chapter 7

ENVIRONMENTAL IMPACTS

7

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Introduction

As noted in Chapter 1, capture-based aquaculture is an overlap between fisheries and aquaculture, since it is based on the removal of “seed” from the wild stocks for subsequent on-growing in captivity using aquacultural techniques. This practice may have an impact on both the environment and the ecosystem. Although these impacts may be negligible, and the benefits to the local communities considerable, it is still necessary to understand and evaluate the potential effect on the overall ecosystem. There are many examples of ecologically-unsustainable development and the need to prevent their repetition on a global basis has been generally accepted. The problem has to be balanced with the requirement for economic development and increased food production in developing countries. Finding the balance between rational use, conservation and preservation is the logical course to optimize man’s use of natural resources on a long-term basis. To assess the sustainability of capture-based aquaculture, all environmental impacts need to be considered, bearing in mind the complexity of the ecosystems involved. This chapter considers environmental impact under two general headings or steps.

The first step, which relates to fisheries, consists of the collection of the “seed” from wild resources. The effects of “seed” collection are direct or indirect and are considered in the next two sections of this chapter, on “resource removal”. The direct effects consist of the fishing mortality exerted on target populations (overfishing), the impact of removing immature fish from the genetic stock, the fishing mortality sustained by non-target populations that are caught or killed along with the target species (bycatch and discards), and the physical impacts on benthic organisms and habitats (by detrimental fishing methods). Indirect effects include the impacts caused by biological interactions between species in the ecosystem (i.e. competition, predation, changes in the trophic chain), the mortality caused by lost gear (ghost fishing), and the environmental effects of dumping discards (Goñi 1998). Indirect effects have the potential to create greater impacts on aquatic ecosystem structure and function than fish removal (Hammer, Jansson and Jansson 1993; Botsford, Castilla and Peterson 1997; Helmlund and Hammer 1999). It is more difficult to characterize indirect effects because they are complex, respond to poorly understood feedback mechanisms and may occur over large areas and at a variety of time scales (Goñi 1998).

The second step, concerns the aquaculture systems used for capture-based aquaculture. These share most of the environmental aspects related to “classical” aquaculture methods. The culture of fish in cages has the potential to cause both onshore and offshore impacts on the surrounding environment, with a severity scaled to the size and the intensity of the farming operation. Such impacts include distortion of the local ecosystem; short- and long-term near-field and far-field eutrophication, chemical pollution (i.e. by xenobiotics), cross-transmission of parasites and pathogens, aesthetic deterioration in coastal areas, organic enrichment, and habitat modification, etc.

Other impacts concerning the aquaculture side of the operation are specific to capture-based aquaculture practices and include both environmental and social effects. One example of this is the towing of the cages used for the collection of live tuna at sea, which can take several weeks or months, depending on the distance between the catching location and the aquaculture site. This operation may result in conflicts with other fisheries and with shipping navigation. The effect of farming operations are considered in the section of this chapter entitled “effects of farming operations (grow-out)”.

It is very clear that there are many potential environmental impacts of capture-based aquaculture. The problems associated with the removal of “seed” from wild stocks are very difficult to quantify or accurately assess, and the concerns of the fisheries sector must be addressed. However, the benefits and potential value-added inputs to a fishery need to be balanced against the negative effects.

Resource removal – direct effects

The direct effects of the collection of wild “seed” for capture-based aquaculture are reviewed in this section of the report.

Overfishing

The main reason why species are chosen for capture-based aquaculture is their high market value. As a result of their value, most of these resources are already heavily exploited by commercial fisheries. Since the basis of capture-based aquaculture is the collection of “seed” from the wild stocks, this activity may increase the fishing effort on the target species. A particular danger arises for populations that are economically valuable but have low reproductive capacities because they mature at a large size.

FAO assessments of the various world fish stocks classify them in a range of categories from “under-exploited” to “overfished”. According to Hall (1999), overfishing can be divided into two types, recruitment overfishing and growth overfishing.

