Coastal aquaculture: Sustainable development, resource use and integrated environmental management

Kıyısal akuakültür: Sürdürülebilir gelişim, kaynak kullanımı ve bütünleşik çevre yönetimi

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Abstract

With a dramatic expansion over the past two decades, aquaculture has now become a world-wide aqua-industry and kept the global fisheries production increasing despite the levelling off the capture fisheries. Annual production from this new industry now approached to 30 million tonnes, while the captures fisheries almost levelled off around 90 million tonnes. Inland aquaculture still continues to play a significant role, but rapidly developing coastal aquaculture produced 43.1% of aquaculture output in 1997. However, aquaculture is not only a producer of aquatic food but also a consumer competing for infinite resources and rapid development brought some problems as well. Therefore, sustainable development such a rate to compensate and ultimately supplement the traditional fisheries in new millennium depends on addressing resource allocation and environmental interactions within the broader framework of integrated environmental management programmes.

This article reviews the recent developments in coastal aquaculture and discusses the available resources and constraints limiting the sustainable development. In particular, the way in which coastal aquaculture interact with the environment has been evaluated.

Keywords: Mariculture, developments, constraints, environmental effects, coastal management

Introduction

"Aquaculture" is the rearing of aquatic organisms under controlled or semi-controlled conditions, or aquatic version of agriculture. This definition encompasses both marine and freshwaters.
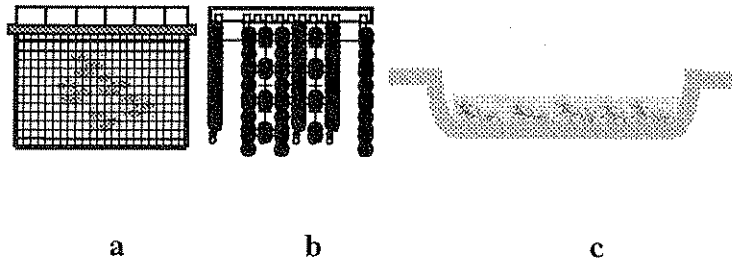

a   b   c

Figure 1. A schematic diagram illustrating types of coastal aquaculture: a) cage fish culture; b) raft bivalve culture; c) shore culture (fish and shrimp).

"Coastal aquaculture" or "mariculture" comprises all shore (land) and water based farming activities of brackish and marine organisms, which are generally limited to within the 2-5 km wide area on the continental shelf and on the low-lying flatlands beyond the tidal zone. Aquatic organisms have been cultured for various purposes, including the stock enhancing, restocking for angling and as ornamental or bait, but aquatic food production for human is the main objective. Compared with traditional animal husbandry, aquaculture is a much more diverse activity. This diversity is a reflection of differences in taxonomic groups (fish, molluscs, crustacea, algae) and the numerous species, wide bio-ecological variations (environmental variations feeding habits, life cycles), the life cycle(s) and culture operations undertaken and culture systems (monoculture , polyculture, extensive, semi-intensive intensive). The levels and patterns of coastal aquaculture practices vary according to these diversities (Figure 1).

Coastal aquaculture has a along history going back to as long as prehistoric times. The ancient versions of coastal aquaculture is still practised in Far East (milk fish, *Chanos chanos* culture in "tambaks") since 1400 AD and in Mediterranean lagoons (valliculture). Molluscs

152

(e.g. mussels) have been cultured in Atlantic coast of France (bouchot culture) and the Dutch Wadden Sea (bottom culture) since 13. and 18. centuries, respectively. However, modern aqauaculture was born during 1970s and 1980s. Recent developments (1970s and 1980s) in countries such as Japan, Taiwan, China, Norway, UK, France, Italy, Israel, and the USA has created this new aqua-industry.

Current rates of increase in world population has stimulated worries on feeding the world population in new millennium. Human population is almost exceeding 6 billion and in 2025 this figure reach 8.5 billion. At the same time agricultural production has stagnated over the last 5 years (Welcomme, 1996). The issue of adequate food security has now become crucial in planning for future and the world seas and oceans, which covers some 70% of the earth and would seem to be available for additional exploitation. Therefore, the fisheries sector is being examined to determine the sustainable contribution it can make to future food supply. Man live on land which occupies a quarter of the surface of the earth, obtains most of his food from the land. Although it varies according to geographical region, at present aquatic resources represent about 1.3% of the overall global food supplies, on average 24% of animal and 6% total protein supply (Shepherd and Bromage, 1998; Barnabe, 1991).

Fisheries is the main way of the aquatic food supply and there seems to be little chance of increasing it. Particularly during the last three decades a combination of multifactorial causes including technological developments, uncontrolled investments, lack of or bad practical management programmes and undesirable ecological changes kept the production of capture fisheries beyond the sustainable limits. The limited nature of fishery resources was not realised until it was almost too late and the production from captures fisheries almost levelled off around 90 million tonnes during the last decade (Figure 2). The latest FAO (1999) report estimated that 44% of commercial fish stocks are fully exploited, 16% overfished, 6% depleting rapidly and 3% recovering under conservation programmes. These figures show that even with an optimistic view the captures fisheries are unlikely to grow by more than 1 or 2% annually and the long-term sustainable harvest from the capture fisheries will not exceed the magic figure of 100 million tonnes.
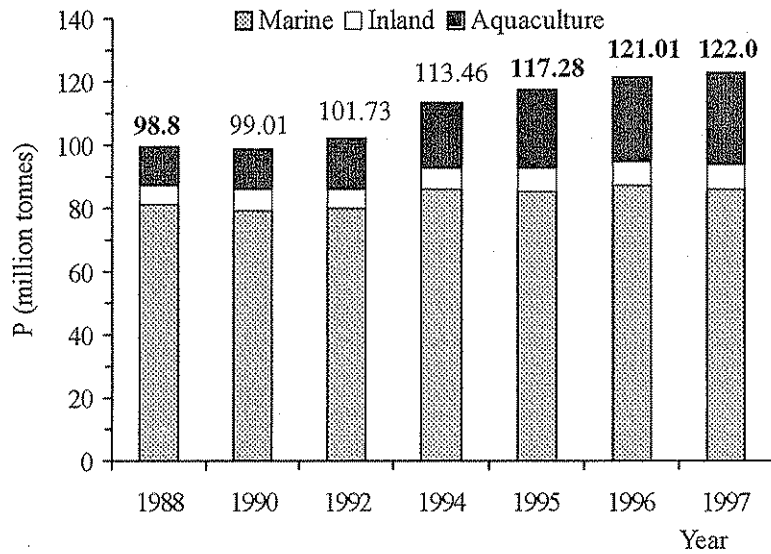
Figure 2. Growth of total and aquaculture global fisheries production (FAO, 1999)

In contrast, as it can be seen in following sections world wide aquaculture production continues to grow and it has been widely proposed as a mean to compensate capture fisheries. For example, during the last decade developing aquaculture kept the global fisheries production increasing. Total global fisheries production almost reached 100 million tonnes in 1988 and peaked with 122 million tonnes in 1997 and despite of nearly 2% of annual growth rate in world population, thanks to aquaculture supplies for human consumption increased considerably, rising per capita annual consumption almost 16 kg.

