## 1. INTRODUCTION

Shrimp are one of the world's most valuable fishery resources. The present total landings are estimated to be around $1.8 \times 10^6$ tons, and an additional demand for 200,000 tons is foreseen by 1990 (Sribhibhadh 1). Tropical penaeid shrimp landings amount to about 700,000 tons (Gulland and Rothschild 2) and their high value and strong demand on the markets of the richer countries (United States, Japan, Europe) were powerful incentives to the development of shrimp fisheries in the 1960s and 1970s. From 1977 to 1981, for instance, the landings increased by 22% and the value by about 60% in terms of U.S. dollars (International Trade Center 3). The high prices for shrimp on export markets have stimulated rapid development, leading in many cases to excessive effort, even with regulatory measures, which have usually been unable to prevent overinvestment, excessive production costs, low or even negative economic returns to the country, and perhaps an overall reduction in total catch value. Most potentially productive areas are now being exploited, and no major increase in landings of capture fisheries can be foreseen. As shrimp prices continue to rise and oil prices are presently decreasing (1986), there is a risk of additional fishing effort being injected into fisheries where conspicuous conflicts have already appeared between small-scale and offshore industrial shrimp fisheries, between shrimp and finfish fisheries, and between shrimp aquaculture and fisheries for the postlarval resources and for the markets. Most fisheries are now in a situation of economic overfishing, shrimp fisheries are the major source of conflict and problems in the tropical zone, and recruitment problems are presently receiving increased attention (Penn 4; Penn and Caputi 5; Garcia 6, 7). Considerable progress has been made in understanding the essential biological aspects of shrimp resources in the past decade and, although the data may not always be as complete as one would wish, an extraordinary amount of information has been accumulated since the pioneering work of Boerema (FAO/UN 8), Gunter (9), and Gulland (10) on shrimp fisheries management. A first review was prepared in 1981 by Garcia and Le Reste (11) and since then three major workshops have been held (Gulland and Rothschild 2; Rothlisberg et al. 12; FAO 13) and management plans for shrimp have been prepared in many countries.

This chapter identifies the major management issues, objectives, and approaches in shrimp fisheries. It does not deal with gathering of information for decision makers, management organizations, or practical implementation because of lack of space and because these aspects either do not differ markedly from other fisheries and are treated extensively elsewhere or are poorly documented (e.g., practical implementation in small-scale fisheries).

## 2. MANAGEMENT ISSUES

Although shrimp fisheries have developed in drastically different socioeconomic contexts (from Australia and the United States to Malaysia or Senegal) a limited number of issues for management are common to all of them (see also Poffenberger 14).

## 2.1. Biological and Economic Overfishing

It is usually assumed that in trawl offshore shrimp fisheries, catches increase more slowly than fishing effort and that some maximum catch (maximum sustainable yield, MSY) and value are reached for some intermediate level of effort. It is also accepted that the maximum economic yield (MEY) is obtained at some level of effort lower than the level corresponding to MSY. Most shrimp fisheries around the world are common property resources, even when the coastal countries have claimed exclusive economic zones, for access is still open to nationals. The usual competition among participants for a greater share of the common resource has often led to an uncontrolled increase of effort to the point where the economic rent is dissipated and often the economic situation of the fishery is very critical, some fishermen no longer being able to cover their capital costs and even sometimes their operational costs. Governments intervene by providing subsidies, soft loans, tax reductions, and so on, which usually aggravate the problem, leading possibly to overall economic losses to the country. The Gulf of Mexico shrimp fishery of the United States, for instance, valued at more than \$400 million annually, was considered to be in a state of "economic overfishing" by Neal (15). The numerous analyses made in the 1970s (Greenfield 16; Griffin and Beatie 17; Blomo et al. 18) confirmed this, gave a good analysis of the situation, and stressed that the crisis was exacerbated by rising fuel costs, and sustained by the fact that the marginal yield in shrimp fisheries was still higher than in potential alternative fisheries because of high prices. A management plan was initiated in 1976 and has been implemented since 1981. Many measures are being enforced (sanctuaries, seasonal closures, etc.) but the limitation and reduction of effort proposed by Rounsefell (19) has not been adopted as a strategy and the present situation is still largely one of overcapitalization (Leary 20). It is worth mentioning also that although in Australia limited entry was enforced in many cases since the inception of the fisheries a decade or more ago, the present situation is not yet totally satisfactory and excess of effort has not been entirely avoided (Bowen and Hancock 21). A similar situation of economic overfishing is encountered in most fisheries around the world, as shown in the various case studies presented at the Key West meeting in 1981 (Gulland and Rothschild 2); the wealthy situation of the shrimp fishery in Saudi Arabia due to sole ownership (R. Willmann, personal communication) is a noteworthy exception.

## 2.2. Optimization of Yield Per Recruit (Growth Overfishing)

Shrimp are very fast growing animals. Seasonal and age-specific fishing patterns have marked consequences on annual yield in weight and in value. One of the key issues in present-day shrimp fishery management is to determine the most appropriate age at first capture and the fishing pattern to reach a specific economic objective or a given shrimp market. This implies the use of bioeconomic yield-per-recruit modeling with preseason surveys, mesh-size regulations, closed areas, and seasonal or temporary closed seasons (see Section 4.1). The problem here is a trade-off between immediate loss of small shrimp catch and future gains in weight and value from the survivors. In many fisheries intensive exploitation starts much too early, leading to growth overfishing, and the solution is not always simple because there are conflicts in the use of the resource.

## 2.3. Conflicts

Problems of resource allocation in shrimp fisheries are similar to those in other fisheries and have international, intranational, and interstate territory or community aspects. These have been considered by FAO (13); I deal here with only two specific issues, that is, the conflict between artisanal and industrial fisheries and the conflict with aquaculture. The potential conflict between shrimp fisheries and finfish fisheries is dealt with in Section 2.6.