Recruitment overfishing occurs when a stock is depleted to a level where there is an unacceptable risk that the remaining adults will be insufficient to produce enough offspring to maintain the stock. This situation is most likely to occur in pelagic species where the individuals often form dense aggregations that can be easily detected, so that catches and catch rates can remain high even when the stock is severely depleted (Hall 1999). Additionally, many pelagic species are prone to dramatic natural fluctuations in recruitment success (e.g. the “*anchoveta*” in Peru and the herring fisheries in the North Atlantic, which both occur without warning).

The other type of overfishing is termed “growth overfishing”, which describes a state where fish are harvested at the wrong time in their life cycle. The extremes are the removal of a few larger older fish, or the capture of many small young fish. In between there is an optimal age at which the product of numbers and body size is maximal (Hall 1999).

Despite apparently substantial efforts to manage fisheries worldwide, there has been an almost universal failure to prevent the decline of fish stocks and the deterioration of the marine environment. Between 73-75% of the fish stocks globally offer no possibilities for increasing catches (FAO 2000).

The difficulties facing fisheries management in reducing fishing effort before the commercial extinction of the target stocks occur are immense. The characteristics of the life history of each species determines the level of fishing effort that will risk the survival of an exploited stock. Those characterized by short-life spans, rapid population growth and high reproductive output (R-selected species) respond rapidly to fishing and can cope with relatively high levels of mortality at young ages. Conversely, species with low natural mortality that allocate more energy to individual growth through competitive fitness than to reproduction (K-selected species), will support relatively low rates of fishing mortality and at older ages (Goñi 1998).

Accurate assessment of the effects of overexploitation on a target population is not a simple task. In most cases this is due to the difficulty in separating natural and fishing-related mortality, and to the lack of stock assessment studies prior to the onset of exploitation. Where a direct link between stock collapse and over-exploitation has been established, natural changes (such as unusual hydrographical conditions) have also been seen to exist (Goñi 1998; Masuda and Tsukamoto 1999).

The selected species that are considered in this report exhibit late reproduction, large size at reproduction, long-life spans, and form large spawning aggregations. This makes them vulnerable to overexploitation. In fact, the impact of intensive fishing is exacerbated by the K-selected life strategies of these genera and their tendencies to form predictable spawning aggregations. This may be critically important for population maintenance and the genetic diversity of the breeding stocks.

Heavy impacts on spawning aggregations are generally undesirable, and every attempt should be made to protect these brief, but important phases of the life cycle of these species from excessive disruption or exploitation. It is also essential to know how long the aggregations last, whether fish spawn throughout the entire period, and whether the same fish return repeatedly to the same site. Additional knowledge concerning the distance individuals travel to each aggregation site, and the proportion of any particular population involved in each aggregation, would facilitate management.

At the present time, none of the life cycles of the selected species is completely understood, and the biology of the species could cause more difficulties for stock evaluation. For an example, the removal of fingerlings from heavily fished adult populations may be an important factor contributing to the population decline of species such as the Hong Kong grouper *E. akaara* (Morris, Roberts and Hawkins 2000). This is likely to be significant because they spawn in limited areas throughout their geographic range. Sometimes this may simply reflect an area that is heavily exploited in general, but the possibility cannot be ruled out that some populations may be partially or fully self-recruiting and depend entirely on one or several aggregations (Rhodes and Sadovy 2002). Capture-based aquaculture seems to influence the status of some local grouper populations due to the “seed” collection for aquaculture practices. According to Sadovy (2000), capture-based grouper “seed” availability has declined in many areas of SE Asia, which may be in part be attributable to overfishing.

Carangid fish such as the greater amberjack have been heavily exploited because they form schools as an ecologically anti-predatory behaviour. Since 1993 (Andaloro 1993; Mazzola *et al.* 1993), some published fishery statistical data on the greater amberjack (*S. dumerili*) have indicated an over-exploitation of the juvenile classes in some areas of the South Mediterranean Sea. The availability of greater amberjack juveniles for capture-based aquaculture today comprizes a bottleneck for the development of this activity in Mediterranean countries. On the other hand, the status of the greater amberjack in the Gulf of Mexico has been estimated to be not overfished (NMFS 1998). Defining a species as overfished is difficult when several factors occur at the same time; this is the case for the Japanese amberjack (*S. quinqueradiata*) in its Pacific sub-population. Terauchi *et al.* (1991) observed a declining trend in adult fish stocks. This was probably due to the collection of larvae (“*mojako*”), which affected recruitment to the adult stock, coupled with a short-term decline due to an environmental factor (an abnormally low water temperature in the Pacific coastal sea area of Japan observed that year).