The productivity coastal of aquatic ecosystems is around 100 $gC/m^2/yr$ or annual total of $3.6x10^9$ tonnes C ($7.2x10^9$ tonnes dry organic matter) (Lalli and Parsons, 1993). This is more than seven hundred times exploited fisheries resources expressed in wet weight. Such considerations suggest that marine ecosystems should have a potential beyond that used currently. Fishing is only one of the ways of exploiting this huge ecosystem and aquaculture that can be considered the second one. Production of marine fish in exploited areas is around 2 kg/ha/year, whilst extensive aqaculture can produce at least 100 kg in the same area, and quite commonly between one and two tonnes.

Unlike traditional fisheries in aquaculture production process and quality can be partly or completely controlled, and ownership, care and environmental responsibility might be more easily established. In

154

addition, it may ease the fishing pressure on wild stocks and even help the sustainability and recovery of stocks by ranching or re-stocking.

The world-wide expansion of aquaculture is already making an increasingly important contribution to the global fisheries production and a growing contribution to food supply, livelihood and national economies (employment and foreign exchange earnings) in some countries (e.g. in Asia and South America). Even in developed countries such as Norway and Japan, aquaculture have been supported by governments to keep the former fishermen in aqua-industry, create new employment opportunities and maintain the sustainable development of coastal and remote areas.
In brief, if, as many people think, we are approaching the limit that can be caught economically from the world oceans and seas, opportunity for aquaculture development would seem to be significant.

The Present Status of the Global Aquaculture Industry
Reliable global data on aquaculture has been only collected and published by FAO since 1984. This data demonstrates the increasing importance of developing new aqua-industry (Figure 2, 3). By 1997 global production reached 28.81 million tonnes (excluding seaweeds and other aquatic plants) million tonnes which accounted for 23.6% of total fishery production or 31% of consumed fishery products. In another word, one of every three fish eaten in the world is now produced in aquaculture (Table 1). Asia and China continues to dominate global aquaculture production providing 89% and 67% of global aquaculture, respectively. Of the top 15 aquaculture producing nations, ten can be found in Asia (Table 2). China has an historic tradition of growing fish and increasing population, diminishing agricultural land and declining fish stocks have forced Chinese fishery development policies to focus on expanding inland and coastal aquaculture.

Although freshwater aquaculture consisted of around 57% of total aquaculture production by volume (quantity), coastal aquaculture produced more value and accounted for 58.2% of production value. This is because the coastal aquaculture mainly depends on luxury species or groups (such as carnivore fish and shrimps). Global aquculture production continues to be dominated by fish, accounting for over 65% of total (Table 1). Fish culture in coastal waters is also increasing rapidly approaching 3 million tonnes per annum. For instance, the aquaculture productions of species such as, Atlantic salmon, milkfish, eels, yellowtail, seabass and seabream are now exceeding the catches from commercial fisheries. Bivalves and shrimps are the major contributors of coastal

aquaculture. When the culture species are ranked by volume, the silver carp occupies the first place (3.2 million tonnes) followed by a marine species pacific oyster (*Crassostrea gigas;* 2.97 million tonnes), other carp species, Yesso scallop (*Pecten yessoensis*), Japanese carpet shell (*Ruditapes philippinarium*) and Nile tilapia. In contrast, by value the tiger shrimp (*Penaeus monodon*) is the first species (3.5 billion US$) which is followed by Pacific oyster, carps, Atlantic salmon, Yesso scallop and Japanese carpet shell.

Table 1. Summary of latest (1997) fish and shellfish (i.e. excluding 7.24 million tonnes seaweed) aquaculture production.

Category	Quantity (Millions)		Value (Billion)	
	Tonnes	%[a]	US$	%[a]
Total production	28.81	23.6[b]	45.5	-
Inland	16.38	56.9	19.0	41.8
Coastal	12.43	43.1	26.4	58.2
Fish	18.84	65.4	28.6	62.9
• Freshwater	16.21	56.3	18.1	39.8
• Marine	2.71	9.4	10.5	23.1
Crustaceans	1.30	4.5	8.1	17.8
• Freshwater	0.17	0.6	0.9	2.0
• Marine	1.13	3.9	7.2	15.8
Molluscs (all marine)	8.59	29.8	8.8	19.3

[a]: of total aquaculture production; [b]: of total fishery production

Table 2. Global aquaculture output by continents and top 15 countries in 1997.

Continent/country	t (x000)	%	Continent/country	t (x000)	%
A) Continents:					
Asia	25647	89.0	Africa	119	0.4
Europe	1754	6.1	Oceania	101	0.4
America	1188	4.1			
B) Countries:					
China	19316	67.1	Rep. Korea	392.4	1.4
India	1777	6.2	Norway	366.3	1.3
Japan	806.5	2.8	Philippines	330.4	1.1
Indonesia	754.6	2.6	France	287.6	1.0
Thailand	575.9	2.0	Chile	272.4	0.9
Bangladesh	512.7	1.8	Taiwan	257.5	0.9
Vietnam	480.0	1.7	Spain	239.2	0.8
ABD	438.3	1.5	Other countries	2002.0	6.9

Sustainability of the Development

Increasing population means around 2.5 billion more mouths to feed by the year 2025. So the challenge for the future is two-fold: to feed larger populations at least at present levels and to feed these people more adequately. Both of these indicate increases in total food production and per capita food consumption.

