# Environmental interactions and initiatives on site selection and carrying capacity estimation for fish farming in the Mediterranean

**Ioannis Karakassis**
University of Crete, Biology Department, Heraklion, Crete, the Hellenic Republic

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**Abstract**

During the past two decades fish farming in the Mediterranean has increased very rapidly particularly in the coastal zone of the Northern part of the basin particularly through the farming of sea bream and sea bass. A series of national and, particularly, EU-funded research projects have addressed complementary aspects of the issue of environmental interactions of aquaculture in the Mediterranean since 1995. These included *inter alia* benthic and pelagic effects, modelling, interactions with fisheries, seagrasses, socio-economic issues etc. This background knowledge now makes possible the attempt to harmonize the regulation of aquaculture among all Mediterranean countries. A series of such initiatives is presented regarding the modernization of the regulatory framework of Aquaculture in the Hellenic Republic and the attempt by the GFCM (General Fisheries Commission for the Mediterranean) to define common environmental standards for site selection and carrying capacity of coastal aquaculture.

## Introduction

Duarte *et al.* (2009) have estimated that aquaculture will have to increase production substantially during the forthcoming decades to increase animal protein supply to the increasing human population. Therefore, it is likely that some of the coastal and shelf ecosystems and particularly those that are suitable for aquaculture developments will face environmental pressures significantly higher than those they have experienced so far. In this context the assessment of the carrying/holding capacity of a receiving environment with respect to aquaculture production and consequently the adoption of good practices and sound environmental regulations is an indispensable prerequisite for the sustainability of aquaculture and the food production sector in general.

In the Mediterranean aquaculture and particularly fish farming has increased almost exponentially during the past 3 decades mainly with seabream (*Sparus aurata*) and seabass (*Dicentrarchus labrax*) farming in sea cages. Some new to aquaculture species have been used successfully for cage farming as well but their overall percentage in the total production figures is still quite small. The Hellenic Republic is the leading producer country in the Mediterranean followed by the Republic of Turkey, the Kingdom of Spain and the Republic of Italy but gradually in all Mediterranean countries the production increases. After 2000 tuna farming has also emerged in various Mediterranean countries mainly the Kingdom of Spain, the Republic of Croatia, the Republic of Malta and the Republic of Cyprus and recently also the Hellenic Republic and the Republic of Turkey.

Mediterranean is a unique marine ecosystem with some specific environmental attributes affecting aquaculture: (a) high temperature in the water column (minimal temperature of 12°C reaching up to 25°C during summer) favouring rapid growth of fish and allowing production throughout the year, (b) microtidal regime (<50 cm in most places) reducing the dispersion and of dissolved and particulate wastes of fish farms and the water renewal in enclosed bays with weak currents, (c) oligotrophic conditions (with a few exceptions such as the Adriatic and some specific bays with riverine inputs), with low concentration of nutrients, primary productivity, low phytoplankton biomass, and relatively low quantities of particulate organic material and high levels of oxygen. These conditions are favourable for fish farming, allowing low stress for the farmed stock but not very suitable for mussel farming, (d) unlike other ocean systems, the limiting factor for primary productivity is Phosphorus rather than Nitrogen and therefore eutrophication (even locally) may occur only if P is released in adequate quantities, (e) rich marine fauna and flora particularly in the coastal zone, with a high percentage of endemic species. However, both abundance and biomass of most ecosystem components are rather low due to oligotrophic conditions.

This waterbody is shared by 21 countries with different cultural traditions, economic structure, societal profiles and legislative frameworks. The Mediterranean history is rich in collaboration traditions but also in conflicts. In other words the Mediterranean is a miniature of the world and therefore a strategy aiming at multinational cooperation, exchange of information and harmonization of regulations which becomes successful here it is likely to be viable also in any other region of the world.

