TECHNIQUES OF RESOURCE MANAGEMENT

"The basic problem of fisheries management is to select the particular control measures which best achieve the objectives of management."

– L. Anderson, 1983

1.0 INTRODUCTION

Choices among regulatory measures in fisheries depend on the management objective. Just as there are multiple objectives for fisheries management, a wide variety of regulatory approaches have been applied in fisheries around the world. These have differed widely in effectiveness. Some techniques attempt to maintain productivity of the resource. Others attempt to resolve conflict among industry groups. Still others are intended to promote efficient use of the resource.

There are a variety of ways to classify these regulatory techniques. Crutchfield (1961) identified two categories: (1) regulations affecting fishing mortality, and (2) those affecting the size and age at which fish are taken. Templeman and Gulland (1965) distinguished between regulations which (1) affect the sizes of fish caught, or (2) affect the total fishing effort. Gulland and Robinson (1973) used a somewhat similar classification based on (1) control of the size caught, (2) control of the amount of fishing, and (3) controlling excess capacity. Their last category exemplified the drive for economic efficiency in the fisheries. Parsons (1980) distinguished two categories of regulation: (1) those controlling the catch composition, and (2) those controlling the total amount of fishing. Pearse (1979a) used a similar system: (1) regulating the composition of the catch, (2) regulating the size of the catch, i.e. the amount of fishing, and (3) promoting efficiency in the fishing process. His third category also recognized the increasing emphasis on economic efficiency.

Clark (1980) summarized these attempts to classify fisheries regulations:

> "Techniques of fishery management can be classified broadly into two types, according to whether they are mainly directed towards the control of the fish population so as to maintain a high level of productivity, or whether they also attempt to maintain economic efficiency of the fishing industry. The methods that have traditionally been used such as total catch quotas, closed seasons and areas, gear restrictions, and so on belong largely to the former category whereas methods such as licences, taxes or royalties and allocated quota systems are of the second type. In practice it may be appropriate to employ a combination of methods of both kinds."

Regulations of the first category are *open-access techniques* and those of the second category *limited-access techniques* (Anderson 1986). This chapter focuses on the *open-access techniques* aimed at control of the fish population to maintain a high level of resource productivity. *Limited-access techniques* are dealt with in Chapters 7, 8 and 9. The distinction between these categories is not clear cut. Any particular regulatory technique can have multiple effects and impact on more than one objective of fisheries management.

This chapter deals with regulations which control the catch composition and the amount of fishing, as well as some auxiliary methods which do not fit either category. These measures include:

— Mesh Size and other Gear Restrictions
— Size Limits
— Closed Seasons
— Closed Areas
— Catch Quotas
— Fishing Effort Controls.

All of these methods have been used extensively in the management of Canadian marine fisheries. The indirect or passive means of controlling fishing such as gear restrictions, size limits, closed seasons, and areas, have been used in managing the Atlantic lobster fishery for approximately a century. The more direct means of controlling fishing mortality such as catch quotas and fishing effort controls are of more recent vintage. In the Canadian context catch quotas were first applied in the Pacific halibut fishery by the International Pacific Halibut Commission in the 1930's and by Canadian management authorities in the Pacific herring fishery from the late 1930's onwards. Catch quotas, more commonly known as *Total Allowable Catches* (TACs), were first widely applied to the groundfish fisheries of the Canadian Atlantic in the early 1970's. TACs were used subsequently as a primary management tool for virtually all finfish species of the Atlantic coast. Fishing effort controls, through limitation of entry, were introduced in the Pacific salmon and Atlantic lobster fisheries in the late 1960's. They were extended subsequently to all major Canadian commercial marine fisheries in the 1970's. This chapter compares the passive and active methods of regulating fishing mortality and provides examples of their application in Canadian fisheries. The particular regulatory techniques applied in five Canadian fisheries — Pacific halibut, Pacific herring, Pacific salmon, Atlantic lobsters and Atlantic groundfish — are examined in greater detail in Chapter 6.

2.0 CONTROLLING THE COMPOSITION OF THE CATCH

2.1 Mesh Size Regulations

The usual intent of mesh size and minimum fish size regulations is to control the capture of small fish to avoid *growth overfishing*. Control of mesh size has been the most widely used technique to protect small fish, particularly in the international trawl fisheries of the North Atlantic. Other measures available include minimum fish size limits and closed areas or seasons. The latter two approaches may be used if the sizes of fish caught differ significantly between areas or seasons.

Mesh size regulations are intended to control size at first capture. The theoretical models assume knife-edge selection with all fish below a certain size escaping to grow to a larger size, while those above this size are liable to be caught at the full rate of exploitation. The length selection curves from experimental studies show a more gradual relationship between the percentage of fish retained at a particular length in relation to various mesh sizes (see Fig. 5-1 and 5-2).

Selection experiments to determine the effect of mesh size on the size of fish caught and released were begun in the Northeast Atlantic in the late 1800's. Extensive mesh selection experiments were conducted in the Canadian Atlantic in the 1950's and 1960's. These became the basis for the first 15 years of management of the groundfish fishery by the International Commission for the Northwest Atlantic (ICNAF). Mesh selection measures were intended to select a mean age (size) at first capture which maximized yield-per-recruit for a given species. The appropriate mesh size depends on the natural mortality and growth rate of that species, based on the yield-per-recruit theory of Beverton and Holt described in Chapter 3. During its early years ICNAF was preoccupied with reducing the wastage of small fish at sea. The first regulations restricting the size of mesh used in the codend of the otter trawl were introduced by ICNAF in 1953. In its first 15 years, ICNAF established some 20 regulations, all of which focused on minimum mesh sizes and trawl construction methods.

Mesh size regulations are based upon calculations of the 'mean selection length,' the size at which half the fish are retained and half are released (Fig. 5-3). This increases with mesh size and differs among different types of fishing gear, e.g. otter trawl and cod trap. In a mixed species fishery such as that for groundfish, each species tends to have a different mesh selection curve.

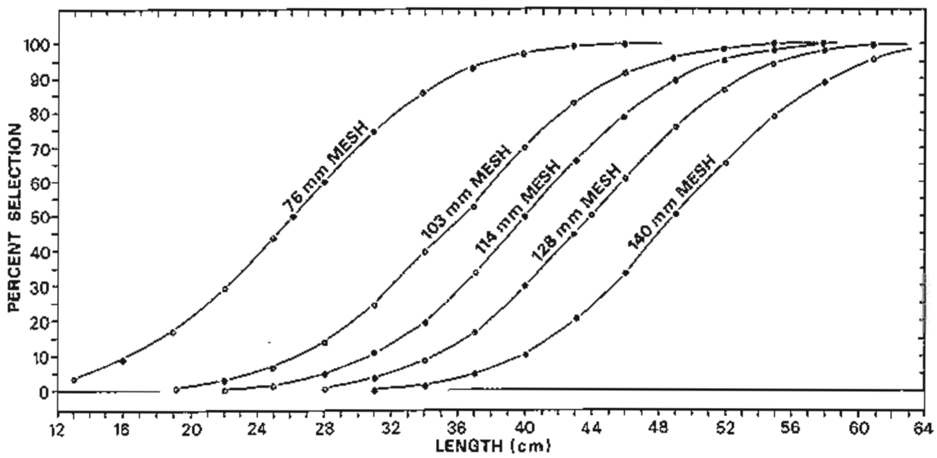

FIG. 5-1. The relationship between percentage of fish retained at a particular length in relation to various mesh sizes for cod in Subarea 3 of the Northwest Atlantic Fisheries Organization (NAFO) (from Hodder and May 1964).

