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Environmental considerations for site selection of marine fish farms

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SUMMARY – Site selection for fish farms (located both inland and offshore) is crucial for the sustainable development of the industry. Degradation of the environment where the farms are installed, as well as interference with other activities, has to be foreseen and avoided as much as possible. Likewise, harm to the cultured crop due to a contaminated or inappropriate environment also has to be avoided. A careful study undertaken prior to any installation should be compulsory, in terms of mitigating any possible effects. Some aspects to be taken into account, before the siting of a fish farm are: permit system regulations, conflicts with other water/land uses, hydrographic conditions of the area (temperature, current speed, etc.), water quality, terrestrial inputs, wave climate, wind patterns, seabed characteristics and dynamics, and accessibility and available facilities. The importance of each of these factors, in the selection of a site capable of sustaining a fish farm without harm to the environment, will be considered. Moreover, the use of hydrodynamic and dispersion models will be presented, demonstrating their use as a powerful tool for coastal managers. Such managers have to decide on licences for fish farms, taking into consideration environmental affection and/or multiple pollutant effects (caused by the non-rational grouping of farms).

Key words: Fish farm, site selection, environmental impact studies, monitoring.

RESUME – *"Considérations environnementales sur la sélection du site pour les exploitations marines de pisciculture". La sélection du site pour les exploitations de pisciculture (à l'intérieur et en mer) est essentielle pour le développement durable de l'industrie. Il est nécessaire de prévoir et d'éviter – autant que possible – la dégradation de l'environnement où on va installer les exploitations ainsi que l'interférence avec d'autres activités. De même, il faut éviter de causer des dégâts aux cultures du fait d'un environnement pollué ou inapproprié. Une étude minutieuse doit être réalisée avant toute installation, en ce qui concerne l'atténuation des effets possibles. Avant l'installation d'une exploitation piscicole il faut tenir compte des aspects suivants : réglementation et systèmes de permis, conflits avec d'autres utilisations de l'eau et de la terre, conditions hydrographiques de la zone (température, vitesse des courants, etc.), qualité de l'eau, contributions terrestres, régime des vagues, situation des vents, caractéristiques et dynamique des fonds marins, et accessibilité et disponibilité des installations. L'importance de chacun de ces facteurs sera considérée dans la sélection d'un site capable d'accueillir une exploitation sans causer de dommages à l'environnement. De plus, on va présenter l'utilisation des modèles hydrodynamiques et de dispersion, en démontrant leur utilité comme un outil puissant pour les responsables de zones côtières. Ces responsables doivent décider en matière d'autorisation d'exploitations piscicoles en tenant compte de l'effet sur l'environnement et les multiples effets polluants (provoqués par le groupement non rationnel des exploitations).*

Mots-clés : *Exploitation de pisciculture, sélection du site, études de l'impact sur l'environnement, surveillance.*

Introduction

The concept of sustained development is a social objective largely accepted for the economical development of natural resources, according to the report of the BRUNTLAND commission (WCED, 1987). It is based on the assumption that the economic welfare, social justice and environmental protection can not be dissociated and are intrinsically interdependent in the long term.

In spite of the recent development of the marine fish farming industry there are already examples of conflicts in the use of coastal water resources; and some cases of farms producing a negative impact have created some serious doubts about the suitability and continuity of sustainability of aquaculture in the coastal environment.

The sustained development of coastal aquaculture is linked to a good understanding with the

environment, respecting it and carrying out actions that lead to diminish possible impacts derived by such activity. Therefore, measures in the production have to be taken in order to avoid degradation of the environment and that at the same time are technically appropriate, economically feasible and socially accepted.

The expansion of marine aquaculture activities in the Mediterranean should take place in a broader frame of integrated planning and regulation with the aim of minimising impacts. A balanced development of the coastal zone requires integrated management plans that should be prepared at a national or regional level. Hence any marine aquaculture enterprise (brackish, on-land or offshore) must pay particular attention to site selection in order to ensure appropriate conditions for a successful activity, which should also be related to the ability of local ecosystems to absorb impacts without lasting harmful effects (UNEP/EEA, 1999).

When taking decisions about locations for aquaculture installations a whole range of issues have to be considered, involving all interested parties and activating a public consultation mechanism.

It is also necessary to increase the dialog between scientist and fish farmers in order to improve the list of items and manage to transfer academic exercises into real situations.

