Marine Pollution Bulletin 69 (2013) 165–171

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

A meta-analysis approach to the effects of fish farming on soft bottom polychaeta assemblages in temperate regions

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ARTICLE INFO

Keywords:
Polychaete assemblages
Fish farm
Organic enrichment
Meta-analysis

ABSTRACT

Marine fish farms could cause environmental disturbances on the sediment due to uneaten food and fish faeces that impact the marine benthos. Polychaete assemblages are considered good indicators of environmental perturbations. The present study aimed to establish groups of polychaetes as potential indicators of fish farm pollution. This study was carried out in ten fish farms along the Spanish coast. Changes in polychaete assemblage were analyzed with meta-analysis and multivariate techniques. Abundance, richness and diversity showed significant decreases under fish farm conditions. Distribution patterns of polychaetes responded to combinations of physicochemical variables. The main ones are sulfide concentration, silt and clays percentage, and stable nitrogen isotope ratio. The results showed that some families are tolerant, Capitellidae, Dorvilleidae, Glyceridae, Nereididae, Oweniidae and Spionidae; while others are sensitive to fish farm pollution, Magelonidae, Maldanidae, Nephtyidae, Onuphidae, Paralacydoniidae, Paraonide, Sabellidae and also Cirratulidae in spite of being reported as a tolerant family.

1. Introduction

Over the last two decades fish farming cages have been rapidly developed throughout the world (FAO, 2000; Belias et al., 2007). In the Mediterranean Sea, Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*) are intensively farmed in most of the countries (FAO, 2004; Magill et al., 2006). It is well known that fish farming interacts with the marine environment at various spatial and temporal scales (Karakassis et al., 2005) and generate variable shifts in composition of benthic (Karakassis et al., 2000; Mirto et al., 2010) and pelagic assemblages (Dempster et al., 2002). These changes are related to the organic enrichment derived from excess of uneaten food and fish excretions, chemical pollution coming from medicines and antifouling products, genetic effects and non-native species introductions (Borja, 2002; Dempster et al., 2002; Macías et al., 2005; Holmer et al., 2007; Borja et al., 2009; Fernandez-Gonzalez and Sanchez-Jerez, 2011).

Organic enrichment produces important changes in the sediment bio-chemistry, being oxygen depletion, derived from the mineralization of organic matter, probably the most serious effect on the sediment (Pearson and Rosenberg, 1978). This reduction of oxygen concentration produced by elevated inputs of organic matter into water bodies is observed in every system, especially soft habitats affected by aquaculture, except in extremely well-flushed systems. The reduction of oxygen in the benthic environment may lead to a shift from aerobic to anaerobic respiration in microbial communities producing elevated concentrations of dissolved sulfide in near-surface sedimentary pore water (Holmer et al., 2005). It is important to remark that the input of organic matter shows different patterns of response according to the sediment structure, thus the type of sediment beneath the farm is a key factor for determining the extent and severity of the impact (Kalantzi

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0025-326X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2013.01.032

and Karakassis, 2006; Apostolaki et al., 2007; Papageorgiou et al., 2010). The role of sediment type is also a factor determining the macrobenthic community structure (Karakassis and Eleftheriou, 1997), and could be used as a sensitive indicator to monitor the environmental impact caused by organic enrichment (Pearson and Rosenberg, 1978; Carvalho et al., 2006). Fish farming effects on the total infauna density and their spatial and temporal fluctuations have also been reported (Grego et al., 2009), serving as a sensitive indicator of organic pollution because of their size, interstitial existence, naturally-occurring high abundances, benthic recruitment, short generation times and asynchronous reproduction (Higgins and Thiel, 1988; Coull and Chandler, 1992; Sutherland et al., 2007).

However, geochemical changes associated to the presence of fish-farm effluents are usually not consistent, as well as the infaunal abundance, which may either increase or decrease beneath the fish cages depending on the site or the farm characteristics (Holmer et al., 2008; Mirto et al., 2010). That spatial heterogeneity on the overall response of infauna to a given stress largely depends on either the fact that the community may be dominated by a mesobenthic fraction, where species maintain a close association with sediment particles (true interstitial form), or epibenthic and endobenthic fractions where species exhibit surface-dwelling and shallow-burrowing lifestyles, respectively (Raffaelli, 1987; Sutherland et al., 2007). In addition, the degree of tolerance to pollution varies among species. Therefore some of them decrease in abundance (sensitive species), some remain unaffected (indifferent species), and some benefit from the changing conditions (tolerant or opportunistic species) increasing their abundance (Warwick, 1988).

Several authors considered polychaetes as the taxonomic group with the highest level of sensitivity to alterations of soft substrates (Grassle and Grassle, 1977; Bellan, 1984; Ros et al., 1990; Del-Pilar-Ruso et al., 2008) due to their trophic flexibility and ability to respond quickly to perturbations (Tsutsumi et al., 2001; Tomassetti and Porrello, 2005; Sutherland et al., 2007). Within this group, several tolerance categories are present throughout the whole organic enrichment gradient, from pristine to heavily disturbed areas. The presence or absence of certain polychaetes in marine sediments provides an excellent indicator of the condition or health of the benthic environment (Rygg, 1985; Tsutsumi, 1990; Pocklington and Wells, 1992; Del-Pilar-Ruso et al., 2009).