This is why FAO, GFCM have promoted initiatives to assist cooperation for the development of aquaculture, to enhance the dialogue among Mediterranean states and stakeholders regarding three main issues i.e. site selection and carrying capacity, sustainability indicators and marketing of aquaculture products. In this review, we will refer to the work carried out in the framework of the Working group on site selection and carrying capacity (WGSC) and the associated project SHoCMed (Siting and Holding Capacity in the Mediterranean) which is co-funded by the EU and the GFCM.

## Environmental interactions of aquaculture in the Mediterranean

During the past 15 years a series of national and EU funded research projects have addressed the issue of environmental interactions of aquaculture in the Mediterranean exclusively or in a broader framework. I could mention a few ones here: **MERAMED** (Development of monitoring guidelines and modelling tools for environmental effects from Mediterranean aquaculture) designed to provide a specific model (MERAMOD) for the benthic effects of fish farming in the Mediterranean and to address a series of hypotheses relating to environmental effects and monitoring; **MedVeg** (Effects of nutrient release from Mediterranean fish farms on benthic vegetation in coastal ecosystems), carried out in 4 Mediterranean countries (the Kingdom of Spain, the Republic of Italy, the Hellenic Republic, the Republic of Cyprus) and focusing on the effects of fish farming on *Posidonia oceanica* meadows; **AQCESS** (Aquaculture and Coastal Economic and Social Sustainability) which has examined both environmental and socio-economic aspects of the aquaculture performance in Europe analyzing conflicts of uses, labour mobility as well as large-scale effects of aquaculture zones; **BIOFAQs** (BIOFiltration and Aquaculture: an Evaluation of Substrate Deployment

Performance with Mariculture Developments), which carried out research on the potential for use floating biofilters as a means for mitigation of aquaculture impacts on the water column; **SAMI** EU FP6 project (Synthesis of Aquaculture and Marine Ecosystems Interactions) which provided a synthesis of the above projects in EU-FP5 incorporating also other issues such as the shortage of fish meal and fish oil and the potential ecological risks from the pressures on marine ecosystems; the **ECASA** EU FP6 project (Ecosystem approach for sustainable aquaculture) which involved 16 research partners (8 from the Mediterranean) from 13 member states. The outcome of this project is the most up-to-date toolbox of environmental models related to aquaculture and an extensive list of indicators that have been developed by a large number of experts and have been discussed with various stakeholders in Europe; the ongoing **SPICOSA** EU FP6 project, (Science and policy integration for coastal system assessment) has also a Mediterranean and a fish farming component and is likely to be of some interest when it is completed; the **PREVENT-ESCAPE** project: (www.sintef.no/Home/Marine/Fisheries-and-Aquaculture/Aquaculture-Technology/Aquaculture-constructions/Prevent-Escape/) a new EU FP7 project which started last year addressing the environmental impacts of fish escaping from fish farms and proposing mitigation measures. Almost half of the scientific effort will be used to address this issue in the Mediterranean.

As a consequence of this research activity, during this period there has been a significant increase in the amount and quality of the published information on aquaculture-environment interactions in the Mediterranean (see reports by Soto and Crosetti, 2005 and Karakassis and Angel, 2008). Most of these papers published in the prime scientific literature, focused on fish farming and ca 25 percent on shellfish. Most of the papers (>80) were related to benthic processes typically with geochemical variables and macrofauna or meiofauna, some (>30) focusing on nutrients and/or plankton, effects on *Posidonia* meadows (>25) and interactions with wild fish (19).

Investigations on the water column in the vicinity of Mediterranean fish farms, there was little observed increase in Chla content (Pitta *et al.*, 1999; La Rosa *et al.*, 2002; Pitta *et al.*, 2005) as was also the case in other surveys in the vicinity of fish farms in other parts of the world (Nordvarg and Johansson, 2002; Soto and Norambuena, 2004). This was despite the continuous nutrient supply which is known to be discharged from fish farming activity (Karakassis, Pitta and Krom, 2005 and references therein). A recent study by Dalsgaard and Krause-Jensen (2006) using macroalgal and phytoplankton bioassays revealed a high primary productivity near the fish cages rapidly decreasing with distance from the farms. The experiment with dialysis bags was repeated using filtered and unfiltered seawater (Pitta *et al.*, 2009) and showed that grazing played an important role in the regulation of phytoplankton communities, which is also compatible with the findings of Thingstad *et al.* (2005) regarding P addition as well as with the findings of Machias *et al.* (2004, 2005, 2006) regarding the rapid transfer of nutrients up the food web.

