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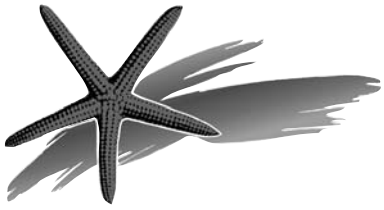

Impact of mariculture on coastal ecosystems

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Ecological relationship between wild fish populations and Mediterranean aquaculture in floating fish cages

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Abstract

Floating fish farms are associated, with important aggregations of wild fish around them. Several studies have shown that there is an important aggregation around all of the Mediterranean farms throughout. The most abundant families are clupeids, sparids, carangids, mugillids and pomatomids, although the dominant species varied markedly among farms and seasons. This important aggregation affects the behaviour and physiology of the local ichthyofauna, and may have important consequences for wild fish populations and local fisheries on a regional scale. Aggregated fish change diet, using aquafeed as main resource, which increases the biological condition but also affects the fatty acid composition, increasing vegetal fatty acids. Floating cages also aggregate post-larvae and juveniles of several pelagic and benthic species which find protection around the floating structures. Wild fish reduce environmental impact on the benthic communities by feeding on the lost food pellets. In addition, protection of this aggregation around Mediterranean fish farms can promote biomass exportation and enhance local fisheries. Therefore, the aggregation of wild fish around fish farms is an important aspect to take into account for coastal managers.

Introduction: fish cages work as 'mega' FADs

Fish are attracted towards a high variety of natural and artificial objects which stimulate the formation of aggregations (Dempster and Taquet, 2004). These objects are defined generally as Fish Aggregation Devices (FADs). This behaviour occurs throughout the different developmental stages of fish, from larvae to adults. One of the most important artificial structures in Mediterranean pelagic systems are floating fish farms, which attract great numbers of wild fish. The phenomenon is widespread and large aggregations around fish farms have been described across the Mediterranean Sea (Dempster *et al*., 2002; Thetmeyer *et al*., 2003; Machias *et al*., 2004).

The effect of attraction seems to be higher around farms than around traditional FADs due to the availability of food, with up to 2,800 times more wild fish in their immediate vicinity than in areas without farms (Dempster *et al*., 2002). A single sea-cage farm covering a sea surface area of just one hectare may have up to 40 tons of wild fish beneath it. Comparison of fish assemblages before and after fish farms deployment in Greece showed that the overall abundance of the fish assemblage increased by a factor of four and the average trophic level of the fish community increased from 3.59 to 3.79 (Machias *et al*., 2004).

In the Mediterranean, the production of the two main species farmed reaches over 140,000 t yr^{-1} and due to the increasing demand of cultured species, production will continue to increase significantly in the future. Therefore, ecological effects of mariculture on wild fish which aggregate around fish farms in coastal areas may become a global concern.

Fish assemblages associated with Mediterranean fish farms

In a study carried out around nine locations in autumn 2001 in SE Spain (Dempster *et al*., 2002), fish farms had greater abundance (52 to 2,837×), biomass (2.8 to 1,126×) and number of fish species (1.6 to 14×) than control counts at all locations. During the study, 28 species belonging to 14 families were recorded. Two families, Carangidae (four species) and Sparidae (12 species), were the most represented. Only fourteen species occurred at fish farms, 13 species were seen in both farm and control counts, and 1 species (*Mola mola*, one individual) was seen at one control location only. *Sardinella aurita* was the most common species observed in the control counts, although the number per count (20 to 200 individuals) was far less than at fish farm locations. Furthermore, the fish assemblage has a marked seasonal variability (Figure 1), mainly dominated by migrations of some species such as *Boops boops*, *Sardinella aurita* and *Trachurus mediterraneus* (Valle *et al*., 2007).

