Ecological effects of fish farming in the Mediterranean

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SUMMARY – The rapid increase of fish farming production in the Mediterranean during the last 15 years has caused conflict with other users of the coastal zone and raised significant public concern over environmental issues. A series of environmental peculiarities of Mediterranean marine ecosystems interfere with fish farming production as well as with dispersal mechanisms and transformation processes of the wastes discharged. A review of the published information from the Mediterranean regarding environmental interactions with fish farming is presented. The documented impacts are relatively low in the water column despite the lack of significant tidal currents. Impacts on benthos are more easily detectable at silty sediment sites. Nevertheless, they have been found to be highly localized, not exceeding a distance of 25 m from the edge of the cages. Full recovery of the system after the cessation of fish farming has been shown to be delayed due to secondary effects resulting from the accumulated organic material on the seabed.

Key words: Plankton, benthos, fish farming, environmental impacts.

***RESUME** – "Les effets écologiques de la pisciculture en Méditerranée". L'augmentation rapide de la production piscicole en Méditerranée au cours de ces 15 dernières années a engendré des conflits avec d'autres activités de la zone côtière, ainsi qu'une préoccupation générale concernant les conséquences environnementales. Une série de particularités environnementales caractérisant les écosystèmes marins méditerranéens, interfère avec la production piscicole et influence les mécanismes de dispersion et les processus de transformation des déchets. Un récapitulatif de l'information publiée au sujet des interactions environnement-aquaculture dans le pourtour méditerranéen, est présenté dans le présent article. Malgré l'absence de courants de marée significatifs, les conséquences sur la colonne d'eau sont relativement modestes. L'influence sur le benthos est plus facilement détectable au niveau des sédiments vaseux ; cependant cette influence est localisée et ne se rencontre qu'à une distance inférieure à 25 m des cages. Malgré cela, la récupération complète du système après arrêt de l'activité aquacole est retardé à cause des effets secondaires dus à l'accumulation du matériel organique sur le fond marin.*

***Mots-clés :** Plancton, benthos, pisciculture, impacts environnementaux.*

Introduction

The fish farming industry in the Mediterranean has grown at an almost exponential rate during the last 15 years. Despite the obvious economic benefits for national and local economies the introduction of fish farming has often faced strong opposition by other users of the coastal zone. The well established tourist industry, which is also a major source of income for most Mediterranean countries is often found to compete with aquaculture for space in the coastal zone and particularly in marine areas of high water quality. In this context, environmental impact of fish farming has become a frequent topic of discussion for local environmentalist groups, has attracted increasing attention by the mass media and has often puzzled politicians and regulating authorities.

Although a large proportion of the available information on environmental impacts of salmonids may be applicable to the Mediterranean, there are important differences in the characteristics of the bream and bass industry and the main features of the Mediterranean ecosystems. Until recently (Munday *et al*., 1994), there was little information available from the Mediterranean regarding the interactions of fish farming and the marine environment, despite the increasing need for such information in order to provide support for policy making.

Mediterranean marine ecosystems present an idiosyncratic combination of characteristics which make them very different from north European conditions. Listed below, these affect both the fish farming industry and the ecological processes determining the fate of aquaculture wastes:

(i) High temperature (annual minimum of 12°C, reaching up to 25°C during summer) induces high metabolic rates, thus affecting both the production of the farmed fish and the activity of microbial communities.

(ii) The microtidal regime (tidal range is typically less than 50 cm) reduces the potential for dilution and dispersion of solute and particulate wastes particularly in enclosed bays were wind-driven currents are relatively weak.

(iii) Oligotrophy: low nutrient content, low primary production, and low phytoplankton biomass are typical of most Mediterranean marine ecosystems, particularly in the Eastern Basin (Bethoux, 1981; Azov, 1986). Low phytoplankton biomass induces high transparency of the water and light penetration deeper in the water column (Ignatiades, 1998) thus allowing photosynthesis at a greater depth.