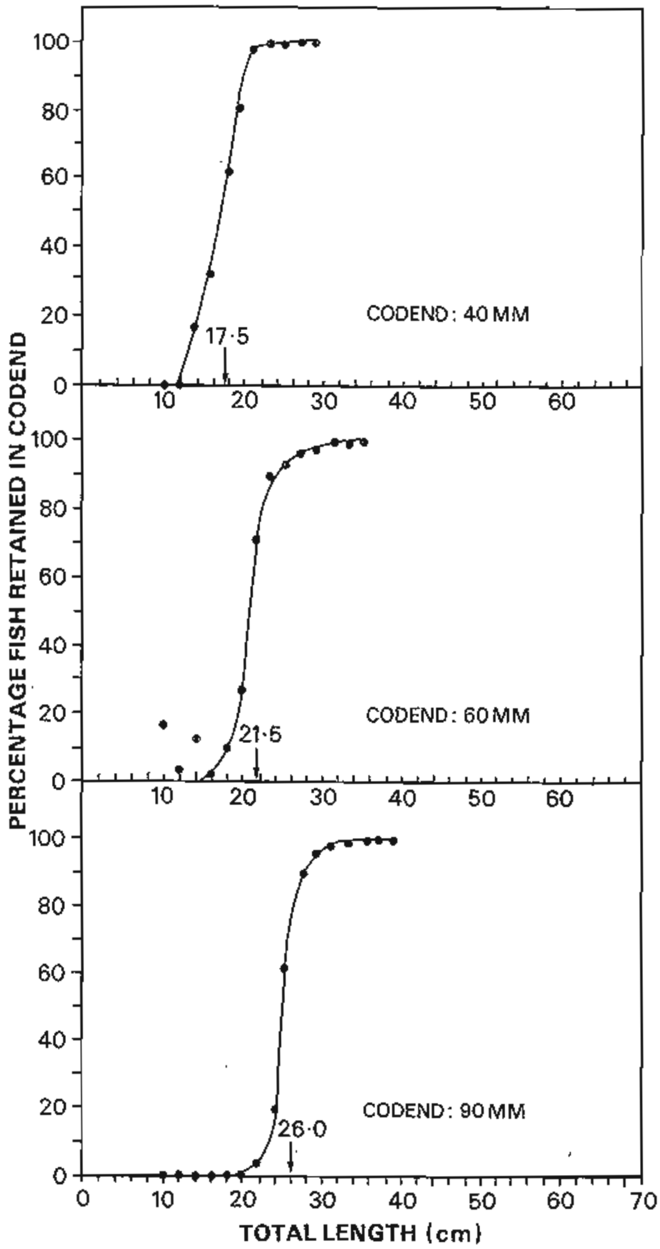

FIG. 5-2. The relationship between percentage of fish retained at a particular length in relation to various mesh sizes for silver hake on the Scotian Shelf (from Clay 1979).

Therefore, different mesh sizes were initially adopted for species such as cod, redfish, and American plaice. ICNAF introduced mesh size regulations when the level of fishing effort was moderate. As fishing effort increased in the 1950's and 1960's it became necessary to progressively increase the minimum mesh size. Following the introduction of the 200-mile limit, Canada implemented a uniform 130 mm mesh size for otter trawls on the Atlantic coast. This excluded smaller species such as redfish and silver hake. It was intended to help enforce the minimum mesh size. However, this resulted in an increase in the average mesh size actually used by approximately 10 %.

Any increase in mesh size has both short- and long-term effects. There are short-term reductions in catch because most of the smallest fish are released. In theory the fish that escape will grow larger and hence produce a greater yield when captured later. Other potential benefits include increases in stock size and future catch rates.

One problem with mesh size regulations is that catch rates will fall in the short-term. Hence, fishermen make short-term sacrifices for long-term gain. Another problem is that, although potential benefits can be calculated, it is difficult to demonstrate such benefits in practice. Changes in stock size or increased yields to fishermen may be masked by natural fluctuations in recruitment.

Mesh regulations have been widely used in Canadian fisheries and around the world. With the rapid growth of certain fisheries, changes in fishing techniques, and the development of "mixed" fisheries, particularly during the 1960's, minimum mesh size by itself was insufficient to regulate the fishery. Mesh regulation suffers from two major weaknesses when used as the primary management measure for otter trawl fisheries:

> First, most trawl fisheries take a mixture of species, with the optimum mesh size for different species often being very different.
>
> Secondly, while mesh regulation can in theory increase the total catch to some extent, the economic benefit will be short-lived unless the amount of fishing is controlled. Indeed, as soon as any benefit becomes apparent, there is incentive for additional effort to enter the fishery. Thus the benefits are dissipated.

Difficulties similar to those with mesh size controls in trawl fisheries occur in other fisheries. Although the size of fish caught in longline fisheries can be influenced by hook size, the relationship is not very exact. In purse seine fisheries for pelagic species it is virtually impossible to use minimum mesh size to regulate the size at first capture.

In addition to their use to achieve a desired type of selectivity, gear restrictions have been used to limit the use of more efficient fishing methods. A classic Canadian example is the virtual ban on groundfish trawlers on the Atlantic coast from 1928 until the Second World War. This was done because of the concerns of inshore fishermen that trawlers would destroy the fish stocks. Only three trawlers were in use from 1928 until the Second World War when this policy

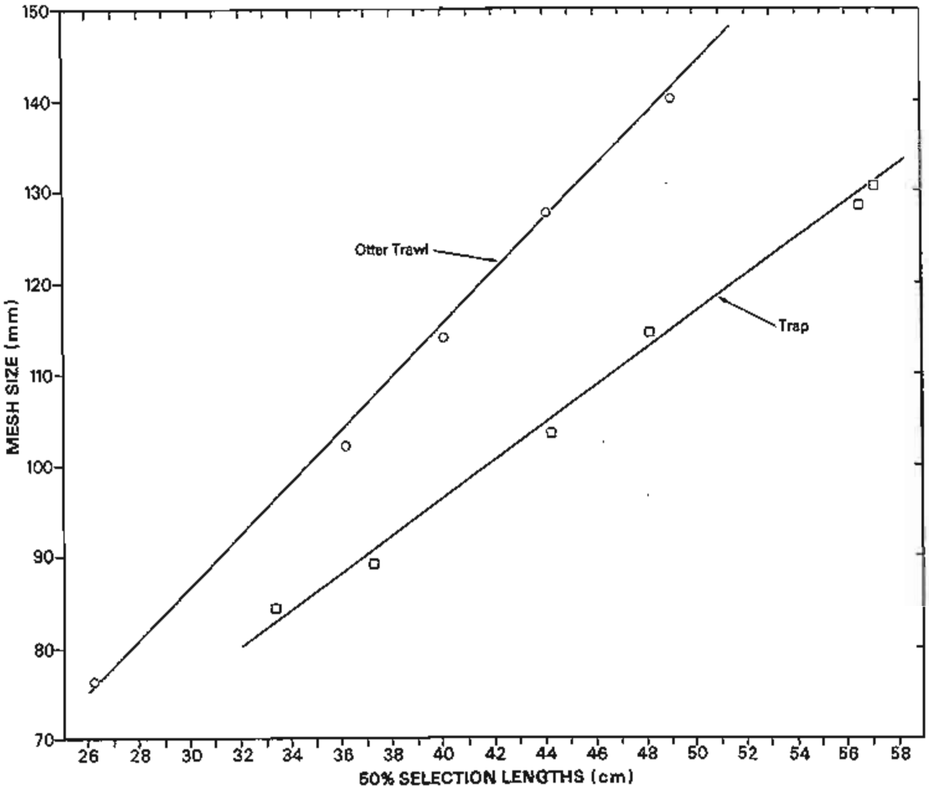

FIG. 5-3. Comparison of 50% selection lengths with mesh size for cod trap and otter trawl (from Bishop 1982).

was reversed. Other examples of the restriction of efficient gears are the prohibition of traps in the Pacific salmon fishery and the prohibition of trawling for Atlantic lobsters. The use of gear restrictions to limit new or more efficient technology leads to an upward regulatory spiral. Regulations may impose artificial inefficiencies on a fishery. However, fishermen will find ways to circumvent these constraints. Regulators then search for new ways to restrict this technology.