Conflicts with other coastal uses

Some of the most common conflicts are with the navigation, conservation of marine reserves, wetlands and mangroves, agricultural, urban and industrial discharges, dams and dikes construction, irrigation and draining, port activities, coastal soil uses, tourism development, etc.

The different types of aquaculture systems (pens, ponds, tanks, racks, raceways, cages, etc.) related to the various environments where they are based, can be the origin of conflicts with other economical activities already installed or to be developed.

Before the development of the technology for aquaculture in cages (Fig. 1), in the 1960s, most of the fish production took place in ponds and tanks. Since the 1960s, the culture of fish species has progressed significantly due to the farming of certain species, like salmon, sea bream, sea bass, etc., in floating or sedentary cages located in bays, coastal lagoons, fjords, estuaries, interior seas and protected straits.

Fig. 1. Sea cages for marine fish farming off the Mediterranean Spanish coast (Corelsa, Spain).

As other traditional coastal industries, the aquaculture industry is in constant and growing conflict with other coastal activities (navigation, fisheries, tourism, industrial development, wildlife, etc.), and coastal zone managers have to be aware of the costs and benefits of this activity in environmental terms, in order to decide the priority of certain uses on specific coastal areas.

The different types of aquaculture systems adapt to the diverse coastal systems, and depending on each case extensive, intensive or semi-intensive systems are defined.

Impact on the coastal ecosystem associated with aquaculture development depends on the type and intensity of farming as well as the physical, chemical and biological characteristics of the selected site. Although severe impacts are commonly associated with large farms and intensive farming systems, the gathering of many small farms, typical of underdeveloped countries, has also shown to cause dramatic ecological changes. Moreover, accumulated effects due to the interaction with other coastal uses should not be underestimated (Pillay, 1992).

Among possible environmental impacts of aquaculture activities in the coastal environment, the major impacts are biodiversity decrease and changes in benthic microfauna, most other changes are rather localised (Chua, 1992) (Table 1). The aquaculture inputs that cause the most serious harms to the environment are feeds and faecal wastes. This organic and inorganic wastes can cause nutrient enrichment and in some cases, with very low hydrodynamics (lagoons, inlets, fjords, etc.), even eutrophication.

Other detectable changes include anoxic sediment formation, acidification of farm sites, depletion of oxygen at the bottom (ADB/NACA, 1991; Wu, 1995), growth of pollution tolerant species (in some cases harmful to the farmed animals) and phytoplankton blooms.

Concerning human health implications, the fact that many fish farms located near the coast can often be contaminated with human pathogens can represent a real problem. These pathogens (bacteria and viruses) have their origin in urban sewage outfalls and any other sources of human wastes. Other type of contamination with human health implications are toxic algal blooms (red-tide) caused by several species of dinoflagelates and diatoms (Hallegraeff and Maclean, 1989; Shumway, 1990).

High levels of toxic chemicals (e.g. pesticides) and heavy metals may be accumulated by bivalves or fish grown in coastal waters contaminated with industrial and agricultural waste waters (GESAMP, 1991).

The extremely rapid expansion of aquaculture in some countries, without adequate planning, can lead to serious socio-economic consequences, like: (i) large-scale removal of valuable coastal wetlands; (ii) land subsidence; (iii) acidification; and (iv) salinization of groundwater and agricultural land and subsequent loss of goods and services generated by the natural resource system (GESAMP, 1991). Other serious socio-economic problems are disease outbreakes and red-tides, which can cause the collapse of the industry due to the immeasurable income loss. Such risks can be avoided in part by adequate environmental management within the industry, which is initially related to a good selection of the site where the farm will be installed.

Site selection procedure

When working on the preparation of a new aquaculture project, it is very difficult to know from the administration(s) which parts of the coastal zone are appropriate or simply forbidden for the establishment of a new fish farm installation. All around Europe, only very few central, autonomic or local administrations are capable of facilitating a relationship of potential sites for the installation of a fish farm; moreover, almost none are able to inform about the possible carrying capacity of a certain zone. Once a fish farmer selects a potential site, it is very difficult to know all the possible conflicts of use that will result in the area. This fact complicates tremendously the selection of appropriate sites for aquaculture development and in terms of integrated coastal zone management.

Thus, the first step is the development of a planning tool capable of co-ordinating all existing interests of the coastal zone. Some of these conflicts imply the existence of incompatibilities but most of them are due to a lack of planning, caused by an absence of dialogue between the different parts.