Conflicts between industrial and small-scale fisheries cannot be overstated and have been particularly acute in Southeast Asia and India (Unar and Naamin 22; Naamin and Martosubroto 23; Silas et al. 24). Shrimp are often exploited by small-scale commercial or sport fisheries inshore as well as trawl industrial fisheries offshore. The overall input and benefits for the combined fisheries varies with the intensity of fishing inshore and offshore, and decisions are needed on optimal fishing patterns and allocation between the various fishing sectors involved sufficiently acceptable to be enforceable. Direct conflicts also exist for space, and small-scale fishermen complain about destruction of their gear by trawlers as well as conflicts for the market when trawlers land large quantities of coastal shrimp at low price. Some answers can be found in setting appropriate closed seasons and areas (see Section 4.1). In some cases, however, more drastic measures have been taken, such as total banning of trawling in Indonesia (Naamin and Martosubroto 23) or total elimination of artisanal fisheries in Cuba (Perez et al. 25).

Conflicts with shrimp culture are increasing in some countries. Extensive aquaculture is growing very rapidly; the present world production, not known precisely, varies between 35,000 and 80,000 tons according to various sources (Pedini, cited by Sribhibhadh 1; Lawrence 26) and great potential for expansion is said to exist. The production could reach 200,000 tons in the mid-1990s (Lawrence 26), and over-optimistic figures of 400,000 tons can be found in the literature. These cultured shrimps compete with wild shrimp on the market and also for growing space and postlarval seed. The largest production of cultured shrimp is obtained by large-scale extensive aquaculture often using littoral nursery areas (mangroves, marshlands) for growing space and wild postlarval seed. According to Lawrence (26) 95% of the present commercial shrimp production in the western hemisphere depends on collection of postlarvae from natural sources, and this situation has created concern regarding the potential effect on capture fisheries. The shortage of wild seed in Ecuador recently and the overall decrease of the capture fisheries have increased this concern. The problem is not easy to address and how to model it as juvenile natural mortality is still unclear.

### 2.4. Variability and Uncertainty

Shrimp fisheries exploit essentially one year class. The annual yield is therefore largely a function of the importance of the annual level of recruitment and the latter is widely influenced by environmental conditions. The consequence is that annual catches vary from year to year either randomly or, more probably, following long-term autocorrelated oscillations. This fact has many consequences on stock assessment, modeling, effort control, and management strategy. Garcia (27) has stressed the existence of year-to-year variations in shrimp production due to environmental conditions, leading to difficulties in establishing an appropriate production model to assess the present state of the stock and to estimate MSY when only short time series are available. Year-to-year variability also renders difficult the use of annual catch quotas for effort regulation. When exceptional year classes enter the fishery, or exceptional prices are obtained, higher than average profitability is generated and it has been shown in the Gulf of Mexico (Rounsefell 19; Poffenberger 14) that these years were usually followed by pulsed increases in boat numbers. Variable resources are therefore less prone to economic self-regulation and lead more easily to heavy overfishing and overcapitalization (Csirke and Sharp 28; Garcia 29). In order to reduce the uncertainty of the production and management sector, it is necessary to elaborate predictive models to foresee the coming year's production a few months ahead and allocate fishing time and effort accordingly. These models are based either on environmental factors such as rainfall or temperature in a given critical seasonal period or on preseason indexes of recruitment. Most of them have to prove their effectiveness, but Leary (20) indicates that the Laboratory of Galveston predicted effectively the 1982 and 1983 annual catches in Texas with a precision of 1 % on the basis of bait shrimp fisheries catch rates used as a prerecruïtment index. It is often argued that, because of the short life-span of shrimp, forecasts will always give too short a lead time to be really useful. This belief was, however, rejected by the industry in Australia, which stated that 1–6 weeks of lead time is largely sufficient to enable cost-effective deployment of the fleets (FAO 13). The question of forecasting models will not be elaborated further here; a review is available in Garcia and Le Reste (11). It should also be briefly noted that when the ability to predict cannot be developed at a reasonable cost the solution consists in evaluating and including uncertainty in the models (Sissenwine 30) as well as developing flexible and efficient reactive management systems.

When recruitment is highly variable and annual production only loosely linked to stock size and effort level, it seems necessary to optimize the fishery on a pre-recruit basis (Gulland 10), regulating mesh size, but above all implementing closed areas and closed seasons. This concept is largely followed in the U.S. management plan for the Gulf of Mexico (Poffenberger 14) and in some Australian fisheries (Bowen and Hancock 21). It appears, however, that without a definite limitation on the level of fishing effort, this sort of "fine-tuning management" is bound to meet with difficulties (see Section 4.1.3).

## 2.5. Recruitment Overfishing

This issue has been neglected for a long time in shrimp fisheries and the accepted paradigm was that because of the high fecundity of shrimp and the importance of inshore nurseries in determining cohort survival, shrimp stocks were unlikely to be exploited intensively enough to cause recruitment problems and that economic factors probably would limit effort to below the level critical for shrimp stock reproduction. Most of the evidence given in the past to demonstrate the existence of stock–recruitment relationships can be interpreted as artifacts owing to the short life-span of shrimp and the autocorrelation in environmental variations (Garcia 6). Penn and Caputi (5) presented some evidence that in a small and well isolated stock off an arid zone, recruitment might be affected by fishing. It is of course obvious that at some high level of effort problems of recruitment are to be encountered, although at levels of exploitation of up to 70–80% no effort–recruitment relationship was encountered in northern Australia stocks (Staples et al. 31). Garcia (7) in examining the reproduction mechanisms of the shrimp populations showed that selective fishing out of the main cohorts by the perfectly aimed shrimp trawl fishery could lead to severe disturbance of the delicate mechanism developed by shrimp through their evolution to cope with a highly seasonal environment. The stock–recruitment question remains open and is certainly worth more attention than it has received in the past.

Two sets of management measures address the recruitment overfishing issue by trying to improve, on the one hand, larval survival and estuarine carrying capacity (see Section 4.4 on stock enhancement and habitat conservation in nurseries), and, on the other hand, the spawning stock size (see Sections 4.1.3 on seasonal fishing closures or 4.2 on overall effort regulations).