2.2 Minimum Size Limits

Another regulatory technique for controlling the capture of small fish is a minimum size limit. This can take two forms: (1) an absolute minimum size limit and (2) a regulation based on the average size of fish landed or on maximum count per unit of landed weight. The former has been applied for decades in the Atlantic lobster fishery. The latter has been applied in the Atlantic scallop fishery.

Garrod (1987) argued that minimum size limits in the Northeast Atlantic have usually been implemented to support minimum mesh size. They are not necessarily closely related to the age at maturity of the fish. The rationale for a minimum size limit in such a situation is that without it there would be continual pressure to reduce mesh size or to ignore the mesh regulation. A minimum size limit sometimes encourages fishermen to avoid areas where juveniles are known to congregate.

Minimum size limits have been used extensively for species such as lobster and scallops where they are particularly useful because specimens under the legal limit can be returned to the sea alive. Their use in the lobster fishery is discussed in the next chapter. They have been used less extensively in finfish fisheries, e.g. Pacific salmon, Atlantic herring, and more recently Atlantic groundfish. The 5-year Atlantic salmon management plan introduced in 1984 (Lear 1993) used a somewhat different approach. It prohibited capture of multi-sea-winter Atlantic salmon, as distinct from grilse, in the recreational fishery. A 63 cm *maximum* size limit was introduced as part of a complex package of management measures which affected all sectors of this fishery. There was considerable debate about the merits of such a measure. Many participants believed that salmon would die upon return to the water. However, studies have shown that salmon released as a result of the hook-and-release policy have a survival rate of 90% or more (CAFSAC 1987a).

Another variation on the minimum size approach is the average meat count regulation in the Atlantic scallop fishery. Caddy (1984) suggested that such regulations be applied under circumstances where:

1) Large numbers of small individuals are captured by unselective gear, e.g. dredges, making an absolute minimum size limit unenforceable, and where mechanical or manual sorting of the catch is not feasible; and
2) Although the gear is unselective, the species in question is either fairly well segregated by size in areas known to the fisherman, or survival of discarded small individuals at sea is known to be high, e.g. shellfish.

This variation on minimum size limits is also intended to increase the mean age of capture and protect juveniles from premature exploitation. The average meat count approach has been compared with the more traditional minimum weight (size) limit for the Georges Bank scallop stock. Mohn and Robert (1984) compared the effects of a minimum meat weight (MMW) of 11.3 g (equivalent to 40 scallops per pound) and an average meat weight or meat count (MC) of 30 scallops per pound. There was not a great deal of difference between 30 MC and 40 MMW. The 30 MC seemed to have an advantage in terms of conservation and stability of catch. They suggested that for each MC there would exist a MMW which would give approximately the same overall catch and stock conservation benefits. The MMW is an abrupt limit while the MC imposes a gradual limitation. In their view, blending tended to spread the effort over a number of ages resulting in greater catch stability. Naidu (1984) reached a different conclusion from a study of the meat count regulation for St. Pierre Bank scallops. He contended that the meat count regulation did not protect young scallops or delay the capture of those recently recruited.

The Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC 1984a) considered the effectiveness of average meat count and minimum meat weight regulations in delaying exploitation of young, rapidly growing scallops. CAFSAC concluded:

> "Either approach to regulation could potentially achieve a reduction in exploitation rates of young scallops. However, in practice the average meat count regulation allows more potential for a significant departure from a gradual recruitment pattern.... The minimum meat weight at a particular count is potentially more effective in protecting young scallops than an average meat count corresponding to the same size. The implementation of a minimum meat weight regulation would be more consistent with the initial objectives of the meat count regulations."

Canada's Atlantic scallop fishery has been managed by an average meat count regulation since April 1973. In 1983 a meat count of 39/500 g was imposed; this was reduced to 33/500 g effective January 1, 1986. In the Atlantic scallop fishery this minimum size regulation was the primary regulatory tool for a considerable period.

Size limits have also been used in the Atlantic snow crab fishery. This fishery developed rapidly in the 1970's and early 1980's but began declining in the late 1980's. Size at first capture for snow crab was set with the objective of ensuring that no females were captured and males were only captured after being permitted to spawn at least once. This was to ensure full utilization of egg production potential. Halliday and Pinhorn (1985) concluded that:

> "Exploitation of the recruited population (males) at 50–60% (F0.1) appears to result in close to full fertilization and the overall strategy clearly avoids recruitment overfishing whereas it may or may not maximize recruitment, and hence usable fishery yields."

The subsequent decline of the Gulf Snow Crab stock raises doubts about this approach. Recently, the appropriateness of the minimum legal size of 95 mm CW for maximizing yield per recruit and for avoiding recruitment overfishing has been questioned (Jamieson and McKone 1988). There is evidence that most morphometrically mature males over 95 mm CW were heavily exploited as soon as they molted to legal size and therefore did not have the opportunity to mate before being caught (Conan et al. 1989). For a fuller discussion of management methods in this fishery, see Hare and Dunn (1993).

2.3 Effectiveness of Attempts to Control the Age at First Capture

Opinions vary on the utility of gear regulations and minimum size limits as management tools. Crutchfield as long ago as 1961 observed that "the history of gear regulation is a testimony to the viciousness of the infighting which develops when technology cuts across the interests of particular groups." He was more positive about the use of mesh size to regulate age at first capture: "The technique is limited in applicability to fisheries where gear selectivity is controllable and where the gear contacts a wide range of sizes in any fishing period. It is therefore most directly useful in achieving optimal average age of fish taken by trawling." Regarding size limits Crutchfield stated: "In most saltwater fisheries size limits do not, of themselves, afford much protection, since losses of undersized fish returned to the water are normally very heavy . There are, of course, some exceptions; and, in addition, size limits provide useful support to other, more effective, regulations designed to allow greater growth before capture."

Gulland and Robinson (1973) concluded:

> "Actions to control the sizes of fish caught generally have no unexpected economic implications. Measures such as control of the mesh size in trawls, or limits to the size of fish that can be landed or sold, allow fishermen to carry on their activities in virtually the same way as before regulations were introduced, except for modifications to their gear or changes in the proportions of their catch that they are permitted to land....Since such measures should make fishing more profitable, without additional management action the long-term effect is to attract further capacity into the fishery, and hence to reduce profitability back to the former level. Therefore, such measures, while economically attractive in the short run, give no assurance of long-term economic benefit."