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, Pittman and Ervik, 1991) and the Baltic Sea (Holmer and Kristensen, 1992). Despite the microtidal regime of the Mediterranean, none of the studies carried out in fish farms in this area showed an azoic zone, in terms of macrofauna, in the close vicinity or even beneath the cages (e.g. Karakassis *et al*., 2000; Tomassetti and Porrello, 2005; Klaoudatos *et al*., 2006; Yucel-Gier, Kucuksezgin and Kocak, 2007; Dimitriadis and Koutsoubas, 2008). Furthermore, Maldonado *et al.* (2005) showed that in 5 semi-offshore farms in the Kingdom of Spain the effects on benthic macroinvertebrate communities were even less possible to detect finding no substantial differences between farm and control sites. In most cases the effects of fish farming on macrobenthic diversity and community structure were detectable and compatible with the Pearson and Rosenberg (1978) empirical model up to a distance of 10–25m from the edge of the cages. Regarding the Water framework Directive of the EU data from Aguado-Giménez *et al.* (2006) from the Kingdom of Spain and Karakassis *et al.* (unpublished) from the Hellenic Republic indicate that the benthic quality directly beneath fish farms cannot be considered as "High" or "Good" no matter what index is used.

Underwater diving census and video surveys beneath fish farms in the Western and Eastern Mediterranean (Dempster *et al*., 2002; Smith *et al.*, 2003; Vega Fernandez *et al.*, 2003; Golani, 2003) confirmed that large numbers of a diverse fish fauna are aggregated under the fish cages during feed supply. Tuya *et al.* (2006) showed that this aggregation was related to the feed supply rather than to FAD-effect since their densities approach "normal" densities after the cessation of fish farming. Dempster *et al.* (2002) have shown that the abundance, biomass and species richness of the aggregating fish assemblages are negatively correlated to distance from shore and positively with the size of the farm. These authors suggest that coastal cage fish farms may act as small pelagic marine protected areas (MPAs). Vita *et al.* (2004) conducted field experiments with sediment traps and concluded that 80 percent of the particulate OM leaving the rearing net-pens may be consumed before settling on the seabed and they have attributed a large part of this consumption to the wild fish aggregating beneath the farms. Fernandez-Jover *et al.* (2007) have found that the wild fish associated with fish farms had significantly higher fat content than the control fish in the area and therefore there is some potential for increase in their spawning ability particularly if they are also protected from fishing.

Investigations in the Eastern Mediterranean basin have addressed the issue of interactions with wild fish at larger spatial scales i.e. beyond the FAD effect. Machias *et al.* (2004) have shown that fish densities in a coastal bay in the Aegean Sea where a fish farming zone is established now are higher by a factor of two in comparison to those recorded in 1987 i.e. before the onset of fish farming in that area. Also Machias *et al.* (2005) using experimental trawling in 3 fish farming zones in the Aegean have shown that the abundance biomass and diversity of demersal fish was significantly higher than at the respective control areas. Also time series analysis of commercial fisheries landings in areas with and without fish farming (Machias *et al.*, 2006) showed a sudden increase in landing biomass after the onset of aquaculture in the fish farming zones. These authors have attributed these changes in a shift of primary production coupled with a rapid transfer of dissolved waste nutrients up the food web in a nutrient-starving oligotrophic system.