Table 1. Possible environmental impacts[†] of aquaculture activities in the coastal environment (from Chua, 1992)

Environmental impact	Aqua
	Cultu orgar
Water enrichment	--
Marine food web	●
Oxygen consumption	●
Biodiversity	--
Biofouling	--
Changes in benthic microfauna	--
Antibiotic resistance	--
Salinization of aquifers	--
Acidification of soils	--
Land subsidence	--
Wildlife	--
Salinization of agriculture land	--
Hardening of seabed	--
Growth of undesirable species	--
Eutrophication	--
Toxicity to marine animals	--

[†]● = Significant impacts; ❍ = Likely impacts; -- = No relationship.

Site selection will depend on the farming practices and on the characteristics of the different sites: different areas may respond differently to the same pollutant dose.

Restrictions to potential sites

The different countries present diverse regulations in identifying site characteristics with environmental implications. In the USA, the Environmental Protection Agency in its proposed rules (Federal Register 39 (115), 1974) requires that applications for approval of discharges from fish farm projects should include, among others:

(i) Details about quantity and quality of pollutants derived by the activity.

(ii) Information on conversion rates and quantity of harvestable product.

(iii) Identification of the species of organisms to be cultured.

(iv) Description of the water quality parameters required for an adequate growth of the cultured species (e.g. dissolved oxygen, salinity, temperature, nutrients, etc.).

(v) Possible health effects including: diseases or parasites, effect on human health, bioconcentrations in the crop and potential for escape.

(vi) Detection of pollutants produced by the cultured species (e.g. ammonia, hydrogen sulphide, organic debris, etc.).

(vii) Description of the disposal method to be used in the case of massive natural death.

There exist some guidelines about production limits (110 tons/km^2), minimum current velocity (5 cm/s) and required water depth related to annual fish production (Pillay, 1992). Depending on the current speed the water depth can be reduced.

Farming operations should not to be permitted on, or in the immediate vicinity of valuable benthic flora and fauna, like habitats of *Posidonia oceanica, Cianodocea nodosa* and eel grass (*Zoostera marina*), kelp beds, rocky reefs, clam populations, nursery areas, wildlife refuges and bird and mammal habitats of special significance.

The use of trash fish as feed, should be no longer allowed since it represents one of the major reasons for insanitary conditions, disease outbreaks and harm to the benthic communities.

The siting of farms causing scenic detriment, should also be banned. There exist some examples (e.g. Scotland) where farms siting close to ancient monuments and historic sites caused adverse effect on tourism, and reduction of employment opportunities.

Potential areas may be identified as sensitive and very sensitive areas. Sensitive areas are those where farming may affect other values and would require special area strategies for management. Farming in very sensitive areas have to be forbidden or subjected to very severe restrictions.

Basic data for site selection

The first thing to do is to observe the regulations established by the competent authorities in terms of any installation on the coastal zone, in order to immediately discard those areas prohibited for aquaculture development. Such prohibition may arise due to conflicts with other uses (as mentioned: navigation, fisheries, army, tourism, etc.), or due to the declaration of some locations as very sensitive areas due to their high ecological value.

In terms of sites we have to differentiate between offshore and inland installations (Fig. 2). Although, the future trends are towards the installation of fish farms further off the coast in the sea, an inshore installation is always almost essential for the processing of the harvest, cleaning of the structures, storing feed, etc., thus the impact of such facilities should also be considered.

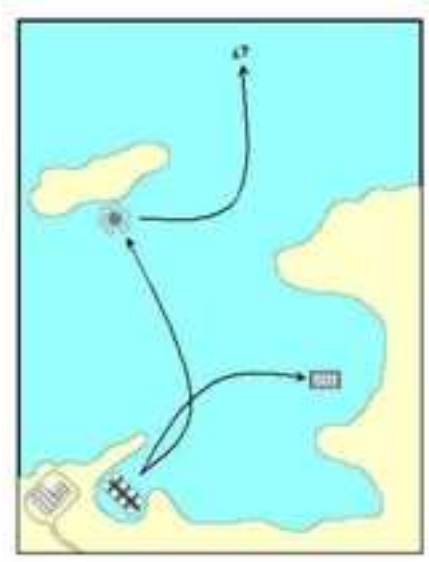

Fig. 2. Potential coastal sites for marine fish farming.