(iv) Primary production is considered to be phosphorus limited (Krom *et al*., 1991) as opposed to nitrogen limitation in the Atlantic and in most of the world's Oceans. In this context, eutrophication could be expected only when phosphate is released in adequate quantities.

(v) The biotic component of the ecosystem, i.e. the fauna and flora, is highly diverse particularly in the coastal zone and consists of a large proportion of endemic species (Tortonese, 1985; Fredj *et al*., 1992) as a result of the dynamic geological past of the Mediterranean. It is typically of low abundance and biomass as a result of the prevailing oligotrophic conditions (Karakassis and Eleftheriou, 1997).

(vi) Finally, the morphology of coastal bays where most of the aquaculture is practiced is also very different from that of Scottish lochs and Norwegian fjords. They are typically not associated with permanent freshwater supply nor do they have a sill impeding the subsurface exchange of water masses.

During the last five years, there has been some progress in the understanding of these processes in the Mediterranean through a series of published papers addressing the impact of fish farming on water column chemistry and parasites (Papoutsoglou *et al*., 1996), the effect on nutrients and plankton (Pitta *et al*., 1999), the effects on seagrass (Delgado *et al*., 1999), the dynamics of sediment accumulation beneath fish farm cages (Karakassis *et al*., 1998), the recovery process of benthos after cessation of fish farming (Karakassis *et al*., 1999) and the effects on sediment geochemistry and benthic organisms (Mac Dougall and Black, 1999; Karakassis *et al.,* 2000; Mazzola *et al*., 2000). These studies involved monitoring environmental variables at one or more fish farms in different regions within the Mediterranean and therefore they may be used to compare results with those reported for fish farming (e.g. salmon farms) in other places of the world. However, there is still a lot to be done before we achieve a full understanding and a reliable modelling of the entire spectrum of effects related to fish farming.

Nutrient release and plankton response

Water quality is an issue extensively used in the arguments regarding the impacts of fish farming on the usability of the coastal zone by other users. However, the scientific basis of these arguments is rather weak since there is little information relating aquaculture to water quality degradation.

Of course, fish farms produce wastes and, in particular, large proportions of N and P are released in solute form into the water column (Holby and Hall, 1991; Hall *et al*., 1992). Furthermore, the pattern of nutrient release presents a significant deviation from the natural fluctuation of nutrient concentrations in the water column (Pitta *et al*., 1999). In temperate regions, such as the Mediterranean, phytoplankton presents seasonal maxima in growth during spring and autumn as a result of nutrient availability due to mixing and other physical processes as well as adequate light conditions; surface nutrient depletion during the summer stratification period results in low phytoplankton growth despite the increased light availability. By contrast, the release of nutrients by fish-farms is a continuous process throughout the year, reaching maximal values during summer when high water temperature imposes the need for higher feeding rates.

A seasonal survey of the water column characteristics (physical, chemical and biological) was carried out in three Mediterranean fish farms (Pitta *et al*., 1999). In two of these farms, no significant difference was found in any of the measured variables between the control sites and the water column in the cages. A significant increase in concentrations of phosphate (PO_4) and ammonium (NH_4) was detected within the cages over the control site in the third farm but without any significant effect on chlorophyll concentration. Analysis of variation within the data set identified location and season as the major factors of variability in most of the variables examined except PO_4 and NH_4, for which variability induced by fish farming seemed to be of major importance. Plankton abundance for the major taxonomic groups (diatoms, flagellates, dinoflagellates and ciliates), microplankton species diversity and community structure were also determined by the effects of season and location rather than by the presence of fish farming.

Beveridge (1996) reviewed a wide range of information sources including papers and technical reports and concluded that in marine waters, several studies have failed to establish a relationship between enhanced nutrient concentrations and phytoplankton growth. A response of plankton community to hypernutrification became evident only in highly sheltered bays in the Eastern Baltic (Wallin and Hakanson, 1991) which is characterized by a microtidal regime and low-salinity.