*Posidonia oceanica* is a slow-growing endemic seagrass species of the Mediterranean thriving in clear oligotrophic waters with high transparency (Holmer, Perez and Duarte, 2003) providing important ecosystem services such as shelter to juvenile stages of various marine species, protection against sediment erosion and carbon sequestration thereby reducing CO2 fluxes towards the atmosphere. The recovery times of *P. oceanica* meadows when damaged are very long, in the order of centuries, and losses of this species are thus considered to be irreversible at managerial time scales. The good water quality required by *Posidonia* makes its' habitat "ideal" for fish farming as well and therefore there are fears that a large proportion of fish farming activity is sited above such meadows despite the existing regulations in most Mediterranean countries. Research results during the past 10 years have provided information on the mechanisms of environmental deterioration related to the loss of Posidonia sites and the spatiotemporal scales of the processes involved. A synthesis paper of the MedVeg project (Holmer *et al.*, 2008) has examined a series of drivers of seagrass decline due to fish farming effects and identified the sedimentation of waste particles in the farm vicinity as the main driver of benthic deterioration. Holmer *et al.* (2008) have recommended a safety distance of 400m for management of *P. oceanica* near fish farms followed by establishment of permanent seagrass plots samples annually for monitoring the health of the meadows.

## Carrying capacity and fish farming

In general carrying capacity is a well defined concept in Ecology i.e. "the maximum population size a certain environment can support for an extended period of time, for a population of a particular species". The fact that there is increasing demand for estimating carrying capacity by various stakeholders including regulators and farmers is a positive sign indicating that it has become understood that aquaculture growth (like most other types of development) has an upper limit. This concept is readily applicable in the case of e.g. mussel farming where the farmed stock directly depends on the availability of plankton resources in the ambient water.

However, in the case of cage fish farming, the farmed stock depends on allochthonous food sources, and therefore the availability of food, as well as that of space and water may be practically limitless. Oxygen availability could be a problem determining carrying capacity in cases where water renewal is rather limited. However, for reasonable densities no oxygen problem at the surface water layers has been recorded either in the literature or in the data we have looked at. Even though theoretically a problem of anoxia in the bottom in extreme cases of organic enrichment, it would be reasonable to stop/reduce farming before reaching this point.

It is therefore needed to determine carrying capacity based on environmental criteria, i.e. by adjusting the levels of production so as not to cause unacceptable environmental change. In this case there is obviously a need to define what is "not acceptable and of course this process includes political decision grounded on value judgments on what should be protected and to what extent. In other words, we must answer the critical question "How much environmental degradation can be tolerated before taking action for the suspension or restriction of the root cause?". Certainly, the environmental impacts vary depending on the particular characteristics of the recipient site, i.e. the variables defining the assimilative capacity of the system, as well as depending on the management practices of a farm, especially with regard to the (unintentional) food wastage (which affects the conversion ratio, FCR, and the economic efficiency of the farm) or limiting escapes but also in relation to care for less environmentally damaging, but certainly unacceptable, effects such as dispersion in the area around the site of solid (plastic) packages from fish feed.

For bivalve farming McKindsey *et al.* (2006) have defined four types of carrying capacity among which "ecological carrying capacity: the stocking or farm density which causes unacceptable ecological impacts". In this context the establishment of a threshold should the point beyond which ecological change becomes unacceptable. Groffman *et al.* (2006) have identified ecological threshold as the point at which there is an abrupt change in an ecosystem quality, property or phenomenon, or where small changes in an environmental driver produce large responses in the ecosystem. On the other hand thresholds may also be defined in a legal framework as the point beyond which pollution load becomes unacceptable. This threshold defines the legal boundary between acceptable contamination and unacceptable pollution (Hassan, 2006).

In this context, Environmental Quality Standards and environmental thresholds become the major prerequisite for estimating the carrying capacity of a fish farm in a given site and also necessary for a meaningful environmental impact assessment and environmental monitoring.