As it has been pointed out earlier, when the amount used for fish meal and oil (around 30 million tonnes) is excluded global fish consumption is around 16 kg/ca/year. Above mentioned populations projections mean that at current level of consumption the world will need 40 million tonnes of fisheries production by the year 2025. Since the capture fisheries levelled off, aquaculture have to produce most of the 40 million tonnes. In addition, income levels will increase and there will be slight declines in prices as a result of increasing production. More importantly with the application of developing biotechnology and environmental control all-year-around supply and diversity of products will affect the consumer preferences in favour of fisheries products. For example, if one aims to supply the same amount of food as people in developed countries, the per capita consumption needs to go up by approximately 30% over current levels. Even if half of (15%) this improvement is targeted, additional demand will be around 25 million tonnes. Thus the demand for the first quarter of next century might be much more than 65 million tonnes. This clearly demonstrates the increasing role of the aquaculture in first quarter of the next century. In other words, aquaculture should expand to compensate this demand and further for shortfalls from catches.

The supply of aquaculture has continued to expand rapidly and growth has been much faster than was envisaged only a few year ago. For example Csavas (1994)'s fish end shellfish projection for the year 2000 was 21 million tonnes, while FAO (1995)'s estimation for 2010 is ranging from 27 to 38 million tonnes (FAO, 1999). However, these projections have already been surpassed. There seems to be every prospects that this dynamic will continue at least during the first quarter of the new century. However, as it can be seen in Figure 2 high growth rates reaching up to 18% observed during 1992-1995 is slowing down. When the present development in main producer countries is considered, annual growth rate for the next 3-5 years seems to be less than 10%, most likely around 6-8%. It means in the medium term sustained growth of aquaculture will be maintained and it seems quite probable that production from fish and shellfish might reach 35 million tonnes in the

year 2000, 40 million tonnes in 2005 and 65 million tonnes in 2015. However, keeping the development sustainable particularly beyond the year 2000 depends upon addressing the following limiting factors and developing "Integrated Environmental Management Programmes".

Major Resources and Constraints

As it has been mentioned previously, aquaculture is expected to compensate for shortfalls from capture fisheries. In spite of its continuing expansion the periods of rapid expansion appears to be over and growth rate is likely to slow down (Figure 3). This is because aquaculture has already hit or about to hit a series of constraints. These can be summed under two interlinked categories: environment and resources.

Resource Conflicts

Aquaculture is not only a producer but also a consumer competing for infinite resources. As with all agriculture enterprises, is dependent on natural resources in sufficient quantity and of suitable quality. The major natural resources required for aquaculture can be broadly categorised as primary resources (water, land, seed, and artificial and natural feed) and secondary resources (skill, information and technology). All these resource inputs interact to define the relationship between the aquaculture activity and the environment. This represents one of the most crucial issues of concern in environmental management of aquaculture and the key to success will be an integrated approach.

The nature of the resources and the manner in which they are used for aquaculture plays a key role in its sustainable development and economic success. In most locations, aquaculture farms are only one of several users of aquatic resources. Its development has resulted in increasing demand and exploitation of many natural resources, such as clean water and suitable sites. As these resources are not limitless in supply and availability, the competition and conflicts between aquaculture and others will be inevitable. Therefore, relationship between aquaculture development and the resources it requires should be evaluated carefully and "a sensitive balance" between aquaculture and the environment should be established (Muir and Beveridge, 1994; Philips, 1995).

Resource use conflicts that may develop in aquaculture can take two major forms; actions of aquaculture operators affect others (e.g. tourism) and poor resource allocation systems and inefficient allocation of resources. The main conflict issues are: a) water and site utilisation; b) waste discharge management; c) access to wild fisheries stocks for

158

broodstock and seed supply, and managing escaped fish. Some of these are evaluated in more details below Approaches to resolve these conflicts work by better defining the rights over how resources may be used and there are two main instruments which can be employed: i) legal regulations, and i) economic instruments (fees and charges on resource use and damage) (Holland and Brown, 1999).

Water and Site/Land Use

Water requirements for semi-intensive and intensive aquaculture systems have been estimated as 55.000 - 2260.000 m^3/tonne for coastal aquaculture, while the land or area requirement is ranging from 0.01 to 5 ha/tonne depending on intensity of production (Muir and Beveridge, 1994). Another indicator of the primary resources utilisation is the production or loading km/km^2 of coastal water/land areas. For example, Csavas (1994) has estimated this value as 2.2 tonne/km for Asia and 0.6 tonne/km for the entire world. So, there seems to be plenty of room for future developments in coastal water or areas. However, since the coastal aquaculture is concentrated along the terrestrial margins, some inland seas and coastal waters (such as Chinese and Taiwanese coasts, Norwegian and Swedish fjords, Scottish sea lochs, Mediterranean and Aegean bays) seems to be heavily loaded. The areas suitable for aquaculture are perhaps more limited than previously supposed.

Environmental Impacts: How Green Is It?

Aquaculture development is taking place a time of unprecedented pressure on natural resources, such as water and land, and increasing awareness of environmental issues, particularly since the 1992 "Earth Summit". With the increasing population and developments there are steadily increasing demands on natural resources and the same time increased sensitivities to environmental issues. Therefore, "sustainable development" and "environmental protection" are principal concepts widely discussed during 1990s. In such circumstances, it is not surprising that there has been growing interest and concern about interactions between aquaculture and the environment. Although, aquaculture is not a major environmental polluter, environmental problems appear to be more commonly reported in coastal aquaculture. This is because: i) aquaculture itself depends on clean environment; ii) the coastal zone used for aquaculture is a narrow strip (with an average width of less than 10 kilometres and the suitable culture area is 5.9 million km^2 globally, Csavas, 1995); iii) in spite of technological developments coastal aquaculture is still confined to sheltered areas; iv) the coastal zone is the scene of intense development activity - including aquaculture and the stiff

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competition between various sectors/sub-sectors of the economy for its use. It is clear that a balance between aquaculture and the environment is certainly essential for long-term sustainable development of aquaculture.

Environmental issues and key problems relating to coastal aquaculture have been highlighted in a number of reviews (New, 1991; Muir and Beveridge, 1994; Philips, 1995; Okumuş, 1997a,b). The potential and observed impacts of coastal aquaculture on the environment vary from local to regional and global effects. These have been summarised in Table 3 and the major considerations are evaluated briefly. The consequences of these problem include local and general environmental degradation, mixing of stock, the imposition of increasingly stringent controls and regulations, limiting existing operations and/or preventing new development, declining productivity, direct economic losses and foregone opportunity.