Most tuna stocks in temperate or tropical waters are under heavy pressure and are intensively or fully exploited. Some stocks are already overfished. Biological overfishing has been avoided on many stocks because of economic constraints and by transferring excess fishing capacity to other areas and oceans (South Pacific, Indian Ocean). By fishing further offshore on domes and thermocline fronts, the potential for increasing the exploitable biomass has reduced effort on more easily accessible, but less prolific stocks. After declines in the populations of bluefin tunas (northern and southern populations) were recorded, these stocks have been managed by regional bodies. The Convention for the Conservation of Southern Bluefin Tuna (CCSBT) was negotiated in 1994 in response to dramatic population declines. In the past, massive overfishing probably reduced the ability of the species to naturally replace itself and maintain healthy population levels (Buck 1995), so that today it is still considered an overfished resource. ICCAT (the International Commission for the Conservation of Atlantic Tunas) has defined two management units, West Atlantic tuna and East Atlantic tuna populations. Tudela (2002b) states that the western stock is overexploited and notes that the assessment of the East Atlantic bluefin tuna stock by ICCAT published in 1998 indicated that there had been a strong decline in the spawning stock biomass since 1993, as well as an increase in fishing mortality rates. The spawning biomass was estimated to be less than 20% of the 1970 level, and projections predicted a high probability of collapse within the following few years. The intense fishing pressure on small tunas seems to be contributing to overfishing and is reducing the potential long-term yield from the resource (Tudela 2002a,b,c). Today it is still difficult to evaluate the stock owing to lack of scientific data. It has been shown that it is difficult to detect overfishing or stock depletion risks in bluefin tuna, as spawning stocks and yields display conspicuous long-term fluctuations. This is the result of a combination of year-to-year variations in recruitment and a long life span, as Fromentin and Fonteneau (2001) have shown using a mathematical model.

There has been a general reduction of the catches of glass eels of the European eel (*A. anguilla*) but recent studies have show that there is no actual decline in the total fishery yields along the Swedish west coast (Svedäng 1999). Globally, the annual catch of glass eels of all species has gradually decreased over the past 25 years (Tanaka 2001) and a shortage of “seed” fish has become a very serious problem for eel capture-based aquaculture.

Recruitment success

Sensible exploitation of a fish stock requires management through legal and social instruments that in some way limit access to the resource. The fundamental biological aim for managing fisheries on a sustainable basis is that the catch rates should be balanced by recruitment. The problem is that for most stocks, recruitment cannot be simply predicted. While biological objectives have been the focus for fisheries biologists (and the sustainability of stocks is clearly a primary consideration), economic and social aspects of fisheries management also have profound effects on the choice of management regime, and the rigour with which it is imposed (Hall 1999).

For the species used in capture-based aquaculture, the problem of predicting recruitment is by far the most difficult facing fisheries biologists, who cannot be held solely responsible for the failure to manage fisheries successfully. Sound scientific advice is often not implemented because political and economic interests overturn it.

In pelagic spawning fishes such as groupers, where eggs are released into the water column to drift within surface currents, early natural mortality rates must be extremely high between egg production and settlement (when young fish change from their planktonic to their benthic phase) (Sadovy and Pet 1998). Estimates suggest that although each female grouper is capable of producing millions of eggs, only two young from each spawn will survive to adulthood under stable population conditions. What is not known is where the bulk of this early natural mortality occurs, and what the causes of this mortality are. If natural mortality remains high for some time after settlement, then the removal of young juveniles for capture-based aquaculture may have little impact on adult stocks, because most juveniles taken would otherwise perish due to natural causes. However, if early natural mortality rates have dropped to low levels prior to juvenile capture, then fishing mortality will represent an important source of total mortality (which is the sum of fishing mortality plus natural mortality).