The inconsistency between nutrient enrichment and lack of a significant increase in chlorophyll *a* may be attributed to limited utilization of the excretory wastes due to rapid flushing time, so that phytoplankton are not present long enough to capitalize on the high production of nutrients, as has also been suggested by Gowen *et al*. (1983). Similarly, Taylor *et al*. (1992) have reported that seasonal environmental characteristics influenced phytoplankton more than salmon fish farms in British Columbia. Mesocosm experiments in the Eastern Mediterranean (Pitta, 1996) have shown that there is a time delay of 3 to 8 days (depending on the season) between nutrient enrichment and the peak of the phytoplankton biomass. Furthermore, it has been proved that there is no linear relationship between nutrient enrichment and plankton production; as shown by Oviatt *et al*. (1986) in a mesocosm experiment, an increase in nutrients by 32 times resulted in an increase of primary production only by 3.5 times, while limited phytoplankton response to moderate nutrient increase has also been recorded in Eastern Mediterranean mesocosm experiments (Pitta, 1996). Further complication results from the fact that different functional plankton groups are shaped by different regulatory forces (Pitta *et al*., 1998).

Pitta *et al*. (1999) have estimated the N and P input from fish farming as a percentage of the total anthropogenic waste production, using: (i) the available scenarios for the estimation of total anthropogenic nutrient loads in the Mediterranean, particularly in Greece (UNEP, 1996); (ii) the available mass balance models for Nitrogen and Phosphorus (Holby and Hall, 1991; Hall *et al*., 1992); and (iii) production figures for sea bream and sea bass in the Mediterranean countries (provided by the Federation of Greek Mariculture). According to these estimations for the entire Mediterranean, the increase (over the entire anthropogenic input) due to mariculture during 1998 was 0.3-1.0% for Nitrogen and 0.4-1.4% for Phosphorus. For Greece (the main producer of sea bream and sea bass in the Mediterranean) these figures increased to 1.9-7.7% for N and 2.9 to 10.4% for P. Of course the increase in total nutrient concentration is far lower since neither the "natural" discharges from rivers nor the existing natural nutrient loads are taken into account in the estimation of the above figures. However, the increase on a local scale (e.g. a coastal bay) could be far higher and therefore public concern is not unexpected.

Benthic enrichment

Most reviews on environmental impacts of fish farming (Gowen and Bradbury, 1987; Gowen, 1991; Iwama, 1991; Wu 1995) have emphasized that the most widely known effect is benthic enrichment beneath the sea farms. Several authors have reported the presence of a loose and flocculent black sediment under fish cages (Hall *et al*., 1990; Angel *et al*., 1995), commonly named "fish farm sediment" (Holmer, 1991). This sediment is characterized by low values of redox potential (Hargrave *et al*., 1993), high content of organic material (Hall *et al*., 1990; Holmer, 1991) and accumulation of nitrogenous and phosphorous compounds (Holby and Hall, 1991; Hall *et al*., 1992). Karakassis *et al*. (1998) emphasized the need for investigating patterns in vertical profiles as a means of assessing fish farming impacts. The measurement of surface values alone, although useful for the assessment of the size of the affected zone, may not provide adequate information on the dynamic processes related to the accumulation of waste material beneath the cages. Some of the environmental variables (and, in particular, concentrations) may be relatively constant in time while the depth of the farm sediment could vary considerably.

Karakassis *et al*. (1998) investigated the seasonal variability in sediment profiles beneath fish farm cages in a silty sediment Mediterranean site. The surface concentrations and the vertical distribution of the sedimentary parameters studied (organic matter, organic carbon/nitrogen, chlorophyll a, phaeopigments, water content and total phosphorous) varied substantially according to distance from the cages and season. The black-coloured top layer (farm sediment) showed high concentrations of organic matter phaeopigments and total phosphorous as well as high water content, while the compact subsurface layer had concentrations close to (or lower than) those at the control site. The thickness of the farm sediment layer under the cages varied with season, while in all seasons it decreased rapidly the further the distance from the cages.