Waste and Nutrient Inputs into Local Environment: One of the major adverse environmental impacts of coastal aquaculture has been the production of large amounts of waste material and dissolved nutrients derived from unconsumed feed, and production of faeces and excretion (Figure 4). These materials are either dissolved in water column or deposited in the seabed in the vicinity of culture operations. Consequences of these inputs might be local hypernutrification leading to eutrophication, modifications in phytoplankton species composition and possibilities of toxic blooms, and chemical changes in sediments and water quality, and biological alterations in benthic community (Table 3). Waste production significantly affected by the system, husbandry and feeding practices and hydrographical features of the environment. Estimates indicate that up to 75% of N and P nutrients delivered to fish cages and shrimp ponds as pelleted feed might be left in environment (Figure 4).

According to Muir and Beveridge (1994) feed loading and solid waste production in intensive fish and shrimp culture are typically 0.01-0.05 kg/m^3 and 0.001-0.015 kg/m^3 water used, respectively. 1000 t fish production could require the use of 100-200 x 10^6 m^3 of water, adding 200-500 t of solids, 150-400 t BOD, 20-80 t of N, 5-25 t of P, plus micronutrients, treatment chemicals, etc. Studies showed that sedimentation rates of particles was 20 times higher below a 40 ton salmon cage farm than at reference sites (Folke and Kautsky, 1989).

160

Table 3. Potential and observed environmental/ecological impacts of coastal aquaculture (Okumuş, 1997a,b).

	Potential Impacts
General	• Disturbance of natural view and aesthetic, and coastal transport • Destruction of unique coastal habitats (e.g. mangrove and wetland habitats), • Conflicts with other users (e.g. recreation and tourism), • Effects of chemical compounds used for disease treatment, • Impacts on species/community diversity or disturbance of wild life (introduction of exotic species, overharvesting of wild seed genes exchange through escaped stocks, disease transmission and new settlement surface for sessile and fouling organisms), • Global or large scale ecological effects (fish meal),
Water column	• Nutrient loadings (N, P, vitamins and minerals) leading to hypernutrification and eutrophication (fish and shrimp culture), • Impoverishment of local ecosystem (bivalve filter feeders), • Potential modifications in phytoplankton species composition and possibilities of toxic blooms (*Gymnodinium aureolum*), • Altering natural water exchange and deterioration of water quality (increments in biochemical oxygen demand on water).
Benthos	• Outputs of solid wastes and increased sedimentation rates and organic enrichment, and as a result reduction in redox potential, increased biochemical oxygen demand in benthos, production of methane and hydrogen sulphide with possible outgassing, growth of sulphur bacteria (*Beggiatoa* sp), • Increment of organic nitrogen remineralisation, • Reduction in macrofaunal biomass, abundance and species diversity, and increments in opportunistic invaders.

Nutrient Removal: One of the basic differences, between intensive fish/shrimp culture and bivalve mollusc culture is that the latter is a more less self-sustaining system, that needs no supplement of food and no

161

treatment with antibiotics or chemicals. In addition, since the bivalves are filter feeders relying upon natural phytoplankton and organic detritus and occupying lower level in marine food web or chain, there are considerably fewer ecological levels from primary production to harvest. Therefore, culturing filter-feeding bivalves is usually considered as ecologically sensible and environmentally acceptable, even beneficial for eutrophication control. However, large scale bivalve culture always removes nutrients (mainly nitrogen) from the environment at harvest and generates large amount of faeces and pseudofaeces contributing significantly to the organic load of the local environment. Approximately, 25-40% of seston (phytoplankton and organic detritus) filtered by bivalves is retained and harvested; so around 1.8 kg organic matter can be ingested by 1 kg mussel during a culture cyle, of which 1.1 kg are returned to the local environment (Figures, 1989; Okumuş, 1993). Although, environmental impacts of bivalve mollusc culture are far less serious than intensive fish and shrimp culture, overuse of traditional mussel and oyster culture grounds in the Netherlands, France, Republic of Korea and Japan has already led to environmental problems (Okumuş, 1993).
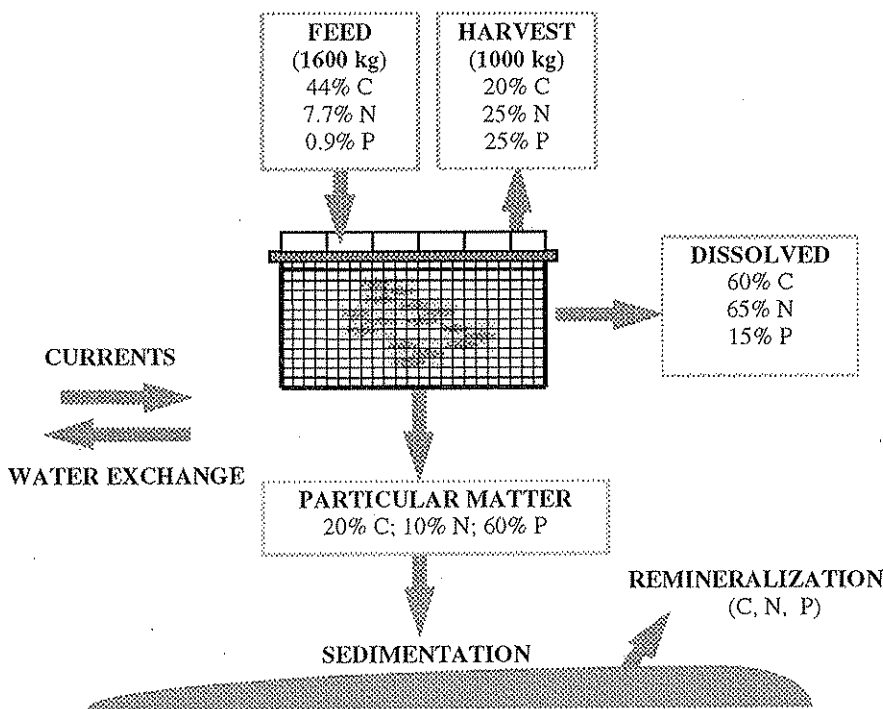

Figure 4. Nutrient (N, P) and particulate organic matter (C) input to marine Environment from atypical intensive fish cage (*Salmo salar*). Feed conversion ratio was taken as 1.6 (modified from Okumuş, 1997b).