Natural mortality drops rapidly during the early post-settlement period in tropical reef fish, i.e. several weeks or months following settlement. This strongly suggests that post-settlement mortality drops within a few weeks or months after settlement on a reef across a wide range of species and, moreover, that any harvest after this early period can negatively influence subsequent stock size (Sadovy and Pet 1998). Specimens taken for culture may be up to one year old at capture, and therefore many are probably caught well beyond the early weeks or months post-settlement. If this is the case, then fishing mortality represents a substantial proportion of total mortality and the fishery should be managed to avoid overfishing.

Fishermen (Figure 128) and researchers in the region agree that they see postlarvae in much greater numbers than grouper fry or fingerlings. This suggests that, as with the reef fish discussed above, there is considerable natural mortality among the postlarvae. Harvesting of postlarvae would thus have a lower impact on future adult populations than the harvesting of fry or fingerlings (Johannes and Ogburn 1999). However, the on-growing of a species in net cages intensifies fry collection in many areas and tends to reduce recruitment (Ahmad 1998).

Bycatch and discards

Most of the collection of “seed” material for capture-based aquaculture is carried out with traditional fishing gear. The aim for capture-based aquaculture is obviously to collect live fish for on-growing; the fishing technique selected should therefore be selective for the species and size of “seed” required for the aquaculture system. However, no gear is known to be one hundred percent selective for a given species or size range of individuals. Most gear and methods have some selectivity; their ability to select targets can be altered through modifications to design and operation. The catch in many fisheries thus consists of a mixture of target and non-target species. What does or does not comprize targets depends to a large extent on the market, and whether there are regulations in place prohibiting the capture of certain species or sizes of target organisms. Non-target species are often referred to as bycatch, a concept which is defined differently by numerous scientific bodies.

Hall (1996) defined bycatch as “that part of the capture that is discarded at sea, dead (or injured to an extent that death is the result)”. The word “capture”, in turn, means all that is taken in the gear. The capture can be divided into three components: 1) the “catch”, which is the portion retained for its economic value; 2) the “bycatch”, which is the portion discarded at sea already dead, and 3) the “release”, the portion released alive (Hall *et al.* 2000). The main reasons for discarding fishes (dead or alive), are as follows: the fish caught are the wrong species, size or sex, or are damaged; the fish are incompatible with the rest of the catch (from the point of view of storage); the fish are poisonous or spoil rapidly; there is a lack of space on board; “high grading”[1] ; quotas have been reached; or the catch was of a prohibited species, in a prohibited season or fishing ground, or achieved with prohibited gear. Unfortunately, some of the gears used in the capture of species for capture-based aquaculture species can cause an incidental catch of non-target species (bycatch) and can collect undesirable sizes of target species.

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[1] Special cases of bycatch that are “high-grading” exist: these comprize the discard of a marketable species in order to retain the same species at a larger size and price, or to retain another species of higher value.

Figure 128. Fishermen repairing their fishing gear in the Philippines (Source: FAO)

The amount of the bycatch depends on the area, the period (season), and on the selectivity of the fishing gear. The bycatch issue is important for capture-based aquaculture species as it is one of the most significant of those affecting fishery management today. Different fishing techniques can lead to distinct types and rates of bycatch such as juvenile fish, benthic animals, marine mammals, marine birds, and vulnerable or endangered species, etc., that are often discarded dead. While bycatch and discard problems are usually measured as the potential loss of human food, the increased risk to a particularly vulnerable or endangered species (e.g. small cetaceans, turtles) is also significant. Bycatch can also affect biodiversity throughout impacts on top predators. For economists, its existence generates additional costs without affecting revenues, and may hinder long-term profitability. For fishermen, it causes conflicts among fisheries, gives them a bad public image, generates regulations and limitations on the use of resources, and has negative effects on the resources harvested through the mortality of juveniles and undersized individuals of the target species before they reach the optimum size. This problem must be addressed by scientists, fishery managers and members of the fishery industry. Although only a few fisheries include bycatches of the target species in their stock assessment, bycatch management will be an integral part of most future ecosystem management schemes (Hall *et al.* 2000). The total global discard (considering all the fisheries) is difficult to estimate. One assessment of the level of discards gave an estimate of 27 million tonnes in 1995 (FAO 1997c).

Besides the bycatches of fish (Figure 129), other animals may incidentally be captured with fishing gears (e.g. various species of whales, turtles and seabirds); although the level of the bycatches of such organisms seldom constitutes a threat to their population size, public concern makes it necessary to reduce them.