## The Greek regulatory approach to adaptation of production to carrying capacity

In the Hellenic Republic the legislation on aquaculture requires an EIA before a licence is given and consensus is needed by 6 major agencies (Ministry of Agricultural Development and Food, Ministry for the Environment, Navy, Archaeology, Ministry of the Merchant marine, GR Tourism Organization). The content of the EIA was relatively unclear and the overall scheme was very inflexible allowing 150 tonnes of production per 10 000 $m^2$, regardless of the characteristics of the site.

A new regulation since 12/06/09 (common ministerial decision by Ministry of Environment and Ministry of Agricultural Development and Food) based on a study carried out by Univ. of Crete aiming at providing a means to adapt production levels to the environmental characteristics of the receiving environment. The Production level is defined by the formula:

$\Delta = [150 + 8(E-10)]\ fA\ fB\ fK$

Where, E = area of the farm site (in 103 m2), fA = distance coefficient, fB = depth coefficient and fK = exposure or current coefficient.

The fA, fB and FK coefficients have different values depending on the characteristics of the site. E.g. the distance from shore coefficient (fA) for distance <100m becomes 1.00, for 101–400m it is 1.25, for 401–1000m it is 1.50 and for >1000m it is 2.00.

These values were determined through a Delphi exercise after asking 31 experts from 20 countries. According to the new regulation:

- Distance between farms should be >500m
- The leased marine area should be 10–100 thousand $m^2$
- Depth >18m and at least 2 times the depth of the nets
- Loading per $m^3$ is provided for different species and size of fish
- Mortality (bream-bass) should be <17 percent and for other Med spp <30 percent
- No new farms on Posidonia meadows
- No expansion of the capacity of the ones over Posidonia beds
- The existing ones will not be renewed after the expiration of their concession

The overall project for the development of the new system comprised the following elements:

- Bibliographic analysis for existing standards in other countries, environmental impacts and regulatory schemes.
- Analysis of benthic data from 11 farms in the Hellenic Republic, some of which had exceeded the production they were licensed for.
- Delphi exercise with experts which resulted in 3 scenarios (conservative, intermediate and expensive) using different percentiles in the experts' responses.
- Proposal for a new system, including most of the above points.
- External evaluation by 5 international experts who participated in the workshop with the stakeholders
- A workshop involving >70 representatives of stakeholders plus the external evaluation committee where the overall scheme was discussed
- The external evaluation committee submitted a report and discussed details in an additional workshop
- The Proposal was revised to accommodate suggestions by the reviewers
- A ministerial decision Political decision was signed (ca 2 years later)

Although the above framework does not include a unique estimate/figure for the carrying or holding capacity eventually provides incentives (increase in licensed production) for the selection of sites which are likely to be more environmentally sustainable than those used so far.

### The SHoCMed approach to site selection and carrying capacity

The objectives of the WGSC of the GFCM and the SHoCMed project are:

- To produce criteria for enhancing the integration of aquaculture in CZM by improving site selection and holding capacity standards.
- To provide a basis for harmonization of standards across the Mediterranean as a means for ensuring equal terms of market competition and minimal environmental damage.
- To know what are the consequences on site selection and holding capacity under a shift in production scale in Aquaculture which is likely to occur in the near future.

- To explore the potential for using Allocated Zones for Aquaculture (AZA) as a means for improving management for aquaculture aiming at (a) increase in production, (b) reducing conflicts and (c) reducing environmental impacts.

To this end, a series of actions have been used to address the issues of site selection and carrying capacity in the Mediterranean such as:

- Reviews of the existing bibliography on environmental impacts in the Mediterranean and establishment of a bibliographic database
- Review of legislative frameworks in the Mediterranean countries regarding site selection, licensing, environmental monitoring requirements and carrying capacity issues.
- Workshop on allocated zones for aquaculture (AZAs) as a site management tool
- Workshop on Environmental Quality Standards and a Delphi exercise to determine thresholds at each variable.