## 2.6. Multispecies Management

Many different species of shrimp with different distributions exist in the waters of any tropical country. Shrimp fisheries tend to begin on white coastal shrimps of the genus *Penaeus* caught during the day. They develop progressively with additional night fishing on brown and tiger shrimps as the effort increases. As overall profitability decreases further they tend also to develop later on more coastal small shrimp of the genus *Xyphopenaeus*, *Trachypenaeus*, *Lithopenaeus*, *Metapenaeus*, and so on, of smaller size and value.

Most of the shrimp fisheries tend therefore to evolve into exploiting a mixture of shrimp species. Management is complicated if these species have different population parameters and value. Compromises must be found regarding optimum mesh size, closed seasons, closed areas, and so forth. Clark and Kirkwood (32), for instance, elaborated a model for two species and two types of boats and used it to define optimal space–time allocation of effort and fleet composition.

Management is further complicated when the accompanying finfish species are taken into consideration. Shrimp are only one element (a major one in value but a minor one in weight) of the fish assemblage available for exploitation on tropical shelves and one of the important characteristics of shrimp fishing is the importance of by-catch and discards, amounting to about 2,700,000 tons and 1,400,000 tons, respectively (Gulland and Rothschild 2). The discards are usually dead when returned to the sea. Because the issue has two facets, the by-catch can be better used or substantially reduced. The question of a better use of discards was debated at a special Technical Consultation in Georgetown, Guyana (FAO/IDRC 33).

Although there are technical problems to keep large amounts of by-catch on freezer shrimpers, the better utilization of discards is essentially an economic problem and discards are more important in some areas, for example, the Gulf of Mexico or the Arafura Sea (Irian Jaya, Indonesia), where markets for "trash" species are more limited than in others, such as India or Senegal, where such markets have developed. The landings of large quantities of trash fish can compete on the market with the fish landed by small-scale fisheries. If the quantities presently returned to the bottom are utilized, the biological problem is to know whether the resulting decrease in food on the bottom will have any effect on shrimp production. The preliminary study by Sheridan et al. (34) indicates that this effect is negligible.

The problem of by-catch is also one of conflict with the finfish fisheries. Shrimpers use smaller mesh than other trawlers (about 40–50 mm stretched) and accidentally capture juveniles of fish species targeted by other trawl, small-scale, and sport fisheries in coastal areas. These gear interactions are not receiving sufficient attention at the moment.

Shrimp fisheries can include nonshrimp species as secondary targets. Lhomme and Garcia (35) showed in Senegal that the proportion of trips aimed solely at shrimp decreased from about 100% in 1969 to only 25% in 1978 as high-value species such as soles, kingklips, and croakers were progressively added to the target list. Haysom (36) indicates an increase in pressure by shrimpers in Australia on sea snakes (for leather), pipefishes (for aphrodisiacs), sand crab, and whiting, leading in the two latter cases to conflict with professional crab fishermen and sport fishermen, respectively. Bowerman (37) indicates that by-catches of whiting helped fishermen to face unfavorable economic exploitation of shrimp, and Walker (38) refers to mixed shrimp/scallop fishery. In Malaysia fairly high economic revenues are achieved by sales of pelagic species taken in the high-opening bottom trawl used for shrimp fisheries (F. T. Christy, Jr., personal communication). Because more species are kept at each trip, it becomes necessary to consider these fisheries as single multitarget fisheries (Gulland and Garcia 39), and to manage them as such. In some instances (e.g., Thailand) shrimp are even considered as a valuable by-catch. A major difficulty arises because the added value to the catch produced by the commercialization of the by-catch or secondary target species may allow fishing effort to remain economical and to develop well beyond the optimum economic level for the highest value species, possibly leading to biological disruption (Penn and Caputi 5).

The solution to reduction of by-catch or by-catch mortality, still at an experimental stage, may be in better trawl selectivity and sorting devices; many attempts have been made, especially with nonpenaeid shrimp with trawls equipped with selection panels (FAO 40) and by-catch excluder devices (Naamin and Sujastani 41). Special on-the-deck "fish-friendly" sorting devices allowing the return of discards to the sea alive have also been developed (Boddeke and Verbaan 42; Boddeke 43). The problem is partly technical because of gear complexity, but also economic because of additional gear costs and potential loss of shrimp escaping with the by-catch. It is also biological because of the predation possibly added on shrimp from potential predators returned alive to the bottom. This last problem might be secondary because few fish caught in shrimp trawls are big enough to eat the accompanying shrimp anyway. Their survival should therefore not affect significantly shrimp predation or natural mortality. Pauly (44) has argued that in the Gulf of Thailand prerecruit survival of shrimp has increased with decreased fish abundance, but his results are still to be confirmed because most prerecruit mortality occurs in estuaries where predators cannot be affected by industrial offshore trawling and also because of bias in the computational procedures used (Garcia 6; Bailey 45). The whole issue remains open, therefore.

## 3. MANAGEMENT OBJECTIVES

The theory of fisheries management usually states that successful management is based on a clear definition of the objectives and their ranking (e.g., Gulland 10). It is, however, also generally recognized that these objectives are rarely clearly defined in reality and are at best expressed as a list of broad and often conflicting goals. The reason for this discrepancy might be that management is not a flow of information, decisions, and controls coming from the administration, advised by scientists, and aimed at manipulating the catching sector, a unidirectional process in which clear and ranked a priori objectives would certainly be the key to success. In practice, the fishery sector is a complex system comprising many subsystems with their own time scales, objectives, and pressure groups (fishermen, boat owners, processors, retailers, consumers, politicians, scientists, administrators, etc.). Ideally, management in this context must offer mechanisms allowing the fishery to evolve toward an acceptable compromise on basic objectives with minimum constraint and maximum consensus. This requires from the managing authority consultations and negotiations with all parties concerned and, unfortunately, a key-condition to successful negotiations for each of these parties is to avoid a priori statement of the true objectives (Brewer 46).

Therefore the objectives cannot always be as explicitly and precisely stated as the advisors would wish, and they will have to accept the difficult task of providing advice under a range of options that will most probably "be significantly tempered in the real world of decision by the inclusion of increased numbers of players or participants and by the presence of institutional mechanisms whose primary function is to temper and enrich the decision context" (Brewer 47).