Feed and Fish Meal

The different types of aquaculture can be considered as falling into two broad bio-economic categories: "extensive" and "intensive" culture systems which also represent two diverse approaches in aquaculture (Figure 5). The intensive aquaculture depends on high value carnivore fish and shrimp species. The protein requirements of these species are high (40-50% of the diet) and mainly supplied as fish of lower economic value, directly or after processing converting into fish meal and then incorporated into pellets. In contrast, extensive system is culture of lower food chain and usually lower value species.

LOW   EXSTENSIVE

Stress and diseases

Natural food - Sustainability

Capital input

SEMI-INTENSIVE

Management- Stocking density

Profitability- Artifical feeds
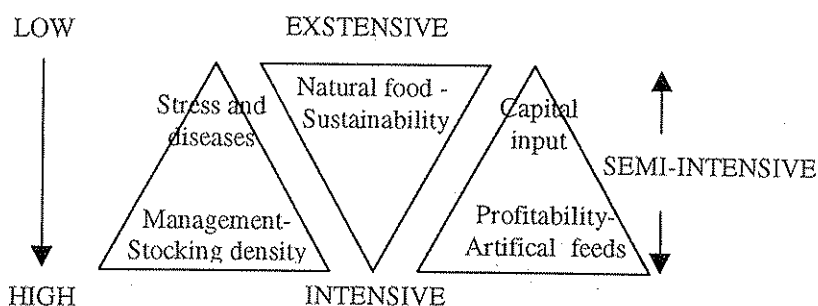
HIGH   INTENSIVE

Figure 5. A schematic representation of extensive, semi-intensive and intensive mariculture practices (modified from Tacon, 1988).

Apart from filter feeding bivalve molluscs and some fish species as milkfish and mullets, coastal aquaculture is an intensive farming activity. The intensification of culture is bound to make it more dependent on artificial, compounded feeds and fish meal is the major ingredient of these. It is known to be the best source of animal protein, essential amino acids and highly unsaturated fatty acids. It is also believed to act as a feed attractant, and is claimed to have unidentified growth promoters. Although partial replacement of it seems to be possible, it remains the main protein source in all compounded feeds used in aquaculture. Stocks of pelagic fishes upon which the fish meal industry is based are already fully exploited world-wide, and supplies of fish meal are limited. Therefore, intensive system mainly depends on the capture fisheries and the biggest constraint to sustainable development, shifts from extensive fish and bivalve culture to intensive fish and crustaceans culture will be the "fish meal trap" of Wijkstrom and New (1989) and Csavas (1994).

163

Based on an average feed conversion of 1.5, production of 1 kg carnivore fish culture requires 1.5 kg of feed and 0.75 kg of fish meal at an inclusion level of around 50%. Since about 5 kg of raw fish is required to produce 1 kg of fish meal, approximately 3.75 kg of raw fish is required to culture 1 kg of carnivore fish. Although, small part of the aquaculture production (10-15%) is coming from carnivorous species, at present over 2.2 million tonnes of fish meal has been used to feed cultured species, accounting 10 million tonnes of captured fish. In other words, approximately 30% of the total world fisheries production (just around 30 million tonnes) are used to produce about 6 million tonnes fish meal and over 1/3 of this is consumed by aquaculture industry. Only 7% of this fish meal is consumed by non-carnivore species, while the rest is shared by shrimp, salmon, trout, eels, seabass/sea bream yellowtail.

The feeding fish with fish (as meal) seems to contradict the expectations that aquaculture is the answer to the shortfall from the global capture fisheries. In the long term it appears that the declining capture fisheries may in fact limit or curtail the growth of the aquaculture industry. Replacing the marine protein component by alternative ingredients seems to be the only solution. As a result of recent inter-annual variations in production some substitution in poultry and pig diets has occurred, however, for the feeds demanding high quality fish meals (such as aquaculture), very little substitution might be expected. In aquaculture fish meal has special role of forming the bridge to get the both amino acids and uniquely valuable highly unsaturated fatty acids (ω-3 and ω-HUFA) which are main nutrients making the seafood unique.

In spite of partial substitutions with soybean, corn gluten and grains, there seems to be no major alternatives to fish meal. Feeds for the lower food chain species, on the contrary, are more abundant, and some can even utilise enhanced production stimulated by natural productivity (eutrophication). It follows then that the best entail for future advances in aquaculture should be obtained using lower food chain species. The rearing of bivalve molluscs such as oysters, mussels, and clams is one of the most effective ways of increasing the economic value of the primary and para-primary production from the seas because the transfer to animal protein is direct. Current expansions in the rearing of these species are, however, limited by consumer preferences and other social and economic factors in some regions of the world. As an altervative, aquaculture itself may become supplier of raw materials for the fish meal industry and support itself. For example, low value fast growing species

such as tilapia, some cyprinids, molluscs can be cultured and used as raw material for fish meal or direct food.

Interactions Between Fisheries and Coastal Aquaculture

As it has been illustrated in Figure 6, aquaculture, wild stocks and fisheries share the same environment and interaction in various ways is almost unavoidable. First of all, aquaculture depends on wild stocks for inputs such as fish meal and oil, brood fish and juvenile supply. On the other hand aquaculture may also support the wild stocks as re-stocking or sea-ranching. The possibility of enhancement of marine stocks through ranching is attracting a good deal of attention. Systematic conservation of diadromous stocks through artificial rearing and release into natural marine environments is, as we have seen, a long established practice especially in the case of the temperate salmonids and sturgeons. Successes with such species have encouraged an extension to other species. Japan is undoubtedly the most advanced in this technology and is currently investigating many species as candidates for such management.
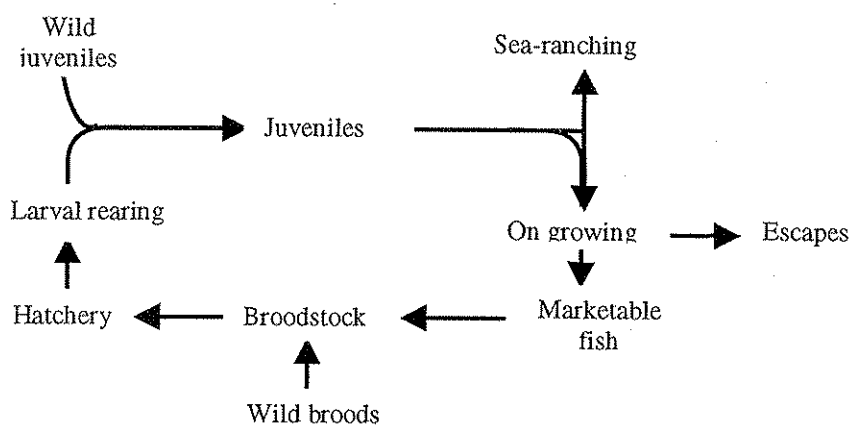
Figure 6. Basic aquaculture cycle and aquaculture - wild stock interactions.