An Expert Consultation on The Regulation of Fishing Effort convened by FAO in Rome in January 1983 concluded:

> "Size limits and mesh size regulations may provide a base level of protection to the stock in many fisheries, particularly if, without such control, the fish would be caught before they became mature and spawned. Minimum size limits, if they can be enforced, should at least prevent the stock from becoming excessively depleted even if other measures controlling fishing mortality are temporarily ineffective.... Gear restrictions and/or size limits can be important components of a management regime; they can be used with considerable flexibility and sophistication to achieve the economic and biological objectives sought. Under favourable conditions — especially in single-species fisheries where the restrictions are understood and accepted by the fishermen — they have been successful. Even in these circumstances they cannot resolve a number of problems, including the economic problem of overcapacity. In other conditions they may be of very limited value" (FAO 1984b).

In general, minimum mesh size and minimum size limit regulations are a useful adjunct to other elements in a comprehensive management plan. By themselves they are not likely to meet either biological or economic objectives for a particular fishery.

2.4 Closed Areas

Closed areas are spatial restrictions on fishing. These are usually intended to protect particular life history stages of a species. They work by protecting a stock from overexploitation at a point where it is particularly vulnerable to exploitation, decreasing by-catches of particular components of the resource or minimizing the likelihood of conflict between users of different types of gear. Area closures can involve long-term or seasonal closures. Closure of nursery grounds or the banning of fishing on spawning or prespawning concentrations are often advocated for conservation purposes when the real objective is to minimize gear conflict.

Canadian examples of area closures include:

1. The limitation of fishing for silver hake on the Scotian Shelf to the "silver hake box";
2. The seasonal closure of the Browns Bank haddock spawning area during the period March – May;
3. The prohibition of fishing for salmon along a portion of the southwest coast of Newfoundland;
4. The closure of certain nursery areas in the Pacific to halibut fishing;
5. The general prohibition on fishing for salmon in certain areas of the high seas on both the Pacific and Atlantic coasts;
6. The general prohibition of fishing by groundfish trawlers greater than 65 feet within 12 miles of the Atlantic coast; and
7. Numerous instances on both the Atlantic and Pacific coasts of prohibiting fishing by particular gears within certain specified areas, e.g. "boxes".

The "silver hake box" on the Scotian Shelf is an example of limiting fishing to a particular area to permit fishing by small-meshed gear for one species without impacting adversely on other species through the capture of juveniles of those other species. Prior to the 200-mile limit, there was a large-scale fishery by the East European fleets for silver hake on the Scotian Shelf using small-meshed gear. Evidence indicated that this fishery was capturing large quantities of juveniles of other species, e.g. cod and haddock, which was contributing to overexploitation of those species. Because of the by-catch problem ICNAF at its Annual Meeting in June 1976 set a 60 mm minimum mesh size and discussed the possibility of limiting the commercial hake fishery to midwater trawls. Additional studies carried out in 1976–77 identified three primary areas in which silver hake fishing with bottom trawl was concentrated. There were substantial by-catches of juvenile cod and haddock in these areas.

At the Ninth Special Meeting of ICNAF in December 1976, Canada announced that it would limit bottom trawling with small mesh gear to deeper water in the summer months when other species would not be concentrated in those areas and established a seasonal limitation on hake fishing (ICNAF 1977). Fishing silver hake with small-meshed gear would henceforth be limited to an area at the edge of the Scotian Shelf (Fig. 5-4). A silver hake season of April 15 to November 15 was also established. This regulatory proposal allowed fishing with small meshed gear (60 mm) south and east of a line which became known as the Small Mesh Gear Line (SMGL).

ICNAF adopted these measures in 1976. In 1977 Canada codified the ICNAF regulation in its Foreign Vessel Fishing Regulations. In addition, regulations were introduced to limit by-catches of haddock to less than 1% and that of other important commercial species to less than 10% of the total weight on board the vessel. Studies of the impact of the SMGL were conducted from 1977 to 1982. Waldron and Sinclair (1985) reported that geographic distributions of by-catch for cod, haddock, and pollock supported the location of the SMGL. They concluded that this method of managing the Scotian Shelf small-meshed fishery was adequate to minimize by-catch and yet permit access to the silver hake stock.

The closure of the haddock spawning areas on the Scotian Shelf in Division 4W to all trawling during the peak spawning season was discussed at the 1970 Annual Meeting of ICNAF. However, this was deferred largely because of objections that the closed area would interfere with fisheries for other species, particularly cod. At the same time, closed season-area regulations were introduced for Division 4X haddock. STACRES was requested to examine the impact on other fisheries. At its 1971 meeting STACRES advised that:

> "In general, such closures will create problems in the southern areas of ICNAF because of the many species. Closure of spawning areas would not be expected to result in any direct

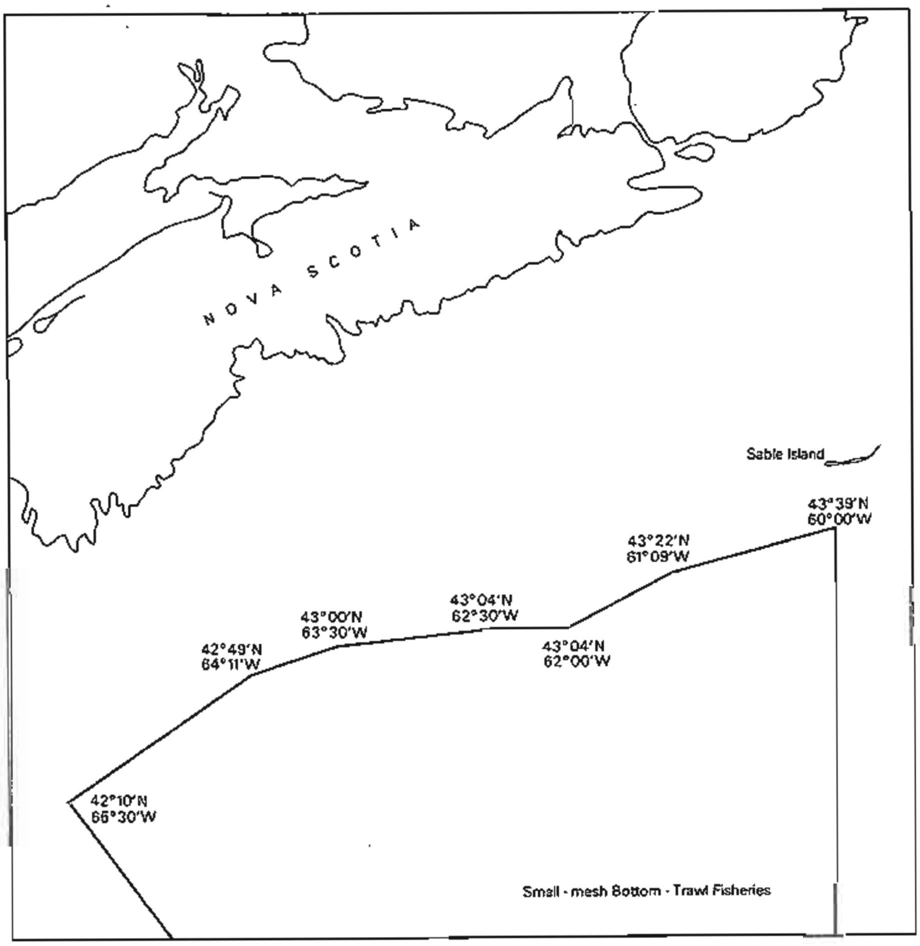

FIG. 5-4. Silver hake box on the Scotian Shelf, as agreed by ICNAF (1976).

significant biological benefits. It is utilized primarily to prevent catches from being concentrated in a short time span. The consequences of closures are thus primarily related to economic or administrative factors. They could be negative in the sense that the period of highest catch rate is closed. Also because fishermen are able to adjust their fishing strategy, such closures may not in fact achieve even the desired result.... The problem of spreading catches over the year is better solved by more direct methods such as seasonal quotas" (ICNAF 1971).