Among the broad range of objectives retained for shrimp fisheries management the following have been noted. The long-term conservation of the resources is usually given top priority, at least rhetorically (Beddington and Rettig 48; FAO 49; Bowen and Hancock 21). The maximization of physical yield as retained, for example, in the U.S. Gulf of Mexico shrimp fishery (Leary 20) is a very traditional one. However, this simple concept of MSY has been repeatedly criticized since the 1960s (Christy and Scott 50; Gulland 51; Larkin 52; Sissenwine 53) and a review of many of the biological, technical, and socioeconomic arguments against MSY as an objective are given in Garcia and Le Reste (11, pp. 169–172). The maximization of other benefits such as economic rent, revenue incomes, foreign currency earnings, and employment are also often retained, although the whole concept of maximization has in fact been criticized because it is clear now that very rarely do managers search for a maximum of any single output that a fishery can generate (Gulland 54). Because of the complexity of the fishery system and the diversity of the objectives of its various components, some viable compromise will be looked for, and the objective mix and ranking considered "acceptable" is likely to change with time as the fishery evolves. Decrease in production costs, improvement of socioeconomic conditions of small-scale fishermen, or protection of sports on recreational fishermen are also mentioned. The better distribution of benefits is a sensitive issue because any attempt to change the established distribution pattern is likely to generate resistance and conflicts. However, it has to be tackled particularly when a disadvantaged social group must be protected. Other objectives include better use of by-catch, improvement of overall biological production by protecting juveniles, and last but not least, the reduction of conflicts. This objective has probably been, and still is, one of the top priorities of fisheries management, and it has sometimes been said that fisheries administrations too often try to solve conflicts reactively, instead of managing the fisheries. One could, of course, argue that the high level of uncertainty resulting from the complexity of the fishery system, the lack of appropriate data or models, the physical and economical environmental variability, and even the institutional uncertainty (Hannesson 55) make rational forecasting very difficult and often force management authorities to consider the fishery system as a black box and to monitor its state and stress through the violence and number of complaints, aiming at reducing them as much as possible. John Pope coined this as the "maximum sustainable whinge" strategy. Considering the potential cost of conflicts, this strategy still has a significant role to play in the future as conflicts increase in shrimp fisheries (see Section 2.3).

## 4. MANAGEMENT STRATEGIES AND TECHNIQUES

These are usually classified into two not entirely distinct categories: the regulation of catch–age composition and the regulation of fishing effort. In practice, a mix of tools from these two categories is needed for successful management. In addition, shrimp are particularly amenable to nursery habitat management and conservation, because year-class strength is largely determined by survival of larvae and postlarvae in littoral fringe areas.

### 4.1. Regulation of Catch–Age Composition

The underlying family of analytical models are based on the yield-per-recruit concept. Methods considered under this heading are aimed at reducing mortality on small sizes in the hope of improving production to the extent that potential gains in weight and value through growth of survivors will compensate for the immediate losses due to their delayed capture. This can usually be obtained by regulating mesh sizes or minimum size limits on landings. Because shrimp are fast-growing animals with seasonal recruitment, similar effects can also be obtained by regulating the fishing season and establishing seasonal or permanent closed areas; the main issue is to determine the optimum time–space allocation of fishing effort.

Because these measures exert no influence on fleet size they cannot prevent excessive investments and fishing costs. In fact these measures are more largely used because they are easier to implement than effort regulations. They are more acceptable to fishermen because they have no obvious redistributive effects; that is, they do not extensively change the traditional distribution of wealth, though in fact they may actually change it (see below). However, because they do not address the main cause of the overfishing problem (an excess of effort) they cannot be expected to solve it.

#### *4.1.1. Regulation of Mesh Size*

The selection process in shrimp is not very effective and the selection range covers a large part of the life-span. Lhomme (56) showed that the selection curves of mesh sizes from 40 to 70 mm (stretched) overlap widely. An appreciable increase in length at first capture would therefore usually involve unacceptable immediate losses. Al-Hossaini et al. (57) concluded that the 50% retention length is not well related to mesh size, perhaps because of the amount of discards and trash usually taken in shrimp fisheries. However, as noted by Garcia and Le Reste (11) the regulation of mesh size can in theory be useful because the long-term gains can be obtained in the same year, without short-term losses, and the unit value of shrimp increases rapidly with size, so that gains in value are therefore potentially higher than gains in weight. In addition, a slightly wider mesh size could also help to reduce by-catch (while affecting shrimp catches very little) and thereby potentially improving the potential yield of coastal finfishes (see Section 2.6).

Mesh-size regulation is often complicated by the fact that shrimp fisheries tend to exploit a mix of shrimp species with different population parameters and market value. Adjusting the mesh size to the most profitable stock (usually the larger species) leads to underexploitation of the smaller ones. When the main associated species is fish (as in the fishery for *Parapenaeus longirostris*, sea breams, and hake in Morocco), optimizing for shrimp, the high-value species, leads to overfishing of finfish.

The selectivity of push nets, stake nets, traps, bamboo weirs, and other types of estuarine devices can, in theory, be modified to allow juveniles to escape. In bamboo weirs, for example, the spacing between the bamboo lattices can be regulated (Le Reste and Marcille 58). However, owing to the artisanal production of such lattices the possibility of enforcement seems rather poor. In addition, because the target is often migrating juveniles, the likelihood of any "long-term" effect to compensate for immediate losses does not exist and it is doubtful that a consensus can be obtained.

Consistent program of control of mesh size are usually necessary in the ports and at sea because fishermen can circumvent the mesh size regulation by using a different mesh size; lining the cod end with a finer mesh size, inside or outside; superimposing two layers of authorized mesh size reducing by about half the actual escapement openings; attaching heavy weights to the cod end; trawling fast or changing the mesh hanging ratio; or lining the regular cod end externally with a larger mesh but making this tighter than the cod end, impeding the cod end from expanding normally and keeping its mesh size closed.

