence. He would have no incentive to invest in a fishing boat which is larger or better equipped than needed to take the expected future catches, and if a bigger boat is more cost effective he would be able to acquire an additional quota allocation by buying it from somebody else.

ITQs can be determined either as fixed tonnages or shares of the TAC. Using fixed tonnages for stocks where the TAC varies from year to year makes it necessary for the fisheries manager to buy and sell quotas, depending on whether the TAC is above or below the total amount of quotas allocated. If the quota tonnage is set low enough the manager would be selling quota more often than buying and would be making money on these transactions (Hannesson 1989). This would amount to a special tax on the fishing industry. Tonnage quotas transfer the risk associated with fluctuating stocks from the industry to the fisheries manager, usually the government. That risk can indeed be greater than the government is prepared to bear. Fixed tonnage quotas were initially tried in New Zealand, but when it became clear that the yield potential of the orange roughy stocks had been overestimated the government backtracked and redefined the quotas as shares of the TAC (Batstone and Sharp 1999). This is the system in use in most of the ITQ systems in the world today. With share quotas the industry has to bear the risk associated with fluctuating TACs, but quota holders can still make rational predictions of the catches they may expect to get on the basis of their quota, using the best evidence available about fluctuations in the stocks they fish and the criteria on the basis of which the TAC is set. Hence boat owners do not have any obvious incentives to overinvest under a share quota system. The so-called share system, by which labour employed on fishing boats is remunerated with a share in the catch value and not through a fixed wage rate, may, however, to some extent distort the system of incentives and entice boat owners to invest more than is desirable from an overall perspective (Hannesson 2000).

There is a large and still increasing literature on ITQs. The idea may be traced back to Christy (1973, 1975). Arnason (1995) and Batstone and Sharp (1999) contain descriptions of ITQs in Iceland and New Zealand. Boyce (1992, 1996) considers bycatch and other problems under ITQs. A much-quoted critique is Copes (1986). Among other contributions are Grafton (1996), Hannesson (1996, 1997a) and Weninger (1998).

12.10 INTERNATIONAL ISSUES

Management by TACs or other methods affecting catches and fish stocks is meaningful only if the country in question can exercise effective control over the stocks. The establishment of the Exclusive Economic Zone (EEZ) in the 1970s was critical in this respect (for an authoritative text, see United Nations 1983; and Christy and Scott 1965, for a discussion preceding the revolution in the law of the sea in the 1970s). In some cases fish stocks became enclosed by the EEZ of a single sovereign state, while in other cases stocks migrate between the zones of two or more sovereign states, so no single state can exercise effective control over them. Nevertheless, in many cases the states concerned have agreed on effective controls over shared stocks, such as setting an overall TAC and dividing it among themselves. Having accomplished this, each country can apply measures such as ITQs to its own share of the TAC, for the purpose of maximizing its economic benefit from its share of the fishery. Norway has, for example, concluded such agreements with the Soviet Union, subsequently taken over by Russia, and the European Union. The member countries of the European Union have agreed among themselves on the division of the North Sea stocks, but fisheries policy is one of the common policies of the Union.

Still there are many stocks that spend a part of their life history outside any EEZ, and some stocks are mainly or even wholly confined to the high seas. Management of such stocks, and of shared stocks, must be by voluntary consent by the parties concerned, as these are sovereign states. It is particularly difficult to achieve such agreements for stocks on the high seas, not least because the number of interested parties is indeterminate.

Game theory seems an appropriate tool for analysing the question of whether nations will come to agreement on fisheries issues. There already exists a voluminous body of literature on this which it is impossible to review here. Important references are Munro (1979), Levhari and Mirman (1980), Vislie (1987), Kaitala and Munro (1997), and Hannesson (1997b). Here a simple model which at least gives a flavour of the issues will be presented.

Suppose a stock can be fished either at an immature or a mature stage. There is no stock–growth relationship to be taken into account; each period a stock S emerges and can be fully depleted without jeopardizing future recruitment, but if the exploitation is delayed by one period, the stock will grow to $S(1+g)$, where g is the rate of growth. Suppose N identical countries have access to the stock. If they all wait for one period and allow the stock to grow, each would get $S(1+g)/(1+r)N$. The discount rate appears because such waiting is an investment, as already explained. If they fish the stock immediately, each would get S/N, but if all except one decide to wait they would wait in vain; the one who does not play along could take it all.