Nonetheless, the Division 4X closed area/season regulation was maintained. The closed area was reduced in size in 1972 and the time of closure extended to include May.

STACRES in 1975 examined the impact of the closed area and season regulations for haddock on the Scotian Shelf and concluded that the regulations had reduced fishing mortality during the months of closure. It observed that regulations in force for 1975 encompassed almost all of the area in which haddock concentrate and that this inevitably interfered with fisheries for argentine, silver hake, cod and pollock. STACRES observed: "minimization of haddock mortality is important to its management. Should present closed area/season regulations prove an unacceptable interference with other fisheries, the Commission should consider alternative methods of regulating haddock mortality" (ICNAF 1975b).

Despite this adverse impact on other fisheries, the closed area/season regulation was maintained. CAFSAC reviewed the spawning ground closure in 1981 and concluded:

> "The rationale behind establishing a closed area to fishing during the haddock spawning season (March–May) was that groundfishing may in some manner detrimentally affect recruitment to the stock through disturbance of the spawning act. Since investigation of this management scheme in 1970 no data have become available to suggest that a closed area has either a good or bad effect on spawning success and thus recruitment. Imposition of the closed area was coincident with application of quota management thus confounding biological interpretation" (CAFSAC 1981).

One of the most effective uses of a closed area regulation was the permanent closure of the Atlantic salmon fishery in southwestern Newfoundland in 1984. This was combined with a mandatory buy-back of fishing licences. These measures were part of a comprehensive package aimed at reversing the decline in spawning escapement. The commercial salmon fishery in this zone was closed because of high interception of mainland-origin salmon returning to mainland rivers to spawn (Lear 1993).

One highly visible application of the closed-area technique was the closure by the Pacific Halibut Commission of designated halibut nursery grounds. The Halibut Convention permitted the Commission to close all halibut fishing grounds populated by small, immature halibut. During the 1930's two nursery areas were closed, one off British Columbia and the other off southeastern Alaska. In 1967, the Commission designated a large section of the southeastern Bering Sea as a nursery area closed to all halibut fishing. These regulations were difficult to enforce (Bell 1981).

Abstention provisions or agreements preventing the fishing of salmon on the high seas are another type of closed area regulation. In the Convention establishing the International North Pacific Fisheries Commission, Japan agreed to abstain from fishing salmon off the coasts of Canada and the U.S. (exclusive of the Bering Sea and of the waters of the North Pacific west of a provisional line approximately along 175° W. Longitude). Both Canada and Japan also agreed to abstain from fishing salmon in waters of the Bering Sea east of a particular line. Subsequently, in the Commission meetings the interest of the United States and Canada lay in moving the Protocol line as far to the west as possible. This would mean that most salmon of North American origin would be east of the line. The Japanese fishing industry wanted to keep the line as far east as possible. Canada and the U.S. had prohibited net fishing by their nationals for salmon outside the "surf line." Following extension of fisheries jurisdiction, the "abstention" line was adjusted to provide further protection for salmon of North American origin (see Chapter 11).

On the east coast, the 1982 Convention for the Conservation of Salmon in the North Atlantic established the North Atlantic Salmon Conservation Organization (NASCO). Article 2.1 of the convention prohibits salmon fishing beyond the fisheries jurisdictions of the coastal States. Article 2.2 stipulates: "Within areas of fisheries jurisdiction of coastal States, fishing of salmon is prohibited beyond 12 nautical miles from the baselines from which the breadth of the territorial sea is measured, except in the following areas:

(a) in the west Greenland Commission area, up to 40 nautical miles from the baselines; and

(b) in the North-East Atlantic Commission area, within the area of fisheries jurisdiction of the Faroe Islands."

While allowing existing high seas fishing for Atlantic salmon to continue under regulations by the relevant Commission, this provision prohibited new fisheries for Atlantic salmon except close to the coasts of the States concerned. This effectively closed a large area of the North Atlantic to salmon fishing.

Other closed area regulations aim to minimize gear conflict. For example, the limitation on the area of operation of trawlers over a certain size is intended to prevent disruption of the fishing operations of inshore fishermen. There are numerous instances on both the Atlantic and Pacific coasts where specific fishing grounds or areas are closed to fishing by particular gear types.

Some closed area regulations reduce efficiency and increase costs for some fishing enterprises, with no biological advantage. These may close spawning grounds or close areas to specific gear types. In other instances, closing areas is clearly beneficial. Examples include the SMGL to minimize by-catches and prohibition of salmon fishing in certain areas to minimize interceptions.

2.5 Closed Seasons

The imposition of closed seasons is one of the most common techniques used to manage fisheries. There are a variety of reasons for closing fisheries for specific fixed periods during a year. The chief objective is to protect a stock from exploitation during part of its life cycle or during seasons of high vulnerability. There are two aspects to this:

1. To maintain exploitation rates at desirable levels if fishing effort is uncontrollable; and
2. To prevent fishing during particular seasons of the year.

Closed seasons of fixed duration to achieve the first purpose are unlikely to protect the stock or maintain a given stock size. Theoretically, such a measure should be enforceable. However in practice such measures may lead to trade in illegally caught fish. De Wolf (1974) cited instances of this in the Atlantic lobster fishery.

Closures of fixed duration during particular seasons may have purposes other than conservation. Quite often closed seasons are introduced for market reasons, e.g. when market prices are poor or when fish quality is poor. These considerations apply in the case of the Atlantic lobster fishery where the seasons were established in many instances to avoid competition with the period of high landings in Maine. The winter open season for the southwest Nova Scotia lobster fishery coincides with high prices and low product availability on the North American market. This is also a period when quality problems are at a minimum (see the next Chapter). Closed seasons are also used in other shellfish fisheries to minimize quality problems, for example, the capture of soft-shelled crabs.

Seasonal openings of variable duration are a primary management tool for Pacific salmon and Pacific herring. In both cases, fishing capacity is far larger than necessary to harvest any surplus to required spawning escapement. The roe herring fishery in B.C. is renowned for its short 15-minute open seasons. The B.C. salmon fishery is highly complex. Five species and a multitude of stocks intermingle on their return to the rivers to spawn. Thus the use of seasonal openings is fine-tuned to account for last minute estimates of stock abundance and permit sufficient fish to get up river to meet target spawning escapements. The closed/open season technique is an essential regulatory tool in the Pacific herring and Pacific salmon fisheries.

Restrictions on time and area fished have been criticized because both will increase the cost of fishing (they constrain the way vessels and gear can be used). See Anderson (1986). If area closures force fishermen to fish on less productive grounds, the cost curves for the individual fishermen and the fishery as a whole will also shift upward. Thus spatial and temporal restrictions on fishing often promote inefficiency because fishing is carried out at times and places where the catch per unit of effort is relatively low.

One of the touted advantages of closed areas and seasons is that they are relatively easy to enforce using patrol boats and airplanes. There are, of course, exceptions. Enforcement of closures, for example, as that during the haddock spawning season on the Scotian Shelf, is relatively expensive.