Mesh sizes are regulated in most shrimp fisheries. However, the age at first capture in shrimp is determined not only by mesh size but also by the distribution of effort in time (in relation to the recruitment period) and space (in relation to nurseries or shallow depths). Garcia et al. (59) have shown in French Guiana that the size at first capture had decreased with time as effort increased, despite the fact that the mesh size had apparently not changed. Experience shows that mesh-size regulations are difficult to enforce on depleted resources and that the use of small mesh sizes by fishermen is often the consequence of overfishing (excess of effort), not its primary cause (Garcia 60), leading to the need to address the problems of excess effort and excessively small mesh size simultaneously and not considering mesh-size regulation as a viable second best alternative to effort regulation. In the case of sequential trawl fisheries operating successively inshore and offshore, the implementation of a common mesh size (or single age at first capture) may lead to a transfer of fishable biomass from the inshore sector of the fishery to the offshore sector and this may be a source of conflict. This point is also discussed in Section 4.1.3 on closed seasons.

### *4.1.2. Minimum Landing Size*

This regulation is intended to render the fishing unattractive in areas where small shrimp are abundant, to make the regulation of mesh size more effective, and to reduce the temptation to evade the mesh-size regulation. It is usually agreed that this method is useless when used alone, and it is difficult to enforce when large adult shrimp are mixed with juveniles. This is the case, for example, in the Gulf of Mexico, where adult white shrimp are mixed with juveniles of brown shrimp. Small shrimp are fished and discarded dead. Rounsefell (19) reported that up to

80% of the catch was discarded. In cases where a minimum landing size has been applied it was often under pressure from processors or dealers with marketing problems and not for serious biological reasons. The regulation has, in fact, been abolished in Texas in the new management plan and replaced by a total seasonal closure (Leary 20). Ruello (61) had already recommended the abolition of such a measure in Australia.

### 4.1.3. Seasonal Closures

The greater part of the very shallow trawlable areas of bays, lagoons, and littoral fringes are occupied by shrimps migrating toward deeper waters for spawning. Here shrimp size varies seasonally in relation to the seasonal migration cycle, and in order to improve the yield per recruit, they must be protected from fishing up to a certain size. The "ideal" optimal size at first capture can be determined by yield-per-recruit analysis by weight and value. Other outputs can be considered as well, if required (e.g., employment and fuel consumption). The trade-off is between catching small low-value shrimp at low operating cost inshore, and catching bigger and higher-value shrimp at higher operating costs offshore. For instance, in artisanal fisheries shrimp can be caught by push nets in lagoon fringes with very little gear and equipment, or later on in the deeper channels during migration, using stake nets, canoes, and outboard engines, or later still in coastal waters using "baby trawlers" or drift nets, and finally, in offshore waters using sophisticated multi-rig freezer trawlers. Because shrimp migrate continuously to deeper waters, there is, for each of these types of exploitation and depth strata, an optimum size at first capture below which there is "local" growth overfishing, and above which there are important losses by natural mortality and migration.

If we consider the whole life cycle, there is also an optimum size at first capture and fishing pattern to achieve the overall highest value per recruit from a stock, but this may involve totally banning some fishing methods, totally protecting some areas, and regulating seasonal fishing in estuaries and at sea. The optimum fishing regime evidently will depend on the objectives retained for the fishery. The highest possible total market value or foreign exchange earnings might be obtained by promoting offshore trawling and licensed foreign fishing for export. The higher level of employment and lower fuel consumption might be obtained, on the contrary, by promoting small-scale fishing. In most cases compromises will have to be found between conflicting objectives of this sort. Another objective frequently retained for closed season management is the improvement of the spawning potential of the stock by closing the fishery either during the recruitment period or during the spawning period.

The problem can generally be considered at two levels: (1) determination of the "best" closed season, on the average, and (2) fine tuning of the opening date and duration of the fishing season from year to year in order to optimize results according to small changes in the recruitment parameters.

The determination of the average "best" season can easily be made using a yield-per-recruit model. The Thompson and Bell model (in Ricker 62) is particularly useful because it offers a time-discrete representation of the life cycle and is easy to explain to fisheries administrators. It has been used, for example, by Garcia and van Zalinge (63) in Kuwait and Willmann and Garcia (64) for the Guyanas–Brazil fisheries. The impact of a seasonal closure depends on its dates and duration, as well as on the overall level of effort and the seasonal pattern of catchability (Garcia 65; Sluczanowski 66). When an inshore and offshore fishery operate sequentially, the overall results of a closure must be considered and the total catch or value, as well as other economic benefits, depend also on the respective effort levels in both fisheries (Garcia 65; Grant and Griffin 67; Nichols 68; Somers 69; Willmann and Garcia 64).

Clearly in sequential fisheries for shrimp, the closed seasons in the inshore bays and offshore coastal areas must be coordinated for optimum results, and their effects may involve not only overall improvement in the fisheries output, but possibly also a change in resource allocation. Garcia (65), Blomo et al. (18), and Nichols (68) have shown that the total output in terms of tonnage or value is not greatly affected by changes in effort in inshore and offshore fishing. The main effect is on allocation and is generated through migration of biomass (and therefore value) from the inshore to the offshore fishery given that the stock may no longer be accessible to inshore fishing if it reopens, as for example in the Kuwait bay fishery for *Penaeus semisulcatus* (FAO 70). This can be a source of social unrest in some countries. A similar problem exists when migration during the closed season transfers some benefits of a closed season to another country. This may be the case between Texas and Mexico (Leary 20) and between Senegal and Guinea-Bissau (Lhomme and Garcia 35).

Once the "average" appropriate period for a closed fishing season is defined, it is possible to fix it definitively. However, shrimp are highly sensitive to year-to-year changes in the coastal environment which vary the onset of spawning, timing of larval recruitment inshore, subsequent growth and survival, dates of the migration of the main cohorts from lagoons, and so on. In such situations fishermen have reservations about arbitrary dates, and it may be necessary to set seasons annually, based on preseason surveys. This has been applied in the Gulf of Mexico (Ingle 71; Ford and St. Amant 72) and in Australia (Ruello 61; Bowen and Hancock 21). The optimal opening date is forecast by extrapolating observed growth rates of the main cohorts to the date at which 50% or 75% of the cohort is at optimum size. Applying this technique can be complicated when two or more species with different life cycles occur together. The problem is discussed by Ford and St. Amant (72) and a solution is proposed by Eldridge and Goldstein (73).