Among the conclusions in the documents of this working group there some points relevant to the present workshop:

- The WGSC suggested that both the lack of EQSs and the variability of monitoring practices leave the aquaculture industry exposed to accusations on responsibility for environmental degradation during conflicts with other users and interests in the coastal zone. Therefore the WGSC has emphasized the need for establishing not only criteria for site selection but also EQSs agreed between the regulators and all the stakeholders in the coastal zone.
- The adoption of the WFD by EU countries implies that by 2015 all coastal areas including those where fish farms are currently established will comply with a set of five-level standards reaching at least the level "Good". This scheme is unlikely to be compatible with cage aquaculture as has been shown by many different studies. The adoption of the AZE (allowable zone of effects or mixing zone) concept used e.g. by SEPA in the immediate vicinity of the farms is a useful tool for addressing the issue of environmental protection in a realistic way.
- The use of a common monitoring scheme for a certain period (long-term monitoring) will allow the assessment of its robustness through a future environmental audit which will result in a further improvement of it efficiency.
- The establishment of EQSs will improve the EIA process since it will allow predictions against predefined and known criteria thus increasing consistency in the licensing and monitoring procedures and increasing transparency in the relations between farmers and regulators.
- The WGSC has discussed also other needs for monitoring that need to be addressed in the final proposal including (a) differences between offshore and coastal aquaculture sites, (b) particular extra environmental variables that have to be monitored in specific types of farming (e.g. tuna), (c) different number of variables and/or frequency of monitoring depending on farm size and/or sensitivity of the receiving environment, (d) specific measures for monitoring AZAs and (e) availability of information regarding the effects of the environment and other activities on aquaculture.

## References

**Aguado-Giménez, F., García-García, B., Hernández-Lorente, M.D. & Cerezo-Valverde, J.** 2006. Gross metabolic waste output estimates using a nutritional approach in Atlantic bluefin tuna (*Thunnus thynnus*) under intensive fattening conditions in western Mediterranean Sea. *Aquacult. Res.*, 37: 1254–1258.

**Dalsgaard, T. & Krause-Jensen, D.** 2006. Monitoring nutrient release from fish farms with macroalgal and phytoplankton bioassays. *Aquaculture*., 256: 302–310.

**Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J.T., Gimenez-Casalduero, F. & Valle, C.** 2002. Attraction of wild fish to sea-cage fish farms in the south-western Mediterranean Sea: Spatial and short-term temporal variability. *Mar. Ecol. Prog. Ser.,* 242: 237–252.

**Dimitriadis, C. & Koutsoubas, D.** 2008. Community properties of benthic molluscs as indicators of environmental stress induced by organic enrichment. *J Nat Hist*., 42: 559–574.

**Duarte, C.M., Holmer, M., Olsen, Y., Soto, D., Marbà, N., Guiu, J., Black, K. & Karakassis, I.** 2009. Will the oceans help feed humanity? *Bioscience*., 59:967–976.

**Fernandez-Jover, D., Jimenez, J.A.L., Sanchez-Jerez, P., Bayle-Sempere, J., Casalduero, F.G., Lopez, F.J.M. & Dempster, T.** 2007. Changes in body condition and fatty acid composition of wild Mediterranean horse mackerel (*Trachurus mediterraneus*, Steindachner, 1868) associated to sea cage fish farms. *Mar. Environ. Res*., 63:1–18.

**Golani, D.** 2003. Fish assemblages associated with net pen mariculture and an adjacent rocky habitat in the Port of Ashdod Israel (eastern Mediterranean) – preliminary results. *Acta Adriat*., 44: 51–59.

**Groffman, P., Baron, J., Blett, T., Gold, A., Goodman, I., Gunderson, L., Levinson, B., Palmer, M., Paerl, H., Peterson, G., LeRoy Poff, N., Rejeski, D., Reynolds, J., Turner, M., Weathers, K. & Wiens, J.** 2006. Ecological thresholds: the key to successful environmental management or an important concept with no practical application? *Ecosystems*. 9:1–13.