This gives rise to the following payoff matrix, which shows the return to one player. The lines show the strategy of the player in question, while the columns show the strategy of the other players, all assumed to adopt the same strategy.

	Wait	*Don't wait*
Wait	S/N	0
Don't wait	S	$S(1+g)/(1+r)N$

Provided $g > r$, it would be better for all to wait. The so-called Nash equilibrium in this game does not result in that solution, however. A Nash equilibrium is a situation in which no player can gain by changing his strategy, given the strategy of the other players. If the N-1 players wait, the best the remaining player can do is not to wait, as $S > S/N$. And if the N-1 players do not wait, the best the remaining player can do is to do likewise, because otherwise he would get nothing.

This certainly makes for a pessimistic outlook with respect to the possibility of achieving a mutually advantageous solution. The situation is not, however, well represented by this framework. Fishing is not a one-shot game; fish stocks are renewable, and fishing is an activity that is repeated year after year. What if we look at a strategy which, loosely speaking, means that 'I'll be nice to you as long as you'll be nice to me, but if you're nasty to me I'll be nasty to you for ever after.' In this setting this would mean that a representative player would wait as long as all the rest do likewise, but if one player does not wait for the fish to grow, the others will do the same forever. The present value of the strategy of playing cooperatively forever is

$$PV_c = S(1+g)/(1+r)N + S(1+g)/(1+r)^2N + \ldots = S(1+g)/rN, \quad (12.36)$$

while the present value of not playing cooperatively is

$$PV_n = S + S/(1+r)N + S/(1+r)^2N + \ldots = S + S/rN. \quad (12.38)$$

Cooperation is profitable if $PV_c > PV_n$, which implies

$$g/N > r, \quad (12.39)$$

which can be interpreted as saying that each player's share in the rate of growth of the stock has to be greater than the rate of interest. Clearly, for reasonable rates of growth and discount rates, the number of participants does not have to be very high to make voluntary agreements unlikely. If the cost per unit of fish landed depends on the stock the likelihood of agreement increases, but decreases again if the costs differ among participants (Hannesson 1995). This game can also be seen as yet another example of how discounting the future makes it worth while to trade off permanent losses

against a short-term gain; if r is zero equation (12.39) will always be satisfied, as long as N is finite.

The most recent attempt to come to grips with uncontrolled fishing on the high seas is the UN Agreement on Straddling Stocks and Highly Migratory Stocks, concluded in 1995. One source for the text of this agreement is FAO (1995), and a review of the status of this agreement is provided by Munro (2000). According to this agreement, the authority to manage such stocks rests with regional management organizations. Any country with a 'real interest' (not further defined) has a right to become a member of such an organization, and all countries, even those who are not members, are obliged to abide by the decisions of such organizations. The above analysis indicates that these organizations will not be likely to succeed unless they manage to limit the number of interested parties and the quantity they are allowed to fish. The latter is not possible unless there is an effective system in place to punish violators. At the present time this is up to the state whose flag the offending vessel is flying, with some rights of other interested states to inspect suspected offenders and to take action if the flag state does not do so.

12.11 CONCLUSIONS

It is impossible, within the limited space at our disposal, to cover all issues that arise in fisheries economics. The most important ones have, I hope, been covered but some still remain. Of those remaining the most important ones are management and enforcement costs (see Schrank et al. 2002; Sutinen and Andersen 1985), the recreational use of fisheries (see McConnell and Sutinen 1979; Anderson 1993), and marine protected areas (see Lauck et al. 1998; Hannesson 1998; Sanchirico and Wilen 1999). The last topic has aroused quite a bit of interest over the last few years, but this approach is unlikely to provide a panacea for all fisheries management problems and is certainly no substitute for ITQs or other methods that would get us close to optimal management. On these subjects we refer the interested reader to the bibliographic entries just cited and the further leads that one would find in these references.

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