High seas closures to improve yield per recruit have met with variable success. In Texas waters the standing stock has been theoretically increased by 30–36% and the benefits reached apparently 6–9% of the annual predicted catch (Nichols 68). A longer closed season would produce higher benefits but probably at a higher cost. According to Rackowe (cited by Sribhibhadh 1), however, the Texas closure had other negative effects such as a decline in product quality because vessels and plants had difficulties in handling very large catches over a short period and the percentages of small shrimp landed rose, obviously contrary to one of the original objectives of the measure.

In Australia (Gulf of Carpentaria, St. Vincent Gulf) management by flexible closed seasons has been very successful and, confirming the earlier statement by Ruello, the benefits are said to pay largely for the costs incurred (Somers 69; Bowen and Hancock 21). Sluczanowski (66) rightly mentions, however, that the likelihood of successful fine tuning of management depends largely on the precison of the parameters used in forecasting and that in Spencer Gulf, Australia, 90% of the optimum results can already be obtained with the average parameter. It can probably be added that the cost–benefit ratio of fine tuning depends on the year-to-year variability of the recruitment parameters. This author also stresses that the losses incurred by suboptimal management increase rapidly with effort. At high levels of effort fine tuning might be essential, but the precision required will be obtained only at high additional research cost. During the discussions organized by the 2nd Australian National Prawn Seminar (Rothlisberg et al. 12) the industry directly involved in undertaking the preseason surveys in the Gulf of Carpentaria declared that the direct cost of the surveys needed for fixing the flexible dates was about A$200,000/yr, and the benefits reached A$2,000,000. It is worth noting that in Australia the closed-season management system operates on the basis of flexible dates within the framework of a limited entry, contrary to what happens in the United States. Blomo et al. (18) underlies that "fine-tuning of the closed season could involve the analysis of optimization of the use of various boat sizes at various depth ranges (probably also during various time periods)." Sluczanowski adds that optimization of management of a complex of stocklets with slightly different recruitment parameters may lead to the need for different closure dates in different subareas.

A very important conclusion of bioeconomic simulations obtained by Blomo et al. (18) and confirmed by Sluczanowski (66) is that the likely upper limit that fishing effort can reach during the open season must be known in order to calculate the optimum fishing dates. Only in the case of a "sole owner" situation as in some Australian limited-entry fisheries or in Saudi Arabia this condition can be strictly fulfilled. This confirms the general statement made earlier (Section 4.1.1) that regulation of size at first capture is likely to be inefficient if total effort level is not properly controlled, and is perfectly in line with optimization theory. In fact, Clark (74) stated "achievements of satisfactory levels of economic efficiency is probably impossible unless some form of exclusive 'property rights' or appropriate substitute can be established with respect to the fishery resource."

In the Persian Gulf, a regional 5-month closed season was implemented from 1980 to 1982 after a major decrease in total catches believed to be linked with excessive fishing effort. Subsequently Morgan and Garcia (75) showed that the long-term decrease in recruitment had no relationship with the increase in effort and suggested that environmental causes were most likely responsible. The closed season was later on reduced to 3 months in Kuwait and flexible dates were recommended. Fishing for a secondary species (*Metapenaeus affinis*) has recently been allowed during the closed season for the main target, *Penaeus semisulcatus*, in specially defined areas (Abdul Ghaffar and Mathews 76). In Saudi Arabia the closed season has been lengthened to 6 months (February 1 to July 31), that is, beyond the legal requirements, by the sole owner fishing company operating in the country, with substantial profits (R. Willmann, personal communication.).

In situations of heavy overfishing it is very often proposed by fishermen to close fishing during the spawning season to help conserve enough spawning potential for reproduction. If fishing is concentrated on juveniles at recruitment it can be easily shown that unless spawning corresponds to a particularly marked schooling behavior (which would drastically increase fishing mortality), it would not be very fruitful to close fishing on spawners once the main cohorts have been decimated by excessive fishing. The fecundity per recruit at a given level of exploitation is in this case increased more significantly by protecting juveniles during the recruitment period (Garcia 65; Garcia and van Zalinge 63).

Moreover, the assured positive effect of protecting spawners or increasing spawning potential per recruit relies on the assumption that there is a stock–recruitment relationship (SRR) and that increasing spawning stock size will increase recruitment and subsequent overall biomass; this has still to be convincingly demonstrated (see Section 2.5). It is, however, obvious that below some level of stock size, problems on stock reproduction are to be expected, and that once a stock or its main cohorts have been driven to excessively low levels of abundance by fishing or by a combination of intensive fishing and adverse environmental conditions, the question of whether or not there is indeed an SRR is not the most relevant. The depleted spawning stock should in that case be enhanced if only to give the stock a higher probability of recovering when environmental conditions improve (Csirke and Sharp 28).

### 4.1.4. Other Closed Periods

Bowen and Hancock (21) refer to moon closures. In Western Australia fishing is periodically closed for 10 nights around the full moon in order to prevent harvesting of a significant proportion of soft newly molted prawns, to restrict fishing during periods of low catchability (sic), and to reduce effective effort.

## 4.2. Regulation of Total Fishing Effort

The concept is to reduce fishing mortality (and economic inputs) to improve stock size, yields, and benefits. The annual fishing mortality by trawling can be defined by

$$F = \sum_{i=1}^{n} q_i f_i = \sum_{i=1}^{n} q_i p_i t_i$$

or by

$$F = Y/B$$

where $q$ = catchability coefficient; $p$ is the individual fishing power of a vessel; $t$ the fishing time; $i = 1, \ldots, n$, the number of vessels; $Y$ the annual yield; and $B$ the stock biomass. Fishing mortality can therefore be reduced by reducing either the power of each vessel, $p$ (gear and vessel limitations), the fishing time $t$ (by catch quotas, institutional reduction of fishing time, moon closures, weekend closures, etc.), or the number $n$ of boats allowed in the fishery (limited entry).