A seasonal survey combining sediment geochemistry and macrofauna was carried out in the Mediterranean (Cephalonia, Ithaki and Sounion) at three commercial fish farms established at a bottom depth of 20-30 m, in areas with different types of substratum (from 80% silt to coarse sand) and with varying intensity of water currents (Karakassis *et al*., 2000). The results of this study indicated that the impacts of fish farming on the benthos in the Mediterranean could vary considerably depending on the specific characteristics of the farming site. At the sampling stations under and near the cages, redox potential was found to decrease but reached negative values only at the silty sediment site. The organic carbon and nitrogen content of the sediment near the cages was found to increase by 1.5-5 times and ATP content by 4-28. No azoic zone was encountered in any of the stations, but the macrofaunal community was affected at a distance of up to 25 m from the edge of the cages. At the coarse sediment sites, abundance and biomass increased by more than 10 times and at all sites diversity indicated that the ecotone was in the vicinity of 25 m from the cages. Similar patterns of succession from the impacted to the normal zones were found in all three areas, although macrofaunal composition differed among the sites.

In a paper reporting data from two sites in Greek coastal waters, Papoutsoglou *et al*. (1996) reported that visual inspection by divers failed to detect any effects on the seabed under the fish cages. Similar results were reported from Selonda Bay by Mac Dougall and Black (1999), who used an acoustic ground discrimination system. In Ithaki and Sounion, visual inspections of the seabed were also carried out by means of divers and ROV (Remotely Operated Vehicle), and they revealed hardly any differences between the areas under the cages and the control sites. However, a closer investigation of chemical and biological characteristics of the seabed showed that marked differences existed in respect of both chemical variables and macrofaunal community composition.

Similar effects were found in studies addressing the impacts of salmon cage farming in Scotland (Brown *et al*., 1987) and the East coast of Canada (Hargrave *et al*., 1993) as well as in a sandy bottom farm in Puget Bay in N.E. Pacific (Weston, 1990). Levels of increase in sediment concentration of organic material comparable to those found in Cephalonia and Ithaki (by a factor of 2) were reported for silty seabed by Brown *et al*. (1987) and Hargrave *et al*. (1993) as well as by Holmer and Kristensen (1992) in non-specified type of sediment. Considerably higher levels of increase (by a factor of four) were reported for a sandy seabed by Weston (1990).

Sediment anoxia, patches of *Beggiatoa* and absence of macrofauna have been reported in relation to salmon farming in the North Atlantic (Rosenthal and Rangeley, 1988; Hansen *et al*., 1991) and the Baltic Sea (Holmer and Kristensen, 1992). Despite the microtidal regime of the Mediterranean, results from the study in Cephalonia Ithaki and Sounion (Karakassis *et al*., 2000) showed that even in the sampling stations under the cages there was no extensive "azoic" zone as defined by Pearson and Rosenberg (1978).

Regarding the effects of bream and bass farming on the wild fish populations, there is little information available. Mac Dougall and Black (1999) reporting data from the Mediterranean and Angel *et al*. (1995) from the gulf of Aqaba, have attributed the relatively low impacts of organic enrichment on the seabed to the consumption of the organic matter by demersal fish and invertebrates. Underwater video observations in Cephalonia, Ithaki and Sounion (Karakassis, unpublished data) confirmed that large numbers of fish of various species were aggregated under the fish cages during feed supply.

Recovery of the benthic system

During the last few years, there has been an attempt to value the environment (Navrud, 1991), and to assess its importance as a provider of goods and services (Costanza *et al*., 1997) to human society. In this context, it would be important to assess the value of public goods, such as the marine environment, assigned to private use. Perhaps the most relevant information needed for this assessment is the potential, and the time needed, for recovery after the exploitation or the disturbance of a particular resource.