Theoretically, enhancement of marine fisheries by release and recapture has a great potential to add to world fish production. However, ranching practices are also being questioned. First of all, number of species suitable for such operations is restricted. Secondly, present return rates in most cases are insufficient to compensate the expenditure. Another main

criticism risen against these practices is potential genetic effects of hatchery reared individuals on wild stocks.

Escapes to Wild and Genetic Contamination: On water based system disintegration of the system, e.g. cage and net rupture, leads to loss of stocks. The genetic risks facing wild populations when they are exposed to escapees from aquaculture operations is probably the main concern in this issue. This might have disturbing implications when potential impacts of accidental escapes or deliberate releases are being considered. The main question is "What happens when escaped fish have the opportunity to enter wild socks?". Perhaps the most commonly-cited threat is genetic contamination and loss of natural stock identity. This means that a number of direct effects can cause changes in the genetic structure of a wild stock. "Swamping" is probably the most dramatic one. The issue has been quite well studied in Atlantic salmon. For example, Clifford *et al.* (1998), examined Atlantic salmon populations in northwest Ireland where nearly 30 thousand adult cultured individuals escaped in the spring 1992 and concluded that some of the escapees had, in fact, managed to reach spawning areas and inbred with wild salmon. Similarly, Skaala (1994) reported that in spite of escapees numbers (approaching 2 million) in Norwegian rivers in excess of the native (wild) broodstock (roughly 100,000) swamping did not occur on a genetic basis. This might partly be due to reduced reproductive success of cultured fish in the natural environment. In light of the fact that some reproduction occurred among introduced fish, this would tend to negate the often-heard argument that cultured fish escaping at an early life stage may be more adaptable to wild.

Diseases and Effects of Chemotherapeutics in Aquatic Environment

The cultured species are particularly subject to diseases exacerbated by high stocking density and adverse environmental conditions which impose stress on organisms and lead to disease outbreaks. Therefore, one of the greatest challenges in intensive aquaculture is the increasing disease problem. These diseases may also threatens wild stocks due to unavoidable water exchange between culture and wild environments. Thus, in the absence of measures to improve husbandry and without stricter controls on water quality and movement of species, the incidence of disease outbreaks will increase with further development and intensification of culture.

One of the major impacts of disease on aquaculture is the uncontrolled and haphazard use of chemotherapeutants. In spite of latest progress in vaccination, treatment of fish with chemotherapeutics is still the main and most widely applied method. A wide variety of chemicals is used in

166

aquaculture and in some countries, there are hundreds of such chemical compounds in use, for example in 1988 there were 39 chemicals registered or approved for use in aquaculture in USA (Schnick,1988) and same year Norwegian aquaculture industry used 18220 kg of oxytetracycline, which corresponds to 0.21 kg/t of fish produced (ICES,1989). Since almost all these antibiotics are administered entirely by mixing the drug with the feed, and a large proportion (about 20%) of the administered feed in salmon farming may be wasted directly (Figure 4), as some part of the medicated feed is not eaten by the fish and falls from the cages and dissolves in the water column and/or accumulates on the sea bed. Some of these drugs entering the environment will be taken up by wild fish, shellfish and crustaceans, resulting in concentrations that exceed those acceptable in food for human consumption. So this level of intensive usage of these chemotherapeutic agents may present potential hazards for the cultured organisms, neighbouring fauna or the environment and human health and the environmental issues associated with use of chemicals have increasingly been raised (Okumuş, 1993).

Quality of Products: Wild or Cultured - Does It Really Matter?

Intensive aquaculture has been blamed of deteriorating the fish quality. Consumers often ask "Which is better, wild or cultured fish?", "How does the aquaculture affects quality of fish" and "Doses it really matter, wild or cultured?"

One of the main obvious differences between wild and cultured fish (particularly salmonids) is the flesh color which is more tense in wild fish as a result of higher levels of carotenoid pigments, mainly astaxanthin and its esters. As a practical solution formulated feeds for cultured fish are supplemented with astaxanthin and the flesh carotenoid levels of 3-4 mg carotenoid/kg muscle could be achieved by feeding the fish feed containing 20-30 mg carotenoid/kg for about 3-6 months before harvesting.

Texture might be another difference between wild and cultured fish. In general texture of wild fish is more firm than that of cultured fish, resulting in a slight chewiness, flakiness, and adherence of muscle fibres to consumer's teeth. In contrast, cultured fish seem to have a softer and more mushy texture. Texture of flesh is associated with differences in activity levels of fish and can be improved by increasing activity levels cultured specimen during final stage of culture operation. Recently discovered facts on muscle fibres of fish exhibit important characteristics of the flesh (Roberts, 1999). Most of the higher vertebrates have constant muscle fibres, i.e. they are born and die with the same number of muscle fibres. These muscles only get bigger and some damaged ones may be replaced. However,

167

fish (or salmonids as we certainly know) are totally different. For example, a salmon fry may have 10.000 fibres in its anterior myotomes, but this increases to 180.000 at smolt stage and almost double at marketing. This high cellularity affects both firmness, texture and color of flesh which are among the quality issues effecting consumer preferences.

In addition to color and texture, there may be flavor and odor differences between wild and cultured fish. These issues are related to feeding and water quality. Therefore, relatively easy to improve by altering the diet or starving fish and increasing water exchange.