### 4.2.1. Limitation of Vessel Fishing Efficiency

This can be done by controlling gear or vessel characteristics. The limitation of gear characteristics is a particularly relevant option for shrimp fisheries where technological progress has been very significant. The shift from single rig (one trawl per boat) to double rig (two trawls), triple rig, and twin rig (four trawls/boats) has produced a significant increase in efficiency (see Garcia and Le Reste 11, p. 34 for a short review). Progress in sorting on board has also contributed to the increase in efficiency. As a consequence total fishing pressure has increased faster than nominal effort. Many shrimp fisheries around the world still present potential for increased efficiency if no gear limitation is implemented, although fishing effort might already be excessive. Gear size is regulated in some countries as well as the number of trawls allowed on each trawler (Ruello 61; Bowen and Hancock 21). Such an imposed decrease in efficiency adds, however, to the cost of fishing and is hardly acceptable from an economic point of view.

Management techniques in shrimp fisheries include such vessel restrictions as limits on overall boat length and/or engine power, especially when effort is excessive, whether or not effort is limited and boat replacement policy is implemented (see Walker 38), for example, in southern Australia). Vessels above a given size, tonnage, or horsepower can then be prohibited, and the shift to a preferred boat size can be accelerated by economic incentives such as special soft loans or subsidies for a particular size. The boat replacement policy is facilitated if the limited factor is quantified in units, which are transferable. A new boat can then be entered into the fishery only if the equivalent amount of units have been bought out (see Bowen and Hancock 21) for an example). Subsidies to promote a given type of vessel can have perverse economic (see Section 4.5) and technological effects.

### 4.2.2. Limitation of Fleet Activity

In critical situations where excessive fishing power exists, fishing time may be reduced by setting catch quotas with or without formally limiting the overall fleet size.

Institutional fleet immobilization by which fishing is restricted some days per week (e.g., weekend closures) or per month (moon closures, see Section 4.1.4) have also been used. Clark (77) indicates that catch quotas alone cannot limit fleet growth and only ''replace overfishing by overcapacity.'' When short-lived animals such as shrimp, squid, and anchovy are involved, regulation by annual total catch quota is even worse. In practice the individual race for catching as much as possible before the overall quota is taken leads to increased fishing power and concentration of fishing earlier and earlier in the season. The same annual catch in weight is taken in a progressively shorter season, and is composed of more and more younger shrimps. Fishing mortality continues to increase and nothing prevents investments from becoming excessive. This policy may result in very high peak catches in a short period of the year, creating problems and high costs of storage. The overall effort could be best distributed by quotas for shorter periods (quarterly or by month). Such regulations would be difficult to apply because they necessitate a good control on landings; this is not always possible, particularly in developing countries. Leary (20) indicates that in the Gulf of Mexico inshore fishery daily catch limits are implemented. Another solution apparently not yet used on tropical shrimp, the transferable individual fisherman quotas (Christy 78; Moloney and Pearse 79), could in theory avoid excessive costs of fishing.

### 4.2.3. Limitation of Access to the Fishery

None of the measures discussed earlier can really avoid biological or economic overfishing when used alone. At best, improved state of stocks and profitability is temporary and the competition between fishermen for appropriation of the newly created rent rapidly leads to its dissipation (see introduction to Section 2). It is important to note that the extension of jurisdiction has not changed the issue for developing countries in the absence of regulated access of citizens to the EEZ resources.

Direct regulation of the level of exploitation by controlling the fleet size and the horsepower is designed to minimize such difficulties to prevent biological overfishing, but also to reduce costs, if effective. Walker (38) indicates, however, that in Australia "even in limited entry regimes there is a tendency to fish prawns to their biological maximum and beyond." A review of the problem of effort regulations in general can be found in Stokes (80), FAO (49), and Beddington and Rettig (48). The limited-entry system has advantages and disadvantages and its chances of success depends on many complicated factors.

In relation to shrimp stocks, Gulland (10) noted that limited entry should be implemented early in the development of fisheries because it is much easier to stop development of a fleet than to reduce it after the crisis has started, although it is probably difficult to convince fishermen of the need for limited entry when earnings are still very high. However, in some Australian shrimp fisheries limited entry has been in force from the beginning of the fishery in 1960 and according to Hundloe (81) and Bowen and Hancock (21) excessive fishing effort and overcapitalization are presently a problem in most fisheries whether or not limited entry was implemented at an early stage. According to Meany (82), however, limited entry has limited/restricted the overcapitalization process. The reason for failure to contain total effort in limited-entry shrimp fisheries lies merely in a rapid increase in effort just prior to closing the fishery when this measure was made public, and subsequently a progressive increase in fishing power by fleet upgrading to the authorized engine or size limit.

Limiting entry consists in limiting the number of fishing permits. It must involve estimation and monitoring of boat performances in order to detect subtle changes in fishing efficiency—"seepage effects"—stemming from technical innovation (see Section 4.2.1) or improvement in the space–time distribution of fishing operations. The number of licenses may have to be adjusted periodically to compensate for the increase in efficiency, for instance, by implementing a buyback scheme, possibly funded from the revenues generated by selling fishing rights. It is usually considered that the efficiency of such a mechanism is improved when the fishing rights are transferable through the market (Clark 77). Logbooks that can be required in exchange for licenses could be an excellent source of data for monitoring the fleet activity and efficiency.

One of the most controversial features of limited entry is that it may result in large rents. If they accrue to the license holders, they add considerable value to the license. This surplus value reached a $150,000 in southern Australia (Sluczanowski 66) and can be cashed by the original first license holder when selling his right (windfall gain). Subsequently the surplus value becomes part of the capital costs to the new entrants. Whether or not this surplus value should accrue to the license holder or be extracted by the governments is a matter of philosophy.

Limited entry may result in social tension if the returns to the group of "privileged" license holders are much greater than in comparable employment opportunities and results in great pressure from those prohibited entry to the fishery. Introduction of appropriate license fees can allow the state to recuperate part of the surplus value created by management, discourages further applications for entry, and provides financing for other governmental initiatives such as the promotion of development of a priori unfavorable areas This last possibility has been used in Australia (Hancock 83).