The level of bycatch associated with the collection of wild "seed" for capture-based aquaculture is not well documented. The same gear could cause different bycatch impacts depending on the area in which it is used. For example, catching bluefin tuna for capture-based aquaculture with the purse seining system in the Mediterranean is very efficient and does not entail high bycatches of cetaceans. This is not the case in other regions, such as purse seining in the Eastern Pacific. The best known example is the tuna-dolphin problem: incidental mortality of dolphins in tuna purse-seine fisheries in the Pacific Ocean during the 1960s was the first bycatch problem that received public attention. After the Marine Mammal Protection Act (MMPA) was introduced in 1972 (Gosliner 1999), dolphin mortality decreased from 133 000 in 1986 to only 1 877 in 1998 (Hall, Alverson and Metuzals 2000).

Improved selectivity can be achieved by modifying the gear design and/or operation, and by using alternative fishing gears. The capture of dolphins in the purse seine fishery for tuna has been reduced to an insignificant level by using a combination of technical changes, rescue techniques, the education of fishermen, and management actions. Experimental research is still going on in order to understand the potential danger represented by the "pinger", an acoustic device that may disturb the dolphins.

Some of the capture-based aquaculture species are collected using floating objects or Fish Aggregating Devices (FADs); pelagic fish are often found in association with FADs as well as other animals (mammals, fish). Other natural structures (underwater mountains, etc.), artificial structures (wrecks or artificial reefs), or specially constructed FADs (like those used in Mauritius for game fishing or the "*cheema*" used in the Maltese "*lampuka*" fishery) are also effective. The reasons for this behaviour are still poorly understood, yet it is believed that by providing a substratum, smaller "feed" fish are initially attracted, which in turn attract the larger commercially valuable species.

Yellowtails are known to associate with FADs, and this is especially true for the greater amberjack (*Seriola dumerili*) and the Japanese amberjack (*Seriola quinqueradiata*). Since the 1980s tuna fishermen have been constructing and deploying artificial FADs, sometimes fitted with transmitter beacons to aid location. These electronically equipped FADs can the be deployed using new spatial strategies (Hallier 1995), and some also have echo-sounders that transmit information about the aggregated biomass by radio (Josse *et al.* 1999).

Harvesting fish associated with floating objects might threaten the pelagic ecosystem, due to various negative effects, such as an increased catch rate of juveniles or pre-reproductive animals, or an excessive mortality of non-targeted species (Hall 1998). A better understanding of these associations is therefore required to design and implement appropriate sustainable management procedures (Fréon and Dagorn 2000).

Other gears and various fishing methods used for catching of "seed" for capture-based aquaculture operations (e.g. grouper) result in a high level of bycatch. For example, research carried out in Indonesia demonstrated that a very high percentage of the total catch captured in artificial reefs (called "*gangos*" in the Philippines) were non-target species, and that this method of harvesting can lead to a high bycatch mortality if not carefully handled (Mous *et al.* 1999). For many other gears used for grouper collection (e.g. fyke nets, scissor nets), bycatches during certain periods can be high. The bycatch comprizes a variety of fish sizes and species that are often thrown back at sea. The exception is in the densely populated areas of many developing countries, where the bycatch has a commercial value and is largely used for local consumption. In SE Asia this has serious implications, and the impact of "seed" fish for on-growing on local foodfish resources cannot be ignored. For example, the bycatch of small juvenile rabbit-fish (*Siganus* spp.) is often high and represents a double loss, because in the same area the larger sizes of this species constitute a favoured food fish (Sadovy 2000).