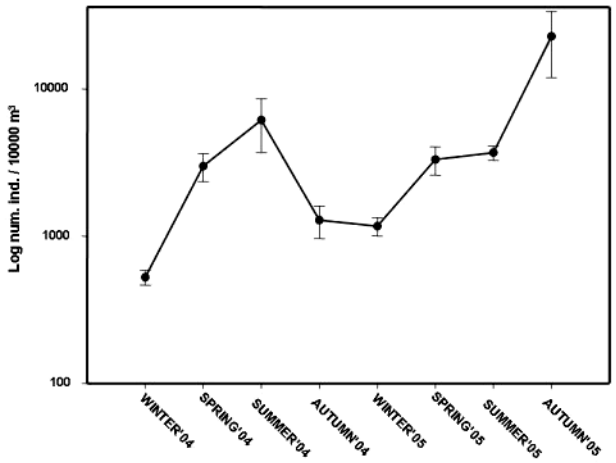

Fig. 1. Seasonal pattern of fish abundance around three fish farm on SE Spain. Each value corresponds with the mean of six visual counts at three fish farm, carried out two random times per season.

Fish larvae attraction to fish farms

The vast majority of demersal teleost fishes have a pelagic larval stage which has major implications for the dynamics of fish populations and fisheries management. Fish farms also aggregate fish larvae around their floating structures, mainly in the upper 2 m of the water column. A survey carried out during 2006 (Fernandez-Jover *et al*., unpublished data) showed that there is a permanent recruitment of post-larvae (individual smaller than 1 cm), mainly belonging to the Sparidae, Mullidae and Atherinidae families. Around a single cage of 12 m diameter *Boops boops* larvae could number several hundreds and up to 1,800 in December 2006 (Figure 2).

The influence of fish cages on the pelagic larval stage could affect the connectivity between larval and adult populations, through a spatial modification of the habitat and altered mortality, due to high aggregations of predatory adult fishes during this pelagic stage.

Changes in diet and physiological effects

Many fish species which aggregate around coastal sea-cage fish farms use food pellets as food, which alter the natural diet. Changes in diet can in turn affect the condition index. Fernandez-Jover *et al*. (2007a) demonstrated that Mediterranean horse mackerel (*Trachurus mediterraneus*) captured at fish farms had a significantly higher condition index than its non-associated counterparts due to a diet based on the lost food pellets. Wild fish that fed around the cages had a

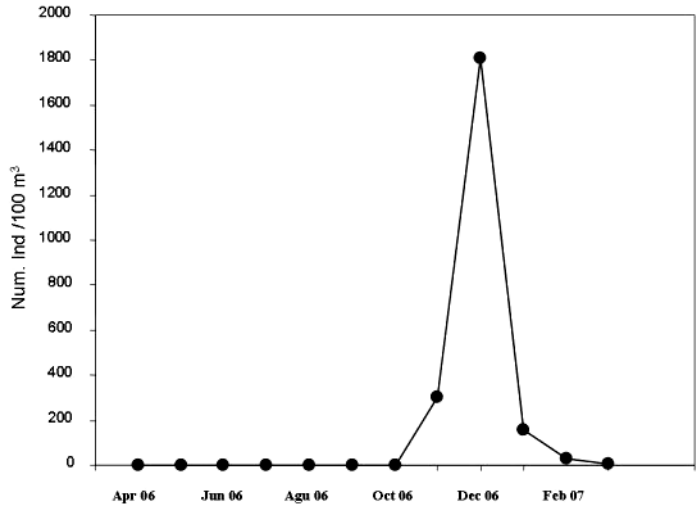

Fig. 2. Temporal trends of *Boops boops larvae* abundance (< 3 cm) around a single farm at SE Spain (El Campello, Alicante).

significantly higher body fat content than the control fish (7.30±1.8% and 2.36±0.7% respectively). This change in body condition due to the extra feeding may lead to changes in their reproductive capacity.

The composition of the food pellets affects the fatty composition of wild fish. Food is composed of fish protein, but also of vegetable-derived proteins and fats. The fatty acid composition differed between farm-associated and control fish, principally because of the significantly higher levels of linoleic (C18:2ω6) and oleic (C18:1ω9) acids (vegetable-derived fatty acids) and lower levels of docosahexaenoic acid (C22:6ω3) in farm-associated fish. Because of the changes in fatty acids, the concentration of ω3 is cut down when wild fish feed on food pellets thus affecting to the taste for human consumers (Skog *et al*., 2003). Furthermore the fatty acids compositions could also serve as biomarkers to infer the influence of a fish farm on the local fish community.