It has been argued that limited entry creates a discrimination against outside fishermen, may allow inefficient fishing methods to continue (Bowen 84), and discourages technical advances by creating a quasi-monopoly (Gulland 10). According to Hancock (83) this has not been the case in Australia, where the techniques have advanced rapidly.

Limited entry to one fishery tends to lead to transfers of the excess efforts into neighboring fisheries or stocks and it usually becomes necessary to limit entry in all neighboring fisheries in order to control such transfers.

In extensive artisanal fisheries, limited-entry management is considered less appropriate, particularly in developing countries where it creates social and economic problems. The identification of fishermen is a significant deterrent to direct attempts of direct control of effort, although licensing of artisanal fishermen has received attention in some areas (FAO 13). In any case, close coordination between authorities in charge of management and development is particularly needed in this sector.

### 4.3. Closed Areas

Areas can be permanently or seasonally closed to fishing. Permanently closed areas or sanctuaries are widely used to protect both very small shrimp from capture and shrimp habitat from degradation by trawling gears. They aim, therefore, at optimization of the yield per recruit in value (as with seasonal closures) and conservation of critical habitats. They have been maintained, for instance, in various states of Australia (Bowen and Hancock 21) and in the Gulf of Mexico (Leary 20). They can be limited to small areas of marshland or extended into the open sea, as in Florida where the permanent sanctuary extends from the Everglades National Park to 18 m deep offshore. The prohibition of fishing can be reinforced by a regulation on minimum commercial size. In extensive deltas in developing countries these measures might be difficult to enforce because of the difficulty of access and also because small shrimps are often commercialized in a dry powdered form and sold as condiment at a high price.

Some areas are only seasonally closed to exploitation in relation to seasonal fishing closures for which the rationale for this measure is similar. The area closed could be only part of the area of distribution of the species (e.g., where the concentration of juveniles is highest) or the whole area of distribution of the species. In Texas, before 1981, only the waters under state jurisdiction (9 miles) were closed to fishing. The measure had to be replaced after this date by a closure of the entire Fishery Conservation Zone of Texas because of difficulties in enforcing the partial area closure. In Kuwait (Mathews 85) the closure concerns only the major area of distribution of the most important species whereas the rest of the fishing zone remains open to exploitation for secondary species.

Areas are sometimes closed to some type of fishing in order to allocate the resource to a particular socioeconomic stratum of fishermen. This is the case for coastal zones prohibited to trawling and reserved for passive small-scale gear. In countries with excessive trawling capacity, encroachment on the coastal closed area is usual and leads to permanent conflict with small-scale fishermen (see Section 2.3).

## 4.4. Estuarine Habitat Management and Stock Enhancement

The concept underlying these management techniques is to maintain and improve the reproductive potential of the stock by increasing larval survival through aquaculture and seeding of postlarvae and young juveniles, or to maintain or increase the carrying capacity of the nursery by habitat enhancement or conservation.

The first of these approaches (larval or postlarval seeding) has been followed in some countries for various species. It has been applied widely in Japan for shrimp (Hiroko 86; Doi et al. 87; Hasegawa et al. 88) and also in Kuwait (Mathews 85). It is usually a by-product of aquaculture and popular with managers and fishermen although its biological and economic efficiency has still to be convincingly demonstrated.

Nursery habitat protection and enhancement is more likely to lead to successful results. The very early stages of the life cycle occur in the intertidal zone of estuaries, in fringing creeks, mud banks, tidal swamps, mangroves, eelgrass meadows, and so on. It has been shown that the potential of a shrimp resource is proportional to the amount of habitat available in the nursery (Turner 89; Barrett and Gillespie 90, 91). The importance of the mangrove area available was shown by Martosubroto and Naamin (92). Doi et al. (87) have shown that the shrimp production in the Seto Inland Sea decreased progressively as a direct function of the amount of estuarine land reclaimed. Habitat conservation is therefore a very important component of shrimp stock management and identified nurseries must be protected from pollution, deforestation, land reclamation, damming, and housing development. One usual problem is that the modification of the estuaries by various user groups is not under the control of the authority managing the fishery. Intensive dredging of lagoon inlets changes the salinity regime in the nurseries and may have important consequences on shrimp stocks, composition, or abundance (Ewald 93). Kurata (94, 95) has proposed actively to manage the nursery areas by constructing artificial tidelands to improve postlarval survival.

### 4.5. Monetary Measures

These measures, used either for management or for development, are powerful tools for influencing fishermen's behavior, and general discussions on their advantages and drawbacks can be found in Clark (77) or Beddington and Rettig (48). Monetary measures have decisive effects on effort levels even though they are often implemented without explicit reference to this effect and their direct use to regulate effort can be difficult (Crutchfield 96). The literature on shrimp fisheries regarding these measures is very limited indeed.

Taxation of fishery inputs seem an obvious way of reducing fishing effort by reducing profits and incentives for expansion, particularly in artisanal fishing. However, the effects depend on the supply response of the fishery and specifically on the price elasticity of the demand for the species; that is, it depends on how far the fishermen can pass on the increased costs to the consumer (Lawson and Robinson 97). Baisre (98) indicates that price manipulations were used in concert with spatial and seasonal regulations to reallocate effort among alternative shrimp stocks after the 1979 hurricane in Cuba.

Subsidies have opposite effects. They can be used, for example, to divert excess effort to underexploited species or influence fleet size composition. In the latter case they can have powerful distorting effects and, according to Hundloe (81), they have increased costs, added to the burden of overcapacity, and led to a boat size structure that might not be ideal in Australian shrimp fisheries. This is particularly important when it is considered that the duration of a profitable fishing season depends on boat size (Penn and Hall, cited by Bowen and Hancock 21). Fishery development measures often have more effect on effort than those of management, and a coordination of action is needed between these two domains of fisheries. Development subsidies should be temporary and suppressed as soon as the aim is reached. Financial resources extracted through license fees could in turn be used for development and excess effort can be channeled.

High license fees can also be considered as a way of accruing part of the rent of the fishery to the country. They would reduce the surplus value attached to the fishing right and therefore the surplus capital cost of new entrants to the fishery.

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