**Hansen, P.K., Pittman, K. & Ervik, A.** 1991. Organic waste from marine fish farms – Effects on the seabed. *Marine Aquaculture and Environment*., 22: 105–119.

**Hassan, D.** 2006. *Protecting the marine environment from land-based sources of pollution: towards effective international cooperation*. Ashgate, Hampshire, United Kingdom. 233 pp.

**Holmer, M., Argyrou, M., Dalsgaard, T., Danovaro, R., Diaz-Almela, E., Duarte, C.M., Frederiksen, M., Grau, A., Karakassis, I., Marba, N., Mirto, S., Perez, M., Pusceddu, A. & Tsapakis, M.** 2008. Effects of fish farm waste on *Posidonia oceanica* meadows: Synthesis and provision of monitoring and management tools. *Mar. Pollut. Bull*., 56:1618–1629.

**Holmer, M., Perez, M. & Duarte, C.M.** 2003. Benthic primary producers--a neglected environmental problem in Mediterranean maricultures?. *Mar. Pollut. Bull*., 46:1372–1376.

**Holmer, M. & Kristensen, E.** 1992. Impact of fish cage farming on metabolism and sulfate reduction of underlying sediments. *Marine Ecology Progress Series.* 80:191–201.

**Karakassis, I., Pitta, P. & Krom, M.D.** 2005. Contribution of fish farming to the nutrient loading of the Mediterranean. *Sci Mar*., 69: 313–321.

**Karakassis, I., Tsapakis, M., Hatziyanni, E., Papadopoulou, K.N. & Plaiti, W.** 2000. Impact of cage farming of fish on the seabed in three Mediterranean coastal areas. *ICES Journal of Marine Science.* 57: 1462–1471.

**Karakassis, I. & Angel, D.** 2008. Aquaculture and the environment in the Mediterranean: available information and proposed steps forward. Report to GFCM/FAO. Rome.

**Klaoudatos, S.D., Klaoudatos, D.S., Smith, J., Bogdanos, K. & Papageorgiou, E.** 2006. Assessment of site specific benthic impact of floating cage farming in the eastern Hios island Eastern Aegean Sea Greece. *J. Exp. Mar. Biol. Ecol*., 338: 96–111

**La Rosa, T., Mirto, S., Favaloro, E., Savona, B., Sara, G., Danovaro, R. & Mazzola, A.** 2002. Impact on the water column biogeochemistry of a Mediterranean mussel and fish farm. *Water Res*., 36: 713–721.

**Machias, A., Giannoulaki, M., Somarakis, S., Maravelias, C.D., Neofitou, C., Koutsoubas, D., Papadopoulou, K.N. & Karakassis, I.** 2006. Fish farming effects on local fisheries landings in oligotrophic seas. *Aquaculture*., 261: 809–816.

**Machias, A., Karakassis, I., Giannoulaki, M., Papadopoulou, K.N., Smith, C.J. & Somarakis, S.** 2005. Response of demersal fish communities to the presence of fish farms. *Mar Ecol Prog Ser*., 288: 241–250.

**Machias, A., Karakassis, I., Labropoulou, M., Somarakis, S., Papadopoulou, K.N. & Papaconstantinou, C.** 2004. Changes in wild fish assemblages after the establishment of a fish farming zone in an oligotrophic marine ecosystem. *Estuar. Coast. Shelf Sci.,* 60:771–779.

**Maldonado, M., Carmona, M.C., Echeverria, Y. & Riesgo, A.** 2005. The environmental impact of Mediterranean cage fish farms at semi-exposed locations: Does it need a re-assessment?. *Helgol. Mar. Res.,* 59:121–135.

**McKindsey, C.W., Thetmeyer, H., Landry, T. & Silvert, W.** 2006. Review of recent carrying capacity models for bivalve culture and recommendations for research and management. *Aquaculture*., 261:451– 462.