Reduction of benthic impact by reduction of lost food

Some studies have detected the effect of aggregated wild fish in reducing the impact on the benthos. Aggregated wild fish reduced the sedimentation of the total organic wastes at one Mediterranean farm by up to 80% (Vita *et al*., 2004b). There are models that include wild fish as removers of feed wastes (<http://www.meramed.com>) but they are only considered as a sink of organic matter. Wild fish that aggregate around fish farms and feed on the lost food pellets influence the environmental impact by excreting nitrogen and carbon to the water column, thereby reducing the input to the benthos. Experimentally, it has been demonstrated that there is an important input of $NH4^+$ and DOC from the faeces of wild fish to the pelagic system, which occurs very quickly in the first minutes (Fernandez-Jover *et al*., 2007b). This reduces the quantity of organic matter that reaches the seafloor because uneaten food pellets start leaching nutrients as soon as they contact water; however, they are rapidly eaten by wild fish in a high proportion.

Based on the conceptual model for nutrient mass budget of Islam (2005), we can estimate the influence of wild fish on the total amount of nitrogen lost to the environment. Using a Food Conversion Ratio of 1.79 for sea bream (Lupatsch and Kissil, 1998), without the influence of wild fish, 22.6 kg of nitrogen would sediment (at 25 °C) for one ton of sea bream production, including both feed and faeces nitrogen. Therefore, there is a severe impact on the surrounding benthic communities. However, if we consider a scenario where wild fish consumed 80% of lost food pellets (Vita *et al*., 2004b) and apply the results on faeces leaching rates (Fernandez-Jover *et al*., 2007b; assuming that all the aggregation is composed of *T. mediterraneus*, only 0.28 kg of nitrogen will reach the sediment. This load of nutrients could be dispersed or assimilated by the pelagic communities and therefore reduce the impact on the benthic environment around fish farms.

NEGATIVE INTERACTION: PREDATION OF *POMATOMUS SALTATRIX* ON CULTURED FISH

The bluefish, *Pomatomus saltatrix*, is an abundant marine piscivorous fish that occurs in all oceans except the eastern Pacific, from oceanic to coastal environments. Bluefish have been shown to be important piscivores, as their diet consists of a variety of fish species of commercial and recreational importance (Buckel *et al*., 1999). Adults are in loose groups, often attacking shoals of mullets or other fishes and destroying numbers apparently far in excess of feeding requirements. Permanent aggregations of bluefish occur around several fish farms in SE Spain, with abundances of 1,000s of individuals (Fernandez-Jover *et al*., unpublished data). Gut contents analysis showed a predominance of *Sardinella aurita*, which are very abundant around fish farms in the diet of the bluefish which also feeds on benthic species such as *Serranus cabrilla* and *Mullus surmuletus*. One of the fish farms studied suffered entries of bluefish from several individuals up to 400 tons. Entry into sea-cages very negatively affects culture conditions because of the aggressive behaviour of *P. saltatrix*. Seabream stop eating and mortality increases dramatically due to predation. Further, it has been detected that escapes increase during such episodes, as the sea-bream more actively seek to escape to avoid predation and do so through the entry holes made by the bluefish.

BENEFIT OF LOCAL FISHERIES BY PROTECTION OF AGGREGATED POPULATIONS

Wild fish that gather at farms tend to be large adults (Dempster *et al*., 2002). This is important as the 'big ones' do most of the spawning and produce the next generation. The constant supply of high protein food when feed is lost through the cages also means that these big fish are in better body condition than their wild counterparts elsewhere in the sea. Better conditions increase the spawning success of fish. Higher-order predators, such as large pelagic fish, rays and dolphins, are also present at farms to feed on the aggregated wild fish (Dempster *et al*., 2002, 2006; Boyra *et al*., 2004a).

Many of the fish species that occur at farms in high numbers are commercially important to coastal fisheries and are already subject to heavy fishing pressure. Fish farms produce an apparently positive effect for local fisheries (Machias *et al*., 2006). If restrictions on fishing are applied within farm leasehold areas, it has been suggested that coastal sea-cage fish farms may act as small (up to 160,000 m^2) pelagic no-take areas (Dempster *et al*., 2002). Groups of fish were not seen more than 50 m away from cages at any farm. This result is analogous to the association of reef fishes with artificial reefs, where a steep decline in abundance is typically observed at distances of just a few meters from the artificial structure. Therefore, wild fish aggregation around fish farms could have positive effects for local fisheries, mitigating partly the negative impact of this activity on coastal ecosystems (Dempster *et al*., 2006).

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