Closure of nursery grounds or the banning of fishing of spawning or prespawning concentrations can have serious implications for fishermen. The effects may be quite different for different groups of fishermen depending upon where, when and how they fish. Thus the political and social consequences of such prohibitions can be as important as the purely biological impacts (Gulland and Robinson 1973).

Area and season closures can be useful adjuncts to more direct methods of controlling fishing mortality. However, they are generally less useful as the primary methods of management. They are useful conservation measures, in cases such as the "silver hake box", to minimize by-catches of other species. They can also be used to optimize spawning escapement in species such as Pacific salmon and herring. DFO has in some instances closed certain spawning and nursery areas for groundfish as a conservation measure, e.g for haddock on the Scotian Shelf.

3.0 CONTROLLING THE AMOUNT OF FISHING

In recent years there has been an increasing emphasis on regulatory methods to control the amount of fishing. The primary objective of controlling the amount of fishing is to achieve some target level of fishing mortality. The choice of the target level will depend upon the management objective(s) for, and the nature of, a particular fishery. Examples of target fishing mortality cited in Chapter 3 were F_{max} and $F_{0.1}$.

Unfortunately, fishing mortality cannot be observed or controlled directly. Therefore, managers usually monitor and/or control two parameters directly related to fishing mortality: catch and fishing effort. These are related according to the following formulae:

$C = F\tilde{N}$

where $\tilde{N}$ is the average abundance of the population during the year, C is the catch and F represents fishing mortality, i.e. the rate at which fish are removed by fishing;

$F = qf$

where f is the fishing effort and q is the catchability coefficient representing the amount of fishing mortality induced upon the population by a unit of fishing effort.

The second equation indicates that the relationship between f and F is a straight line passing through the origin with slope q, a constant catchability coefficient. In practice, q is rarely constant. A particular amount of fishing effort will not always remove the same proportion of the stock.

Catch or nominal effort will be satisfactory measures of the fishing mortality if $\tilde{N}$ or q remain constant. Variations in $\tilde{N}$ or q mean that controlling the catch or effort at some particular value will not achieve the desired level of fishing mortality. If they fluctuate randomly with only a moderate degree of variation, this would not be serious. However, if there are significant trends in the variation of $\tilde{N}$ or q, the effects could be substantial. An obvious example would be an increase in fishing mortality, sometimes undetected. Thus catch limits generally have to be adjusted annually, particularly when there are significant year-to-year changes in population abundance. Regarding fishing effort, the fishing mortality exerted by a nominal unit of effort tends to increase with technical improvements in a fishery. This can be accommodated by adjusting the unit of effort to reflect increased fishing power provided the latter can be determined. However, it is difficult to standardize different vessel-gear combinations from a variety of countries or even within a single country. It is usually very difficult to determine the increases in efficiency of particular vessel-gear units.

Changes in abundance of the fish stock under study can often result in undetected changes in catchability (q). This has been observed for pelagic species such as herring. Reductions in stocks of these species may be accompanied by a shrinking area of distribution of the fish. Under such circumstances, monitoring of catch per unit effort (CPUE) and nominal effort may result in erroneous calculations of the fishing mortality being applied to the stock. Thus unadjusted fishing effort controls can have detrimental effects similar to those mentioned for unadjusted catch controls.

To account for these factors, the limit used to control fishing mortality, whether it be catch or fishing effort, must be regularly adjusted. Catch quotas are generally adjusted annually. Adjustments are based on the most up-to-date information on stock abundance. Limits on the amount of fishing effort are more difficult to modify because of difficulty of documenting changes in fleet efficiency. Catch quotas and effort controls have different advantages and disadvantages as regulatory measures.

3.1 Catch Quotas

In the 1970's and 1980's the setting of limits on total catch became the most common method of controlling the amount of fishing. These are now widely known as Total Allowable Catches (TACs). Catch quotas were used in the North Pacific halibut fishery as early as the 1930's. They were applied to Pacific herring shortly thereafter. Immediately after the Second World War they were introduced for Antarctic whales.

It became accepted in the 1960's that the amount of fishing in the North Atlantic should be controlled and that mesh size regulations were ineffective for this purpose. Catch quotas were chosen as the primary regulatory instrument because it was easier to implement national allocations under a system of catch quotas than under a system of effort limitations. Following their introduction by ICNAF in 1970, TACs were rapidly adopted as a management measure for finfish stocks in the North Atlantic. This was accompanied by national allocation of shares of the total quota.

Catch quotas can be readily understood by fishermen and the fishing industry. They can also be readily compared between countries and between fishermen. By comparison, effort quotas and allocations are complicated to devise and difficult to implement.

TACs as a regulatory method were reasonably quickly accepted in multinational fisheries and within particular countries. The rationale for establishing a particular level of TAC has not been as readily accepted. Internationally, this has been the case in the area beyond the Canadian 200-mile limit on the Atlantic coast. For complex political reasons, the European Community repeatedly objected in the late 1980's to TACs established there by the Northwest Atlantic Fisheries Organization (NAFO) (see Chapter 11). Within Canada debate has often raged about the scientific basis of TACs for certain stocks. Examples are the controversies surrounding the TACs for Gulf of St. Lawrence redfish, Gulf herring and northern cod during the 1970's and 1980's. There were ongoing mini-wars about the appropriate level of TAC. These battles were often couched in terms of challenges to scientific advice but the root cause was often conflict over how the resource should be shared among competing user groups.

Where the TAC system has been applied it has generally been accepted. It has worked reasonably well from national and international perspectives. Exceptions have taken three forms. Some countries or managers have satisfied competing user groups only by setting TACs larger than scientists recommended. A second problem has arisen from erroneous estimates of stock abundance. Sometimes this has resulted in dramatic adjustments in the level of TAC advised from one year to the next (see Chapter 18).

One major disadvantage is the need to ensure timeliness in the setting of catch quotas by minimizing the time lag between the collection and analysis of data and the quota period. In practice, this is often difficult to achieve. During the 1970's and 1980's catch quotas for most groundfish fisheries off the Canadian Atlantic coast were recommended 6 months in advance of the fishing season based on assessments performed 8 months earlier using data from the year previous. For example, the 1990 TACs would be recommended in May–June of 1989, based on 1988 data. Ideally, the assessment should be conducted and catch quotas established just prior to the next fishing season using data from the current year's fishery. Although this is possible for a few fisheries, it is the exception rather than the rule.

The effects of time-lags are least significant for long-lived fish. Failure to set the TAC "right" in one season can be compensated in the following season without significant loss in yield or overfishing. Also for long-lived species individual year-classes can be monitored as they recruit to the fishery. Thus potential yields can be predicted up to 2–3 three years in advance with some reasonable confidence.

Major problems can arise with short-lived species whose abundance fluctuates widely from year to year, e.g. capelin and silver hake. If a weak year-class enters the fishery, and the catch quota is not altered in time, a high fishing mortality could lead to overexploitation of the year-class. This could have major consequences for the stock. To avoid this, it is necessary to predict reliably the strength of recruiting year-classes and adjust the quota during the season. In the case of the Pacific salmon fishery, for example, adjustments are made weekly, even daily, by varying the duration of open/ closed seasons.

Errors in estimating stock abundance and identifying trends in fishing mortality can be substantial (see Chapters 18 and 20). One source of error arises from control by catch, rather than effort. To calculate TACs it is common to use a method called Virtual Population Analysis (VPA) (see Chapter 3). Results of the analysis depend critically upon the choice of the "terminal F": the fishing mortality assumed to occur in the last year for which data are available (Pope 1972). For example: In 1990 when the TAC for 1991 is being calculated on the basis of 1989 data, the value of F for 1989 could be under-estimated. This would mean that the stock in 1989 was less than was estimated. The catches during 1989 will in this case take a higher proportion than expected of this smaller stock. Hence, the extent of over-estimation of the stock at the beginning of 1991 and the TAC for 1991 would probably be considerably greater than the original degree of under-estimation of terminal F.

