Marine Environmental Research 71 (2011) 22–30

Contents lists available at ScienceDirect

Marine Environmental Research

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

Relationship between sedimentation rates and benthic impact on Maërl beds derived from fish farming in the Mediterranean

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ARTICLE INFO

Article history:
Received 23 June 2010
Received in revised form
25 September 2010
Accepted 28 September 2010

Keywords:
Mediterranean
Particulate wastes
Finfish aquaculture
Trophic groups

ABSTRACT

The aim of this work was to study the dispersion of particulate wastes derived from marine fish farming and correlate the data with the impact on the seabed. Carbon and nutrients were correlated with the physico-chemical parameters of the sediment and the benthic community structure. The sedimentation rates in the benthic system were 1.09, 0.09 and 0.13 g m^{-2} day^{-1} for particulate organic carbon (POC), particulate organic nitrogen (PON) and total phosphorus (TP), respectively. TP was a reliable parameter for establishing the spatial extent of the fish farm particulate wastes. Fish farming was seen to influence not only physico-chemical and biological parameters but also the functioning of the ecosystem from a trophic point of view, particularly affecting the grazers and the balance among the trophic groups. POC, PON and TP sedimentation dynamics reflected the physico-chemical status of the sediment along the distance gradient studied, while their impact on the benthic community extended further. Therefore, the level of fish farm impact on the benthic community might be underestimated if it is assessed by merely taking into account data obtained from waste dispersion rates. The benthic habitat beneath the fish farm, Maërl bed, was seen to be very sensitive to aquaculture impact compared with other unvegetated benthic habitats, with an estimated POC-carrying capacity to maintain current diversity of 0.087 g C m^{-2} day^{-1} (only 36% greater than the basal POC input). Environmental protection agencies should define different aquaculture waste load thresholds for different benthic communities affected by finfish farming, according to their particular degree of sensitivity, in order to maintain natural ecosystem functions.

1. Introduction

In recent decades, seafood production from marine aquaculture has undergone almost exponential growth worldwide in terms of cultured biomass and is expected to follow the same trend in the future (FAO, 2007). A combination of factors, including production levels, feed characteristics and feeding efficiency, influences the quantity and quality of the wastes released by fish farming (Islam, 2005). The main negative impact of finfish aquaculture is the resulting organic enrichment derived from these wastes, which mainly consist of fish faeces and uneaten food and which may spread from tens to hundreds metres from the fish farm (Brown et al., 1987; Hall et al., 1990; Iwama, 1991). Such wastes take two forms: particulate and dissolved. In the water column, the levels of dissolved wastes rapidly reach background levels, whereas particulate wastes tend to sink and accumulate on the seabed. This process may produce important changes in sediment geochemistry and in the benthic communities (Brown et al., 1987; Weston, 1990; Karakassis et al., 2000; Holmer et al., 2005).

The spatial dispersion and potential effect of aquaculture particulate wastes on the ecological benthic status is site-specific and influenced by local physical-chemical and biological parameters (Karakassis et al., 1999; Sanz-Lázaro and Marin, 2006). Benthic impact due to organic enrichment has been extensively studied in unvegetated beds (e.g. Black, 1998; Karakassis et al., 2000; Brooks and Mahnken, 2003; Aguado-Gimenez and Garcia-Garcia, 2004; Kutti et al., 2007), identifying a well defined gradient (both in distance and time) from the source of contamination (Pearson and Rosenberg, 1978). In contrast, the impact of aquaculture has been

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0141-1136/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marenvres.2010.09.005

less studied in vegetated beds (Sanz-Lázaro and Marin, 2008). The influence of finfish farming among vegetated beds, finfish farming influence has been studied to some extent (e.g. Ruiz et al., 2001; Holmer et al., 2004; Apostolaki et al., 2010), while, as regards Maërl beds, to the best of our knowledge, only one study, performed in Scotland, that has looked at the impact of aquaculture in this type of habitat (Hall-Spencer et al., 2006).

Research into the impact of fish farming on the benthic system has focused on two separate but closely related topics. Some studies have focused on predicting the reach of aquaculture particulate wastes by means of particulate waste dispersion modelling, while others have directly assessed the benthic impact of aquaculture by studying chemical and biological changes in the seabed. However, many of the studies carried out to date, with some exceptions (e.g. Pusceddu et al., 2007; Díaz-Almela et al., 2008; Kutti et al., 2008; Hargrave et al., 2008), cannot be considered integrative since they study isolated processes (i.e. either the benthic impact or the aquaculture particulate wastes in the water column) and make no attempt to merge them.

There is continuing pressure for aquaculture to become a more ecologically sound activity (Naylor et al., 2000; Lazard et al., 2009). Consequently, studies linking aquaculture waste dispersion rates with ecological benthic status must be performed to define thresholds below which finfish farm-derived organic matter deposition does not substantially affect benthic communities. In this way, protection agencies will be able to ensure the sustainability of aquacultural practices (Sanz-Lázaro and Marin, 2008).