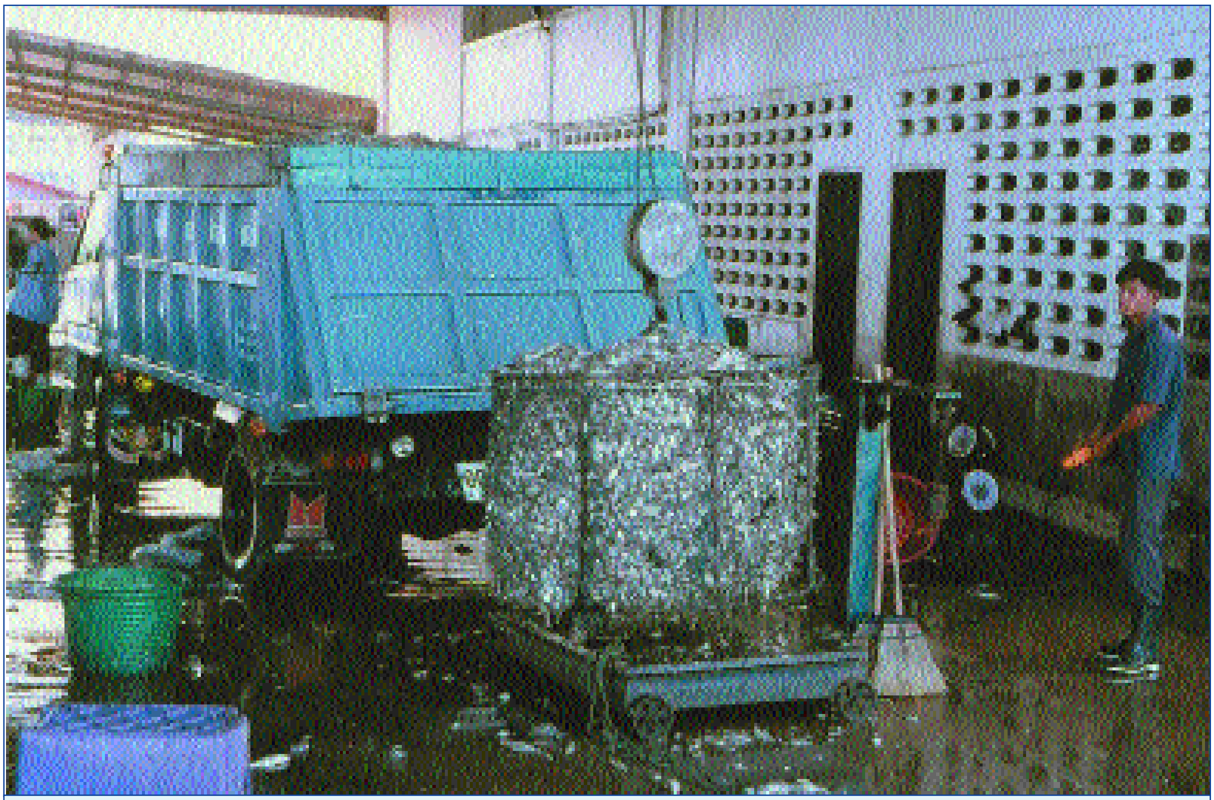

Figure 129. Bycatch being delivered for fish feed in Thailand (Photo: FIIU-FI-FAO)

The use of trawls for eel fishing leads to a substantial bycatch. Due to their small mesh size, the trawl net affects many juvenile fish and up to 99% of the catch consists of species different from the target species, the eels (Hahlbeck 1994). The fyke net is another catch method that captures non-target species (Naismith and Knight 1994).

Direct physical disturbance and habitat destruction

Capture fisheries not only reduce the abundance of targeted stocks, but can have significant effects on the overall ecosystem and food chain, with consequences in other ecological and fishery-dependent systems, including those of mammals (Dayton *et al.* 1995). In addition, many nearshore ecosystems are substantially altered through habitat destruction caused by particular fishing methods.

The use of sodium cyanide, widely employed in the Philippines to catch groupers for capture-based aquaculture, is contributing to the destruction of coral reefs (Goñi 1998). This method not only causes direct damage to the habitat but also has collateral effects, including the death of non-target species of fish and invertebrates (Mous *et al.* 2000), as well as poor quality "seed". The effects of poison on fish can be expected to be rather non-specific and alterations in the fish community structure and ecosystem appear likely.

Other gears used in Southeast Asia for the collection of "seed" for capture-based farmed species can be detrimental to near-shore habitats which are important nursery areas for many species. The use of scoop nets can cause significant impacts on the seabed and on benthic communities (Sadovy 2000). Benthic organisms are crushed, buried, or exposed to predators, and clouds of sediments arise. Alterations to the seabed biogeochemistry are also possible. Development management strategies that are designed to protect habitats are now established, and the use of scoop nets in several regions has now been banned or is regulated to reduce potential impacts.