Gulland (1974) suggests that catch quotas are "comparatively easily controlled and enforced." In an earlier paper (Parsons 1980) I disagreed, pointing out that the number of days fishermen spend on the fishing ground is more readily controlled under a system of aerial patrols, supplemented by at-sea surveillance. This has been proven in managing fishing by foreign vessels in the Canadian zone. Experience over the past 15 years with the TAC system in the North Atlantic has shown that the most serious indirect effect of catch quotas is the falsification of data on the fishery. There have been numerous instances where the actual landings have been considerably larger than the reported figures. One glaring example was the underreporting of catches in the Bay of Fundy purse seine fishery for herring during the 1980's. Similar cases have been reported from the Northeast Atlantic where in several instances ICES scientists have advised that it was no longer possible to assess the state of the stocks (see Chapter 20).

Gulland (1984) observed that attempting to control the amount of fishing through catch limits is often a "second — or third best method." He analyzed management by catch quotas using four criteria — (1) maintaining the resource; (2) economic efficiency; (3) equity; and (4) transaction costs. In practice, knowledge of the resource is less than perfect. Thus the catch quota set will not be the correct value to achieve the desired fishing mortality. Its effectiveness relative to other types of control depends on the year-to-year variability of the stock and the degree to which this can be measured and predicted. Thus, catch quotas are highly suitable for whales. With stocks of long-lived fish, for which year-class variability can be monitored reasonably well, control by catch is suitable, "though probably no better than effort limits." With short-lived stocks, for which it is difficult to make accurate estimates of abundance in the following year, other types of control, e.g. on fishing effort, may be more effective. For pelagic schooling species, the catchability coefficient varies inversely with abundance. These are a special case: controls on nominal effort do not control the actual fishing mortality. Catch quotas may be used successfully if acoustic surveys can provide a direct estimate of the current abundance.

The impact of catch quotas on economic efficiency depends upon the extent to which the total catch is allocated among participants in the fishery. Global quotas which are not allocated to individual groups are clearly inefficient. They lead to a mad race to catch the quota. This can be overcome by various forms of allocation of the global quota. The relative equity of catch-versus-effort controls depends upon the manner in which these are applied. For a discussion of this, see Chapters 7, 8 and 9.

Acquiring the scientific knowledge base necessary to permit year-to-year adjustments in catch quotas is costly. Large amounts of data must be collected, costly research surveys conducted and scientists diverted from the broader questions of resource assessment and management. Costs of enforcement can also be high.

Catch quotas have been successfully applied in many fisheries to solve the conservation problem for single species. By themselves, they do nothing to address excessive fishing capacity. In many instances global catch quotas can exacerbate overcapacity unless other measures are introduced to address the problem.

3.2 Effort Controls

Superficially, regulating fishing mortality by control of effort appears to offer advantages over catch control. Target fishing mortality rates might be more directly achieved by controlling fishing effort than by controlling catch. In theory, once an appropriate level of fishing effort is determined, this level may be maintained without year-to-year adjustments dependent on annual stock assessments. Certain studies have suggested that during periods of low productivity fish stocks are less vulnerable to pronounced reductions in biomass when they are regulated by a constant fishing mortality (effort) than by a constant catch approach, e.g. Reeves (1974).

If the measures of effort were accurate, it would not be necessary to adjust quotas from year-to-year to account for year-class fluctuations, nor would it be necessary to monitor the strength of recruiting year-classes quite so closely. In practice a fishing effort regulation is intended to harvest a proportion of the stock. Determination of the level of fishing effort depends on the assumption that a given unit of fishing will harvest a constant proportion of the stock so that, once the proportion is determined, the number of units of effort is defined. This requires converting a target fishing mortality to a quantity of fishing by a standard unit and its reconversion to component units. Usually, this derivation depends at some point on comparing catches over time of different vessels. This system is particularly liable to error if the regulatory constraint changes fishing patterns, as is often the case. Studies in ICNAF from 1973 to 1976 demonstrated considerable changes in efficiency of the fleets of various countries over the previous 10–20 years. Actual fishing effort, and hence, fishing mortality was increasing even in cases where the apparent fishing effort remained the same.

Thus there are two aspects to selecting an appropriate level of fishing effort to achieve a target fishing mortality. The first is to detect and measure changes in efficiency. The second is to compare and calibrate effort by two or more fleets fishing the same stocks. Increases in efficiency may be obvious or subtle and can often only be derived by guesswork. Such guesswork is rarely an acceptable basis for adjusting effort quotas allocated to particular segments of a fishery. Another difficulty is that many of the adjustments made by scientists depend on hard-to-verify reports by fishermen. Also the number of hours fished per trip may change over time. This might not be accounted for when regulating the number of days on the fishing grounds, should that be the effort measure chosen. Regulating the number of fishing hours, a more accurate measure, would be impossible to enforce.

STACRES (ICNAF 1973a) examined the implications of regulating effort on the basis of hours fished, days fished, and days on ground. It concluded that "days fished" was the best measure of fishing mortality. Regulating "days fished" had two drawbacks however. One was the difficulty of monitoring in the international fishery the number of days being fished. The second problem is that fishermen from one country, or fleet sector, cannot always determine whether other vessels on the fishing grounds are in fact fishing. This might lead them to make erroneous conclusions about compliance with regulations. "Hours fished" suffered even more from both those drawbacks. "Days on ground" may lack the precision of days fished in relation to fishing mortality but it has a smaller margin of error than just regulating the number of vessels. "Days on ground" can be more easily monitored, are easily observable by fishermen, and thus could represent a more credible regulation than "days fished."

It is very difficult to regulate fishing mortality precisely by control of fishing effort. Effort control is most beneficial in situations where a precise cause and effect relationship is not needed. Direct control of the number of vessels and/or vessel days on ground could then be useful. The latter approach might be appropriate to halt declines in resource abundance pending the introduction of a more sophisticated system.

Effort regulation has been applied to marine commercial fisheries less extensively than catch regulation. In their review of possible conservation actions for the ICNAF area, Templeman and Gulland (1965) observed: "There must be some direct control of the amount of fishing. All methods of doing this raise difficulties, but that presenting the least difficulties is by means of catch quotas. There must be separate quotas for each stock of fish, e.g. for cod at West Greenland, and preferably allocated separately to each section of the industry."

Following the introduction of national catch quotas in ICNAF in 1970, the USA proposed effort regulation for the area off the northeastern USA. However, ICNAF rejected the proposal. A two-tier catch quota system was adopted instead. Canada secured a commitment from ICNAF in 1976 to a 40% reduction in fishing effort by distant-water states off the Canadian Atlantic Coast. Once Canada extended fisheries jurisdiction in 1977, it instituted a licensing system for foreign vessels. The number of vessels and vessel days on ground were regulated to provide effort control to supplement catch quotas.

Licensing has been widely used in domestic fisheries. Limited entry licensing is usually intended to allocate resources among user groups or to control capacity to increase economic efficiency. It is not generally sufficiently fine-tuned for directly regulating fishing mortality, the subject of the present chapter. The pros and cons of limited entry licensing are discussed in Chapter 7.