Finally, and probably more importantly, aquaculture may affect the nutrient composition of fish flesh. Balanced amino acid and polyunsaturated fatty acid (PUFA) compositions of the flesh make the fish nutritionally unique. Since the fish get these nutrients from their foods, consumers often think that artificial or formulated feeds may diminish the nutrient quality of fish. However, opposite may also be valid: "fish are what they eat or what they are fed". Thus, aquaculture or formulated feeds may also increase the nutritional quality of cultured fish and the opportunity to harvest fish with a virtual guarantee of abundant PUFAs makes the aquaculture unique.

Unsaturated fatty acids are the main nutrient compounds that play a major role in the uniqueness of the fish flesh. Omega-6 (ω-6 or n-6) are unsaturated fatty acids abundant in plants. In contrast, n-3 fatty acids prevail in fish and shellfish. It has now been recognised that the long chain n-3 polyunsaturated fatty acids (PUFA), docosahexaenoic acid (DHA, 22:6n-3) and eicosapentaenoic acid (EPA, 20:5n-3) are responsible for the human health and well being. Both n-6 and n-3 PUFAs are "essential fatty acids = EFA", i.e. cannot be synthesised by higher vertebrates including most fish and human. These originate mainly from the base of marine ecosystems, microalgae or phytoplankton and are assimilated by filter feeding zooplankton and pass to zooplanktonivorous fish such as anchovy, capellin and herring used for fish meal and oil production. Thus, marine fish commonly have a luxury of PUFAs in their natural diets and flesh. Such findings clearly demonstrate the importance of the essential fatty acids in nutrition of fish and in aquaculture. As it is mentioned above wild fish obtain these requirements from various natural foods. In intensive aquaculture, however, fish depends merely on the artificial feeds. The dietary essential fatty acids of marine fish are 20:4n-6, 20:5n-3 and 22:6n-3 and the requirements for the latter two being some 10-50 times that of the former. Thus, fish contain much higher levels of 20:5n-3 and 22:6n-3 than 20:4n-6.

Fatty acid compositions of the fish flesh reflect the quantitative and qualitative composition of diets. Thus, marine fish fed by soybean oil will

had much more linoleic acid than those fed marine oils. In addition, the final fatty acid composition of cultured fish can be enriched through dietary changes in the four to six weeks prior to harvest. These facts may also practical implications. At present, salmonids and marine fish in general are fed diets containing fish oil as a source of both essential fatty acids and energy, particularly high energy feeds can contain more than 30% of their weight as fish oil. Therefore, as fish meal, fish oil is a finite natural resource subjected to marked variations and that continued dependence of aquaculture on fish oils will soon seriously restrict development of the industry.

In brief, when the protein is considered, both wild and cultured fish have essentially the same amount and quality of protein. Lipid content and fatty acid compositions, however, differs somewhat (Table 5). The major species of cultured fish seem to have more lipid than their wild cousins, but the fatty acid compositions, with exception of salmons, seem to be similar. Cultured rainbow trout, for example, have more lipid and PUFA than wild specimen. This is mainly because as a freshwater and cold-water species rainbow trout utilise both linoleic acids and PUFAs.

Social and economic constraints

Socio-economic constraints seems to be among the most serious limitations for introducing or diversifying aquaculture particularly in underdeveloped countries or regions where the potential is good but the practice is so far lacking. Although some degree of technical solutions are usually available even under marginal conditions, problems such as changing attitudes towards this new development or allocating scarce financial resources are still remaining (Welcomme, 1996).

Table 5. Comparison of protein, lipid and fatty acid contents of wild (W) and cultured (C) fish (Nettleton, 1990).

Species	Protein (g/100 fillet)		Lipid (g/100 g fillet)		PUFA (mg/100g fillet)	
	W	C	W	C	W	C
Rainbow trout	20.2	18.8	3.4	7.6	560	1120
Atlantic salmon	-	-	6.3	8.3	1450	980
Coho salmon	20.6	20.0	5.8	8.6	1490	1330
Channel catfish	15.6	16.2	6.9	2.4	170	100
Carp	-	-	1.2	2.4	150	190
Red drum	20.1	19.4	0.8	2.1	160	210

Consumer attitudes against fisheries products (e.g. shellfish are still not eaten by some rural communities) are also influencing development and particularly species and product diversity. Although, in many regions fish are

not accepted as a regular item of diet, with increasing education and shortages in food supply such cases are becoming rare. In addition, socio-economic development, health considerations and urbanisation are creating demand for more varied diets, including fisheries and aquaculture products. However, the increase in demand by the richer nations for health reasons, coupled with their higher purchasing power, means that much fish produced in the poorer regions of the world is exported in the form of value added products. For example, the penaeid shrimps produced in the southern hemisphere, but consumed in the north. This has caused the over-commercialisation of this aqua-industry (New, 1991). The most widely publicised successes in recent years have been precisely in those high value sectors such as shrimp, salmon and marine carnivores which most appeal to urban markets of industrialised countries and which have attracted the bulk of research funds. In this case the main beneficiaries will be powerful rich investors and development of more commercialised aquaculture will negatively affect underdeveloped rural areas and remote communities (e.g. resource competition, selling all most all of the products to earn more money).

Integrated Environmental Management of Coastal Aquaculture

The experiences gained so far demonstrated that environmental limits to the growth of coastal aquaculture really exist and developing integrated environmental management programmes for sustainability is the key, and particularly in areas where the limits are being approached or have been surpassed, needs urgency.

Criteria and Implementation: The concept of environmental management is relatively a new idea. It is designed to identify interactions between production process and the consequent impacts on the environment. It can be summarised as "plan, do, check and act". Key benefits of such an programme may include; i) improved environmental protection and performance; ii) reduced individual liability; iii) competitive advantages; improved compliance; iv) reduced costs; v) enhanced consumer trust, and vi) sustainable development of the sector. In practical terms, an effective environmental management programme of aquaculture should be simple (easy to operate as much as possible and clear and understandable), rational (based on logical and scientific foundations), fair (operate fairly all those using the resources) and affordable. Global Aquaculture Alliance (GAA, 1997) has published detailed environmental management criteria for aquaculture "Guiding Principles for Responsible Aquaculture".

According to these criteria, the main components for environmental management of aquaculture might be (Muir and Beveridge, 1994): at the installation stage: an environmental impact assessment procedure appropriate for reviewing new project proposals, or amendments or supplements to existing projects, prior to their establishment, at the operational stage: an

170

environmental management procedure capable of monitoring the effects of aquaculture activities, and if necessary providing guidance for modifying installations and/or operations to minimise impacts.