Several organizations (e.g. the International Marine Life Alliance and the Nature Conservancy) have alerted coastal communities to the threat posed by destructive fishing, and "sustainable mariculture practices" and "best management practices" are rewarded at all points along the supply chain with increased prices and better market acceptance of products (Sadovy 2000; Hair, Bell and Doherty 2002).

Resource removal - indirect effects

The indirect effects of collecting "seed" for capture-based aquaculture include the impact on biological interactions between species in the ecosystem (i.e. competition, predation, changes in the trophic chain), mortality caused by lost gear (ghost fishing), and the environmental effects of dumping discards. The removal of fish with key characteristics and functions in a specific ecosystem may result in loss of resilience and a change from one equilibrium state to another. Fisheries managers are becoming increasingly aware that the impacts of fishing and overfishing can spread through the entire food chain because of changes in competition and predation patterns. It is very difficult to separate natural and man-induced causes for the changes observed at different levels of the ecosystem. Evaluating impacts on fisheries and on communities is also difficult because there are normally no control sites where fishing has not occurred (Goñi 1998).

Fishing for capture-based aquaculture species can alter the structure of marine communities by selective removal of some species and by changing the physical support for the communities. Biomass replacement, in which a dominant species is driven to low levels and is substituted by another species, can occur as a result of fishing and can cause ripple effects on other components of the ecosystem. While biomass flips in species abundance in a pelagic marine ecosystem appear to be caused by density-independent environmental changes (affecting nutrient entrainment, primary production, and recruitment success), dominance flips in several continental shelf marine ecosystems are attributed to density-dependent predation, which includes fishing (Goñi 1998). Hughes (1994) showed how this recovery mechanism has been hindered on Jamaican coral reefs by human activity. Since the 1950s, the Jamaican coral reefs have been chronically overfished to such an extent that sharks, snappers, jacks, triggerfish, groupers, and a number of other target species have declined markedly. The loss of herbivorous and predatory fish species has reduced total fish biomass and altered the taxonomic composition of the fish community. However, the ecological effects of this decrease in biodiversity were not realized for several decades, as the reef appeared to be healthy with large coral cover and high benthic diversity. This was largely due to the high abundance of one grazing echinoid *Diadema antillarum*, which held the growth of algae on the reef in check. With the decline of fish predators and competitors, the abundance of *Diadema* increased.

Other indirect effects have been caused by discards and offal; the large quantities that can result from the processing of fish at sea and from discards may cause changes in the structure and biodiversity of marine communities. Assessments of these effects requires knowledge about the fate of the discards and offal that, until recently, has been largely neglected in studies of fishery-ecosystem interactions (Goñi 1998).

Fishing procedures also pollute the environment through the accidental loss of fishing gear and/or by the dumping or abandoning of gear that may continue to capture and entangle animals. The impact of such "ghost fishing gear" is basically unknown but there are indications that the problem is increasing to significant proportions (Goñi 1998).

Though there has been some work on the indirect effects of fishery activities in general, only a few specific impact studies related to the capture of wild "seed" for capture-based aquaculture species are documented. For example, Sadovy (2000) showed that some grouper seed collection methods have significant impact on the long term status of the stock. The authors of this report consider it unlikely that these fishing methods have a greater effect on fish than other types of fisheries.

Effects of farming operations (grow-out)

Capture-based aquaculture implies the on-growing of selected species in captivity using "traditional" aquaculture practices. Typically the capture-based farmed species are enclosed in a controlled system, such as ponds or cages. In these they can be raised under suitable conditions, sheltered from predators and competitors, fed, and sometimes treated with medicaments to control diseases. The fish are confined at high densities and ideally supplied with all nutritional requirements. Thus, the more intensive the operation, the larger volume of wastes generated and potential impact on the local environment, and the greater the potential for disease.