A great number of waste dispersion models have been developed to estimate the reach of organic residues derived from aquaculture (e.g. Cromey et al., 2002; Perez, 2002). Nevertheless, these models are frequently deficient as regards to their accuracy for forecasting (Chamberlain and Stucchi, 2007). This is partly due to the fact that robust and defensible information is not available for some of the key model parameters, such as waste dispersion and sedimentation rates (Islam, 2005), for which the accuracy of the different models varies greatly (Chamberlain and Stucchi, 2007). Field measurements associated with finfish aquaculture-derived particulate wastes are scarce and reliable replication over time is lacking, especially in the case of the Mediterranean (Holmer et al., 2007). Hence, more data related with aquacultural waste sedimentation dynamics are needed in order to refine models and improve their forecasting capacity.

The aim of this work was to: (1) quantify fish farm particulate organic carbon, particulate organic nitrogen and total phosphorus and (2) correlate them with physico-chemical parameters of the sediment and the benthic community structure at a fish farm in the Mediterranean.

2. Methods

2.1. Study area

The study was conducted at a marine fish farm located in Águilas, SE Spain (Western Mediterranean; 37°24′56.2″ N, 1°32′4.0″ W), which produces gilthead sea bream (*Sparus aurata*) and European sea bass (*Dicentrarchus labrax*). The fish farm consisted of two groups of 12 fish cages with an annual production of 1000 tonnes. Each fish cage had a diameter of 25 m and the bottom of the cage reached a depth of 19 m. The fish cage studied was located at the edge of the fish farm facility, "up-current" to the current flow of the other cages, and contained only gilthead sea bream. The water depth at this point was 31 m. During the sampling period (September and October 2006) an average of 83,000 kg of fish were cultured in the studied fish cage and the daily feed input varied greatly: 994 ± 70 kg day^{-1} (mean ± SE; Fig. 1).

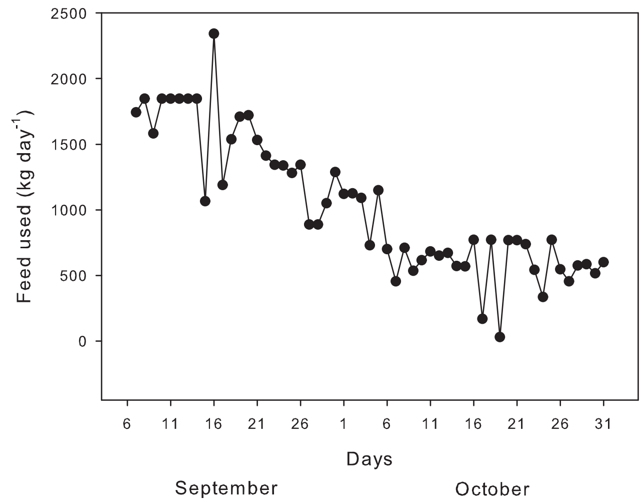

Fig. 1. Feeding rate of the studied fish cage during the time span that the sedimentation traps were deployed. During that the same period of time the fish cage contained an average of 83,000 kg of cultured fish.

The computerized feeding system of the fish farm automatically distributes feed from the silo among the fish cages at an optimal rate and frequency according to satiety, which is controlled by the fish farm staff through the use of underwater cameras.

The feed pellets supplied to the fish were cylindrical, with a diameter of 6 mm, and contained 45.8, 7.3 and 0.9% of particulate organic carbon (POC), particulate organic nitrogen (PON) and total phosphorus (TP), respectively. During the study time the residual current direction was NE with a mean value of 0.08 m s^{-1} (Valeport 106 current meter, Valeport Limited, Dartmouth, UK; located in the fish farm ∼30 m from the studied fish cage at a depth of 15 m; Fig. 2). The water temperature, at a depth of 6 m, during the sampling period ranged between 21 and 26 °C. The seabed consisted of carbonate, coarse and medium sand, with an unattached Maërl bed habitat.

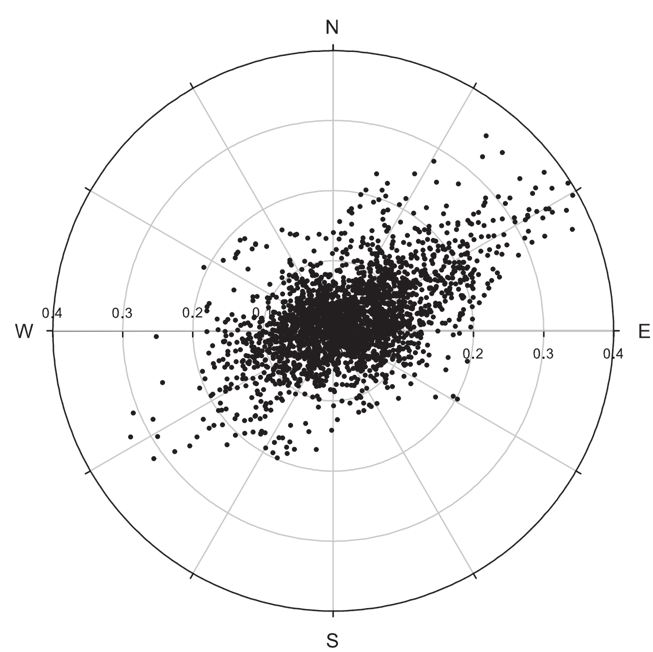

Fig. 2. Current intensity (m s^{-1}) measured every 20 min in the fish farm during the time that the sedimentation traps were deployed. Data was obtained from a current meter located ∼30 m from the studied fish cage at a depth of 15 m.