Fish cages represent typical installations based off the coast. Such installations have to fulfil some requirements in order to maintain a good relationship with the natural environment, but also have to be aware of the conditioning imposed by the physico-chemical characteristics of the environment.

Physical restrictions to open sea culture systems are water temperature, wave climate of certain zones, existence of nearby rivers or fresh water sources (provoking undesired salinity, suspended solids and nutrient fluctuations), lack of appropriate currents in order to assure a good renewal of the water in the cages, or existence of too strong currents resulting in problems to the structure of the cages [reduction of volume due to effect of the currents on the nets produces stress on the fish population (Turner, 2000)].

Among the chemical restrictions, the most restricting is the existence of pollutant sources (submarine outfalls and contaminated river (watercourse) inputs) which can cause high mortality rates or low growth rates, when not bioaccumulation. Input of nutrients associated to eutrophication problems or algal blooms, are also consequence of undesired wastes in the vicinity of the fish farms. The farm itself may become a focus of chemical pollution if enough flushing of the installations is not assured.

A factor that seldom is considered, is the bottom dynamic condition of the selected site. It is very important to determine areas of erosion, transportation or accumulation of oxygen-consuming organic material. On the one hand, if cages are installed in areas of erosion and transportation, the accumulation will be minimised and spread over the surrounding waters and sediments. On the other hand, in an area characterised by accumulation processes, the spread of organic materials will be restricted. If the bottom water exchange is small, oxygen deficiency will be higher, and this can lead to the formation of undesired H_2S, which at certain concentrations may become lethal (Pillay, 1992).

Areas of erosion are characterised by bottoms dominated by sand and harder materials and generally exposed to wind-generated waves and currents, whilst areas of accumulation are characterised by fine sediments and higher organic matter contents. Resuspension of fine materials occur mainly in areas of erosion; such process enhances nutrient loading of the waters.

The sensitivity factor of a given coast is a function of several variants, such as coastal volume, water retention time, mean depth, accumulation, transportation and erosion, etc. The affection of the environment to the farm and vice versa depends upon the interrelation of all these factors.

Some countries stipulate the areas where farming can be undertaken, based on site characteristics including depth and exchange rate of water. Cages are generally required to be at least 4 m above the seabed in marine systems in terms of ensuring adequate dilution and distribution of effluents (Pillay, 1992).

Another critical aspect for siting of fish farms is the benthic life (fauna and flora) beneath the cages. Any affection of the exploitation of the farm should be avoided, therefore before the installation of any fish farm a good knowledge of the habitat should be compulsory. Bionomic cartography is nowadays a common practice in many Mediterranean countries. This information should help the management authorities, to decide about potential sites for offshore marine farms, selecting those areas, where of lower biological importance.

Numerical models of the hydrodynamics and dispersion of contaminants, are valuable tools to describe any possible affection to the bottom communities (Karakassis, this volume). However, many studies have to be performed (e.g. settling of suspended solids, reduction of BOD, etc.), in order to calibrate these models and allow them to reproduce faithfully the processes involved in a fish farm.

Open sea cage technology is developing rapidly in order to progressively occupy areas further away from the coasts. This practice will minimise environmental effects, avoid conflicts with other coastal users (e.g. tourism), and at the same time assure the best possible quality of the waters for farming. Other practices like multi-system culture, susceptible of minimising environmental impacts will be dealt in another communication (Giménez-Casalduero, this volume).

Inshore installations should be selected attending to typical criteria like communication facilities, water availability, etc. Special protection areas should be avoided, and landscaping of the facilities should be performed.

Site selection guidelines

Some guidelines, not regulations, have been presented to help possible investors in getting approval for their sites and to assist in the management of the enterprises (Crown Estate, 1987). These guidelines should fulfil the requirements of all the countries.

(i) Get information about any possible restrictions or regulations referring to the installation of fish farms and their waste production.

(ii) Selected sites have to be appropriate to available technology or appropriate technology has to be found for the selected sites.

(iii) Agree with other possible investors about desirable separation between farms, or come to joint arrangements which would permit closer siting.

(iv) Limit the size of the site to the minimum necessary.

(v) Consult the rest of the users about possible locations, trying to avoid fishing grounds, scenic and wildlife areas.

(vi) Adopt measures in order to minimise effects to the environment and try to use design techniques to avoid visual impact of the installations.

Apart from these basic procedures it has to be considered that the environmental impact of fish farms will depend predominantly on the cultured species, the culture method, the type of feeding and the hydrographic conditions.

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