**Nordvarg, L. & Johansson, T.** 2002. The effects of fish farm effluents on the water quality in the Aland archipelago, Baltic Sea. *Aquacultural Engineering.* 25: 253–279.

**Pearson, T.H. & Rosenberg, R.** 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology. An Annual review* 16: 229–311.

**Pitta, P., Apostolaki, E.T., Giannoulaki, M. & Karakassis, I.** 2005 Mesoscale changes in the water column in response to fish farming zones in three coastal areas in the Eastern Mediterranean Sea. *Estuarine, Coastal and Shelf Science.* 65:501–512.

**Pitta, P., Karakassis, I., Tsapakis, M. & Zivanovic, S.** 1999. Natural vs. mariculture induced variability in nutrients and plankton in the Eastern Mediterranean. *Hydrobiologia* 391:181–194.

Pitta, **P., Tsapakis, M., Apostolaki, E.T., Tsagaraki, T., Holmer, M. & Karakassis, I.** 2009. 'Ghost nutrients' from fish farms are transferred up the food web by phytoplankton grazers. *Marine Ecology Progress Series* 374: 1–6.

**Rosenthal, H. & Rangeley, R.W.** 1988. *The effect of a salmon cage culture on the benthic community in a largely enclosed Bay (Dark Harbour, grand Manan Island, N.B., Canada).* Fish Health Protection Strategies, 299 pp.

**Smith, C., Machias, A., Giannoulaki, M., Somarakis, S., Papadopoulou, K.N. & Karakassis, I.** 2003. Diversity study of wild fish fauna aggregating around fish farm cages by means of remotely operated vehicle (ROV). Abstr 7th Hel Symp Oceanogr & Fish p 227 (ISSN 1107-6534).

**Soto, D. & Crosetti, D.** 2005. The environmental situation of aquaculture in the Mediterranean Sea: a review. (www.fao.org/docrep/009/a0466e/A0466E07.htm)

**Soto, D. & Norambuena, F.** 2004. Evaluation of salmon farming effects on marine systems in the inner seas of southern Chile: a large-scale mensurative experiment. *J Appl Ichtyol*., 20:493–501.

**Thingstad, T.F., Krom, M.D., Mantoura, R.F.C., Flaten, G.A.F., Herut, B., Kress, N., Law, C., Pasternak, A., Pitta, P., Psarra, S., Rassoulzadegan, F., Tanaka, T., Tselepides, A., Wassmann, P., Woodward, E.M.S., Wexels-Riser, C., Zodiatis, G. & Zohary, T.** 2005. Nature of Phosphorus limitation in the ultraoligotrophic Eastern Mediterranean. *Science*., 309:1068–1071.

**Tomassetti, P. & Porrello, S.** 2005. Polychaetes as indicators of marine fish farm organic enrichment. *Aquacult. Int*., 13:109–128

**Tuya, F., Sanchez-Jerez, P., Dempster, T., Boyra, A., Haroun, R.J.** 2006 Changes in demersal wild fish aggregations beneath a sea-cage fish farm after the cessation of farming. *J Fish Biol.,* 69: 682–697.

**Vega Fernandez, T., D'Anna, G., Badalamenti, F., Pipitone, C., Coppola, M., Rivas, G. & Modica, A.** 2003. Fish fauna associated to an off-shore aquaculture system in the Gulf of Castellammare (NW Sicily). *Biol. Mar. Mediterr*., 10:755–759.

**Vita, R., Marin, A., Jimenez-Brinquis, B., Cesar, A., Marin-Guirao, L. & Borredat, M.** 2004. Aquaculture of Bluefin tuna in the Mediterranean: evaluation of organic particulate wastes. *Aquacult. Res.,* 35:1384–1387.

**Yucel-Gier, G., Kucuksezgin, F. & Kocak, F.** 2007. Effects of fish farming on nutrients and benthic community structure in the Eastern Aegean (Turkey). *Aquacult. Res*., 38: 256–267.