Most of the studies identifying changes on benthic communities due to fish farming have been done at scale of kilometers, examining a few farms within a similar region (e.g. Karakassis et al., 2000; Aguado-Giménez et al., 2007; Grego et al., 2009), but only few studies have applied meta-analysis aiming to generalize the results. To that end, we used meta-analysis to integrate the results from ten fish farms and control areas distributed along thousands of kilometers around the Spanish coast in order to define the effects of this activity on polychaete assemblages at the taxonomic level of family. Meta-analysis is defined as the quantitative summary of research domains, and it refers to a specific set of statistical quantitative methods that are designed to compare and synthesize the results of multiple studies (Mullen, 1989; Hunter and Schmidt, 1990; Arnqvist and Wooster, 1995).

Thus, the aim of this study was to detect which families of polychaetes are the best indicators of fish farming impact on soft habitats along the Mediterranean Sea and near Atlantic Ocean, using data from several spatial scales (10, 10^2, 10^3 and 10^4 m). Additionally, a secondary objective was to explore which geochemical variables better explain the changes on polychaete assemblages. Further results will be applied to establish a benthic fish farming impact identification protocol based on polychaetes. It may need identification skills but it is a useful tool given the rapid response of polychaetes to changes on their environment.

2. Materials and methods

2.1. Study area and sampling methods

The study was carried out in floating-cage cultures of seabream and seabass with annual mean productions of around 1000 tons per year, at depths ranging from 20 to 40 m between 2009 and 2010. Two sampling campaigns were conducted: the first one just after the summer, the most intensive period of feeding and highest water temperature. The other one was at the end of the winter, which is the lowest feeding intensity period and having the coldest water temperature of the year. To cover the natural spatial and temporal variability of soft habitats, ten fish farms were selected in five Spanish locations from Catalonia to the Canary Islands (Fig. 1). Two zones were set in each farm, an impacted zone below the cages and an undisturbed one located at 1 km away from each fish farm, a distance far enough as to dilute the fish farms effect (Porrello et al., 2005). In each zone, three sites with three random replicates were sampled. Samples were collected using a Van-Veen grab with a surface area of 0.04 m^2 and a maximum penetration of 10 cm (Valencian Community, Andalusia and Murcia) or by scuba-divers using cores of 7 cm diameter and a maximum penetration of 25 cm (Canary Islands and Catalonia). Immediately after collection, the samples were sieved with seawater through a 1 mm mesh (Lampadariou et al., 2005) and the residues were preserved in 4% buffered formalin. At the laboratory, polychaetes were sorted from them, and preserved in 10% alcohol. The polychaetes specimens were identified to family level, because this group can explain changes derived from organic enrichment (Lampadariou et al., 2005; Del-Pilar-Ruso et al., 2008).

Three additional replicates were collected in each site for sediment geochemical analyses. Several physicochemical measures were performed at the laboratory; total free sulfides (TFSs) content was analyzed by the method described by Wildish et al. (1999), total sulfur (TS), total nitrogen (TN) and total organic carbon (TOC) were determined with a CHNS autoanalyzer (elemental autoanalyzer LECO 932) and ^{15}N isotopic composition was measured using an EA-IRMS (Thermo Finnigan) analyzer in continuous flow configuration jointed to a stable ratio mass spectrometer Deltaplus.

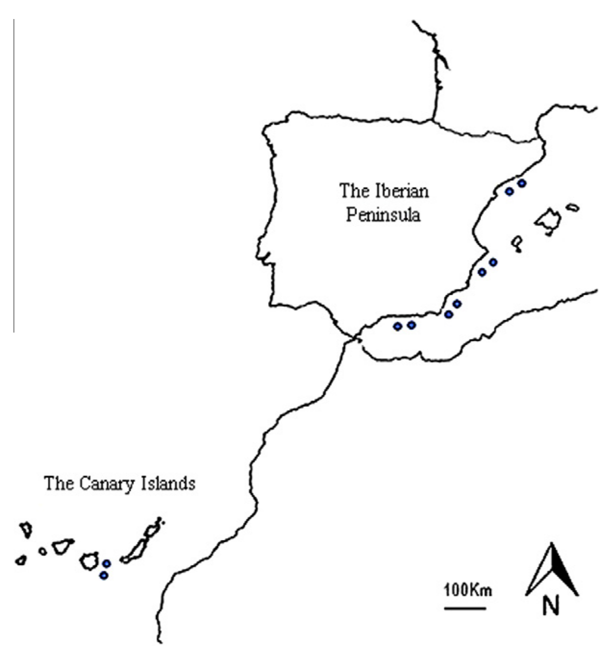

Fig. 1. Location of the ten fish farms along the Spanish coast.