Environmental management programmes can be designed for macro (regional coastlines), meso (provincial/local) and micro (individual sites) scales. These scales may be inter-related and modelling can be applied to; i) a specific type or form of aquaculture, ii) different forms of aquaculture, or aquaculture and other activities, iii) integrated approaches in which potential interactions between resources and activities are recognised. Ideally, coastal aquaculture development would be assessed within an integrated context, incorporating other activities, as it may only represent part of the system loading. Effective coastal management requires knowledge of the functioning of the complete coastal system, together with specific details of individual areas/sites (Muir and Beveridge, 1994).

Monitoring: One of the primary approaches in environmental management of coastal aquaculture is to model the potential effects and define local capacity. This can be used to determine suitable locations, and to define the forms and combinations of aquaculture which might be practicable. Monitoring major characteristics of operations and activities that impact the environment allows to assess meeting environmental goals and objectives, and developing "carrying capacity" models. In modelling the carrying capacity of an environment for aquaculture, it would be necessary to define (Muir and Beveridge, 1994): (i) the physical and ecological characteristics of the environment, and the determinants of its productivity; (ii) the interactions with cultured stock in terms of food inputs/wastes; (iii) responses of environment to these changes; (iv) changes permissible.

Legal Regulation: While the fundamentals of effective environmental management can be defined in broad terms, one of the most critical constraints in practice has been the absence of an effective legal regulations in which these can be established. According to FAO (1999), few countries have appropriate legal frameworks and policies for aquaculture management. Often, comprehensive policies and associated legal frameworks have been overlooked because development has been seen mainly in technical terms and support has been largely focused on technical aspects of production. In addition, policy-makers have often treated aquaculture in isolation from other sectors, thus ignoring important interactions. However, the continuing rapid growth of the sector and growing competition for resources have focused attention on the need for policy measures and regulatory frameworks.

Governments should create and maintain a suitable framework for sustainable growth of the sector. Such a framework comprises economic, legal, social and physical components and ensure a balance between need for development and the need for ecosystem conservation fair access to resources, mechanisms for conflict resolution and access to information,

171

credit and markets. The economic criteria are very important, both in terms of conventional resource allocation decisions, and concerning the questions of economic instruments for pollution control, including licensing procedures, loading-related charges, and environmental recovery taxes. Many of these approaches, based around the "polluter pays" principle, and based also on the ideas of maximising economic rent for natural resources, are coming into planning and regulatory approaches.

Conclusions and Recommendations

The issue of sustainable development of coastal aquaculture and associated problems have been addressed in this extensive review with the following conclusions and recommendations:

- aquaculture is growing substantially against a generally static or even declining capture fisher, and the expansion of aquaculture and culture-based fisheries may drive the current level of growth in fisheries sector well beyond 2000,

- coastal waters seem to have substantial potential for aquaculture,

- aquaculture is not only a producer of aquatic food but also a consumer competing for infinite resources and relies on its success for the quality and quantity of natural resources,

- rapid development of aquaculture also caused undesirable environmental changes which have been shown to affect the long term economic viability of the operation itself, therefore, these must be predicted, monitored and evaluated,

- particularly nutrient discharges from aquaculture have received more attention than any other environmental effect and should be reduced by developing "environmentally friendly feed management strategies",

- genetic modification of wild stocks should be recognised by all concerned and loss of cultured to the environment should be prevented by all practical means,

- emphasis should be given to low culturing species in food chain (herbivore and omnivore species such as bivalve molluscs), ecologically sensitive culture systems such as extensive, semi-intensive and integrated approaches (e.g. fish cage and suspended mussel culture),

- disease transfer to wild stock seems to be very serious in certain circumstances, thus there is an urgent need for effective, economically viable, integrated and multidisciplinary health management programmes,

- integration is the key word for sustainable aquaculture and if it is performed within the broader framework of integrated coastal zone management programmes, planned and properly managed aquaculture development could be a productive use of the coastal areas,

172

In brief, aquaculture is playing an increasingly important role in the world's aquatic food production. Instead of becoming another problem contributing to irrational resource utilisation and environmental degradation, this aqua-industry should meet the challenge for sustainable development by addressing constraints such as fish meal and ecological or environmental impacts using an integrated environmental management perspective and keeping present level of intensive bio-technological studies.

Özet

Son 20 yılda dramatik gelişme bir gelişme gösteren su ürünleri yetiştiriciliği, günümüzde küresel bir akua-endüstri halini almış ve balıkçılıktaki durgunluğa rağmen toplam küresel üretimdeki artışı devam ettirmiştir. Günümüzde, balıkçılıktan sağlanan yıllık üretim 90 milyon ton civarında kalmasına rağmen, yetiştiricilik yoluyla sağlanan üretim 30 milyon tona ulaşmıştır. İçsu türlerinin yetiştiriciliği hala önemli role sahip olmasına rağmen, hızlı bir gelişim gösteren deniz canlıları yetiştiriciliği toplam yetiştiricilik üretiminin %43.1'ni sağlamıştır. Bununla beraber, su ürünleri yetiştiriciliği, sadece akuatik bir gıda üreticisi değil, aynı zamanda sınırlı kaynaklar için rekabet eden bir tüketicidir ve hızlı gelişim beraberinde bazı problemler de getirmiştir. Bu nedenle, yeni bin yılda yetiştiriciliğin geleneksel balıkçılıktaki azalmaları telafi edecek ve nihayetinde ikame edecek sürdürülebilir gelişimi sağlayabilmesi, kaynak tahsis ve çevresel etkileşimler gibi problemlerin bütünleşik çevre yönetim programları çerçevesinde çözümlenmesine bağlıdır.

Bu makalede deniz canlıları yetiştiriciliğindeki son gelişmeler irdelenmiş ve mevcut kaynaklarla sürdürülebilir gelişimi sınırlayıcı faktörler tartışılmıştır. Özellikle, deniz ürünleri yetiştiriciliğinin çevre ile etkileşim şekli ele alınmıştır. Konu, artan nüfusun gıda ve rekreasyon gereksinimlerinin karşılanması amacıyla oldukça yoğun baskı altında olan kıyısal ekosistemin korunması ve sürdürülebilir kaynak kullanımı açısından büyük önem taşımaktadır.

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