Generally, intensive fish farming in cages generates a large amount of organic waste in the form of unconsumed feed, and faecal and excretory matter. This results in localized sediment build-up with its attendant risks from self-pollution and disease, which may threaten the operations own sustainability. The particulate waste matter, originating from a single source, can accumulate in the sediments below or close to the farm, causing considerable organic and nutrient enrichment that may adversely affect benthic communities. Major effects can be observed on the seabed and, to a lesser extent, on water quality. Careful site selection is critical for a successful, sustainable operation of all fish farms; special care is required in the case of marine aquaculture (Figure 130).

Figure 130. Philippines capture-based aquaculture (Photo: S. Fazi. Coastal Resource Management and Sustainable Tourism in Ulugan Bay Project implemented by (UNESCO/CSI/UNDP/Puerto Princesa City Government 2001)

Selecting a poor site may result in oxygen depletion in the bottom water, leading to the development of anoxic conditions in the sediment and the production of toxic gases such as hydrogen sulphide. These phenomena will adversely affect benthic organisms as well as the lower portion of the cages where the water is shallow. Furthermore, a reduction in dissolved oxygen level and an increase in Biochemical Oxygen Demand (BOD) and nutrients will occur in the water column around a fish farm, especially where the flushing rate and water exchange levels are too low for the biomass being raised. Other effects will also be observed, including an increase in suspended solids, chlorophyll and phaeopigment concentration, etc.

Usually, most fish farms have limited and localized environmental impacts associated with waste release; these are restricted to those areas in the immediate vicinity of the farm. In shallow waters, or in aquatic ecosystems with a poor water renewal rate, localized eutrophication around farms is possible. Polluted waters may result in fish disease and the mass mortality of cultured fish. The severity of environmental impacts depends upon the relationship between the intensity of fish culture operations and the water circulation/depth at the culture site (e.g. stocking density, feed input and the characteristics of the site). The level of sustainable production at any particular site is therefore a balance between the environmental waste loading (nutrient and organic matter) caused by the farm, and the renewal of the water at the site which prevents a build-up or significant change in the existing local environmental conditions. The use of mass balance equations and management mitigation measures can prevent this occurring. The most obvious changes caused by poorly located intensive marine culture systems for carnivorous fish in cages, are those to the local environment. These impacts, mainly on the benthos, may cause long term changes at sites in relatively quiescent waters, that may persist for many years after culture activity has ceased (Black 2001). Wu (1995) suggested that the degree of impact from the effluent wastes of cage aquaculture is dependent on the species, culture method and feed type, and on the nature of the receiving environment in terms of physics, chemistry and biology.

In the Mediterranean, the capture-based aquaculture of tuna is relatively new and so little is known about its environmental impact on the marine ecosystem. Tuna “farming”, among other activities, has been the target of criticism from environmental and other pressure groups due to the perceived impact of the industry on the environment (for an example of such views, see Tudela 2002a). A system that minimizes its impact, which removes uneaten food and consists of using a collecting net similar to that used in salmon farming, has proven to be successful (Agius 2002).

On the contrary, the impact of grouper capture-based aquaculture is clear, since there are lot of problems concerning water quality in the production areas (as also is the case for the yellowtails cultured in Japan). For example, water quality conditions are particularly poor in Hong Kong, parts of China, the Straits of Johore Bahru (Singapore/Malaysia) and the Philippines; in these locations fish densities are poorly managed, trash fish use is extensive, and there are problems with water contamination or low dissolved oxygen levels because of poor cage positioning. In the early 1990s, grouper production in Hong Kong was about 3 000 tonnes a year; in the last few years production has dropped to 1 000 tonnes a year due to several production and environmental problems (Sadovy 2000). There is an increasing interest in monitoring the environmental degradation from fish farming; thus, many countries have introduced tighter controls. Since 1999, Japan has introduced new legislation for the monitoring of sediment and water quality in fish farming areas, in order to assess sustainability (Pawar *et al.* 2001).

Advanced research efforts aimed at developing technical improvements in the systems used for eel farming are increasing, especially with regard to water quality, which has been a traditional problem in this type of culture (Gatta, Romagnoli and Venzi 2000). The problems to be addressed vary, depending on the species, area, stocking density, environmental capacity of the aquatic bodies, etc.

For the sake of simplicity, we have divided the main environmental effects of capture-based aquaculture into the following categories: feeding, organic pollution and eutrophication, effects of chemical use, algal blooms, benthos modification, and other interactions.