4.0 CONTROL OF MULTISPECIES FISHERIES

We have discussed various regulatory techniques for managing single species stocks. In practice trawl fisheries are seldom based on single species. Instead, they harvest a complex of resources of varying interest to different countries or fleet sectors within a country. In such mixed fisheries, a framework of individual single-stock catch quotas may be incompatible with TACs on species caught together. Thus it may not be possible to achieve the TACs of all simultaneously.

The degree of complexity of fisheries interactions ranges from the relatively simple, where fisheries on two different species are so distinct that they can be managed quite separately, to an extreme situation where the species are so evenly mixed on the fishing grounds and in the catches that no preference for one species or another can be detected. In the latter instance, the species complex should be managed as a unit. The complex of species can be so large that the only practical method is to treat the catch as if it came from a single species. This is true for some tropical areas. It is better to introduce simple management approaches early than sophisticated management too late.

For an intermediate degree of fisheries complexity, Garrod (1975a) suggested two alternatives: (1) to establish the TACs of individual stocks with minimum stock size constraints for particular stocks, or (2) to consider the resource complex in particular areas as a whole and adopt either catch or fishing effort regulations for the whole. Garrod (1975b) described the formulation of catch regulations based on designated stock size. This assumed that the first responsibility of management is to maintain a stock size that will ensure continuity of the resource. He concluded that this implied a variable catch and fishing mortality to maintain a constant stock (Garrod 1975a). This would necessitate defining a minimum spawning stock level.

Some stocks have been depleted to 10% of the unexploited level. Garrod suggested a 15% minimum spawning stock constraint. This proposal, however, was not widely supported. The most acceptable approach would be to adopt a spawning stock level which is known to be adequate. Given the uncertainties about stock and recruitment described in Chapters 3 and 18, this is unlikely to be easy for any stock. It will be impossible for some stocks.

Doubleday (1976) suggested that an equilibrium spawning biomass constraint at a biomass level about two-thirds of that of the virgin stock could provide an adequate biomass buffer to maintain stock stability in the face of large fluctuations in recruitment. In practice, with the exception of the salmonids, minimum or optimum spawning stock sizes have been established for very few species and stocks.

In the 1970's there were some attempts to use general production (Schaefer-type) analyses of catch in relation to fishing effort (see Chapter 3) for the groundfish fisheries of the Northwest Atlantic to estimate an overall Total Allowable Catch level or overall level of

By-catches in a mixed fishery.

fishing effort for managing these "assemblages" of species. Brown et al. (1976) estimated the projected maximum sustainable yield from Schaefer yield curves for the finfish resource off New England as 900,000 tons. The sum of the MSYs from individual assessment studies was 1,300,000 tons. This suggested that summing the MSYs from individual assessments might overestimate the total MSY because of species interactions and by-catch complications.

Pinhorn (1976) used the Schaefer general production model to estimate the groundfish MSY for Subareas 2 and 3 at 900,000 to 1,000,000 tons. He concluded that catch quota regulations for 1975 would not prevent continuing stock decline. A reduction in fishing effort of 30–40% might be necessary to reduce fishing effort to the MSY level. In a similar analysis, Halliday and Doubleday (1976) estimated the MSY of groundfish on the Scotian Shelf to be 250,000 tons (excluding silver hake). They concluded that the catch quota regulations for 1974 and 1975 could not halt stock decline. A reduction in fishing effort of 37% from the 1973 level was required to reduce effort to the MSY level.

Pope (1976) and Horwood (1976) considered the case of pronounced biological interactions where one species may increase to replace another which is heavily fished. They found that the overall MSY of the resource complex may only be achieved by a very specific mixture of fisheries aimed at the different species. Outside these limits the species composition of the complex, and catches, will depend heavily on the level of fishing mortality. However, the overall total catch may be fairly stable. If there are no biological interactions, attaining the MSY will depend on the species preference of the fisheries involved. If these vary with species abundance, the yield may be stable over a range of fishing. However, this may not be the theoretical MSY of the resource. The overall MSY will be associated with a particular species composition. Its attainment will depend on matching the fisheries exploiting the complex to the "optimal" species composition.

Thus general production models do not necessarily indicate the MSY of a complex. They may only indicate the MSY of fisheries with the species preference observed during development of the fishery. If the total level of exploitation were regulated by an overall catch or effort regulation, the "true" MSY is likely to be achieved only by a very mixed fishery. The level of catch may remain fairly stable over a wide range of levels though there is a progressive change in the species composition. Thus the resource composition may shift towards species which were initially of least value.

Hence, a single overall catch regulation might not achieve the MSY. It would not protect particular stocks but would allow a shift in the species composition. Equally a single overall effort regulation might not achieve the MSY but could tend to fix the species composition of the resource.

Of the various measures available, control of fishing effort is least suitable for modifying the balance between species. In practice fishermen will continue to seek the highly valued species. Closed areas and seasons could help differentiate between species. If one species is heavily exploited, it may be preferentially protected if there are areas or seasons where it is particularly abundant or easily caught. If the dynamics of the resource complex were known, an array of individual catch quotas might achieve the yield objectives. Since these dynamics are not fully understood, it is necessary to protect the individual species so far as possible. This could be augmented by an overall catch or effort control to provide a cushion against unknown interactions and preserve a satisfying resource configuration. An overall regulation cannot be regarded as a precise measure. However, it may be necessary because the exact sizes of all individual stocks are unknown.

Single species regulation is also imprecise. A catch quota will be most heavily influenced by the error in estimating numbers of young fish entering the fishery. Effort regulations will be influenced by year-to-year or within-year variations in the catchability coefficient of the units of effort. In both cases, it was suggested in the 1970's that the level of exploitation achieved by a regulation will have a coefficient of variation ± 20–30% of the intended level (Pope and Garrod 1975). Recent studies (see Chapter 18) suggest that the uncertainty can be greater than this. Multispecies fisheries introduce additional error because of undetected biological or fisheries interactions among the component resources. Where catch quotas are used, the overall TAC will, in general, be less than the aggregate of the individual species TACs because of the by-catch problem.

Where effort controls are used, the amount of effort directed to particular species could be expected to vary with short-term variations in abundance and species preference. This could change the catchability coefficient. As with errors in stock size, it is impossible to quantify the errors involved in projecting the present effect of fishing to their presumed effect in 2 years time. They may be very specific to each species complex and vary with time within it. With respect to such errors, neither method (TACs or effort control) is clearly superior.

Catch quotas present better opportunities for differential species management. One approach experimented with in the 1970's was a two-tier system consisting of catch quotas on individual species/stocks within an overall catch quota for all species/stocks. This approach was in effect during 1974–76 in Subareas 5 and 6 off the U.S. Atlantic coast. Another option for regulating multispecies fisheries is combined catch and effort regulation. The chief problem is the need for compatibility between the two regulatory approaches. Such a system was implemented off the Canadian Atlantic coast in the last years of ICNAF. These approaches to management of the Atlantic groundfish fisheries are described in Chapter 6.

5.0 CONCLUSIONS

In summary, a variety of regulatory methods have been devised for marine fisheries. The two primary methods involve controlling the age (size) at first capture, through minimum mesh size or minimum size limits, and controlling the amount of fishing, through catch quotas or fishing effort controls. Other auxiliary methods include closed areas and seasons. In practice, no one method is ideal to achieve resource management goals for any particular fishery. Generally, a combination of various regulatory methods are necessary depending upon the objectives for a fishery.