A recovery experiment was carried out at a silty sediment site (Karakassis *et al*., 1999). After the removal of fish cages at an intensive aquaculture site, the sedimentary environment was seasonally monitored over 23 months for geochemical variables and macrofauna. At the stations near the farming site, the sediment was initially found to be anoxic and overlain by a highly organic black layer. Although initially (during the first 6-10 months) there was a rapid improvement in benthic conditions, subsequently the system showed large fluctuations in the values of most variables over the 23 months, indicating that the environment had not fully recovered until the end of the observations. This regression was attributed to a secondary disturbance due to a benthic algal bloom, caused by the seasonal release of nutrients from the farm sediment. It is concluded that the recovery process of heavily enriched benthos in a dynamic coastal environment is subject to the influence of different factors resulting in progress and regression and therefore the succession model proposed by Pearson and Rosenberg (1978) may not be applicable in the early stages of succession.

Delgado *et al*. (1999) studied the recovery process of a *Posidonia* meadow after the cessation of a fish farm in the Western Mediterranean. Although the water quality had recovered early, the *Posidonia oceanica* meadow was still declining three years after the cessation of the fish farming. The authors attributed this decline to mineralization of settled organic material and increased nutrient fluxes. Those nutrients in turn favoured the growth of epiphytes and phytoplankton which both reduced light availability for *Posidonia* photosynthesis.

Mazzola *et al*. (2000), have shown that meiofaunal abundance (i.e. benthic organisms smaller than 0.5 mm) had returned to the levels recorded prior to establishing fish farming in less than six months after the cessation of fish farming. It should be noted that this experiment was carried out at an extremely low time scale (<1 year) and that there is no established relation between benthic enrichment and meiofaunal community structure. However, it is assumed that meiobenthic organisms play an important role in mineralization of organic material on the seabed by interacting with microbial populations. Therefore, the dynamics of meiobenthos is potentially an important factor, particularly in azoic (in terms of macrofauna) sediments.

Research priorities and policy requirements for sustainable management

The available information does not justify concerns about degradation of Mediterranean marine ecosystems due to fish farming wastes under the present production levels. However, there is a need to increase scientific understanding of the ecological processes affected by fish farming in order to develop indicators of environmental health and to produce widely accepted environmental quality standards. This information will aid decision making on further expansion of the industry, avoiding adverse ecological consequences and undesirable effects on farmed stocks.

It is particularly important that research addresses region-specific problems since there are considerable differences among different regions (N. Atlantic, Mediterranean, Baltic, etc.) in terms of the environmental attributes, the fish farmed and the socioeconomic implications. In this context, uniformity in regulation on a regional scale is important for sustainability both in terms of effectiveness and in relation to ecological consequences. Legal restrictions and monitoring obligations could increase the production cost locally. This would favour the expansion of the industry in the less-regulated areas and this might result in further environmental degradation (Karakassis, 1999). In particular, regionally important issues such as species introductions and restriction in the use of antibiotics should be subjected to uniform regional regulations and monitored with equal efficiency region-wide, since the prevention system in this case is as efficient as its least efficient component. The region-specific criteria for site selection in the Mediterranean (PAP/RAC, 1996) as well as the monitoring protocols proposed by GESAMP (1996) could serve as a basis upon which future improvement may be based.

Conclusions

(i) No signs of eutrophication nor significant increase in phytoplankton biomass or organic carbon in the water column were found, despite the temporary increase in ammonium and phosphate concentrations.

(ii) Diel fluctuations in ammonium and phosphate have been reported resulting in concentration increase by a factor of seven during midday.

(iii) A large proportion of the P wastes was found to settle on the seabed in the case of sea bream and sea bass cage farming.

(iv) The impacts on the seabed beneath the cages were found to range from very significant to relatively negligible, depending on sediment type and the local water currents.

(v) In silty sediments, there is higher potential for degradation of benthic conditions with bottom anoxia and H_2S emissions.

(vi) Impacts on the sediment were not observed beyond 25 m from the footprint of the cages

(vii) A seasonal recovery pattern was found which is related to reduced feed supply and the environmental conditions during the winter period.

(viii) Benthic recovery in silty sediments after the cessation of fish farming may be considerably delayed (more than two years) due to secondary disturbance and new carbon fixation.

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