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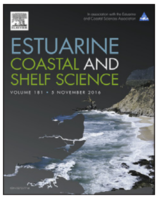

Potential retention effect at fish farms boosts zooplankton abundance

D. Fernandez-Jover*, K. Toledo-Guedes, J.M. Valero-Rodríguez, V. Fernandez-Gonzalez, P. Sanchez-Jerez

Department of Marine Sciences and Applied Biology, University of Alicante, P.O. Box 03690, Alicante, Spain

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ABSTRACT

Coastal aquaculture activities influence wild macrofauna in natural environments due to the introduction of artificial structures, such as floating cages, that provide structural complexity in the pelagic system. This alters the abundance and distribution of the affected species and also their feeding behaviour and diet. Despite this, the effects of coastal aquaculture on zooplankton assemblages and the potential changes in their abundance and distribution remain largely unstudied. Traditional plankton sampling hauls between the farm mooring systems entail some practical difficulties. As an alternative, light traps were deployed at 2 farms in the SW Mediterranean during a whole warm season. Total zooplankton capture by traps at farms was higher than at control locations on every sampling night. It ranged from 3 to 10 times higher for the taxonomic groups: bivalvia, cladocera, cumacea, fish early-life-stages, gastropoda, polychaeta and tanaidacea; 10–20 times higher for amphipoda, chaetognatha, isopoda, mysidacea and ostracoda, and 22 times higher for copepoda and the crustacean juvenile stages zoea and megalopa. Permutational analysis showed significant differences for the most abundant zooplankton groups (copepoda, crustacean larvae, chaetognatha, cladocera, mysidacea and polychaeta). This marked incremental increase in zooplankton taxa at farms was consistent, irrespective of the changing environmental variables registered every night. Reasons for the greater abundance of zooplankton at farms are discussed, although results suggest a retention effect caused by cage structures rather than active attraction through physical or chemical cues.

1. Introduction

Over the last three decades, fish-farming cages have rapidly developed throughout the world (FAO, 2004; 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 and generates 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 from medicines and antifouling products, genetic effects and non-native species introductions (Dempster et al., 2002; Holmer et al., 2007; Borja et al., 2009; Fernandez-Gonzalez and Sanchez-Jerez, 2011).

Moreover, the deployment of these massive artificial structures in the pelagic environment may provoke severe changes in the wild biota composition, from phytoplankton (Dalsgaard and Krause-Jensen, 2006) to macrofauna (Carss, 1990; Franks, 2000; Dempster et al., 2002) and megafauna (Díaz López and Bernal Shirai, 2007; Arechavala-Lopez et al., 2014, 2015). Complex artificial structures drive changes in the behaviour or physiology of affected species (Fernandez-Jover et al., 2007a) but in turn, adult species aggregated to the fish farm environment may alter chemical or nutrient dynamics in the pelagic (Fernandez-Jover et al., 2007b) or benthic systems (Katz et al., 2002). It is noteworthy that the influence of coastal fish farms on ichthyofauna is not strictly limited to adult fish, since juvenile fish from several different families generally use farm structures as settlement grounds, with potential consequences for their physiology and growth (Fernandez-Jover et al., 2009; Fernandez-Jover and Sanchez-Jerez, 2014). The forces driving this behaviour have already been investigated, like for instance the food availability for juvenile fish in the water column around farms. It was found that resources may be at least as accessible as they are in traditional settlement environments such

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* Corresponding author.
E-mail address: jover@ua.es (D. Fernandez-Jover).

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as natural shallow rocky shores. The main prey of aggregated juvenile fish are typical zooplankton taxa, *e.g.* adult and juvenile copepods, cladocerans, nauplius larvae or amphipods (Fernandez-Jover et al., 2009).

In the SW Mediterranean, it has already been corroborated using light traps that European seabass and gilt-head bream farms favour the presence (among others) of holoplanktonic amphipods in the pelagic environment. In this way, Fernandez-Gonzalez et al. (2014) detected an abundant community of planktonic amphipods at farms when compared to environments where these structures were absent, comprising strictly pelagic species and also benthic and fouling-community species that apparently undertake incursions into the pelagic zone at night. Therefore, the higher presence of a common prey may act as an enhancing factor favouring the abundance of early life-stages of different fish species. In this sense, farm nutrients release is also thought to increase plankton communities in oligotrophic environments (Tsagaraki et al., 2013).

Light devices have been traditionally used for capturing early life-stages of fish (Faber, 1981; Floyd et al., 1984; Doherty, 1987), but also with the objective of studying zooplankton communities (Miller and Shanks, 2004; Shaw et al., 2007; Tor et al., 2010; Fernandez-Gonzalez et al., 2014; Sigurdsson et al., 2014). Furthermore, the relationship between artificial light attraction and zooplankton has already been studied at farms; McConell et al. (2010) detected a higher presence of zooplankton communities at salmon farms illuminated during the whole night, finding that abundances of invertebrates, like bivalves or gastropods, as well as some larval and juvenile fish species, were greater at night-lit farms. However, the zooplankton communities at non-illuminated farms were not compared with areas not influenced by aquaculture activities, including the potential prey availability for early life-stages of fish.

Consequently, we relied on light traps to achieve four main objectives, to: i) assess their suitability for the study of zooplankton and early life-stages of fish at sites where traditional sampling tools such as plankton hauls are difficult to employ, and to determine if zooplankton taxa abundances vary in response to a fish farm environment, ii) evaluate changes through time in zooplankton taxonomic composition at two farms during a whole warm season, and finally iii) estimate if the abundance and family composition of early life-stages of fish are different at farms compared to control locations.

2. Material and methods

2.1. Study area and sampling effort

This study was carried out in coastal waters, in Guardamar del Segura bay (Alicante, Spain: 38° 5′ 7.45″ N; 0° 35′ 51.40″ W) from 12th June to 10th October 2012, the warm period in the Western Mediterranean. Sampling was conducted at two fish farms (Fig. 1A) producing seabass (*Dicentrarchus labrax*) and seabream (*Sparus aurata*), and two control areas, on 16 arbitrarily chosen nights. Control samples were also taken randomly within the bay with the condition that they were at least 2 km away from the nearest fish farm and at a minimum depth of 23 m, which was reached at least 3 km away from the shore. All four localities (2 control and 2 farms) were located 3–4 km offshore at depths ranging from 23 to 30 m. Each farm consisted of 18 rings with a diameter of 19 or 25 m and cage nets reaching depths from 12 to 15 m, enclosing a cage volume up to 7400 m^3. Changes in abundances and species composition in the plankton population were investigated by sampling farm and control areas with light traps.

Light-trap design used in this study was a modification of that employed by Floyd et al. (1984) and Kissick (1993), which consisted of a plexiglas collection chamber measuring 40 × 40 × 40 cm, with eight panels forming four funnel-shaped entrances 3 mm wide. The light source was a hand diving-torch (Led Lenser D14, 150 lumen) coupled to a white plastic container that produced a diffuse point of illumination.

The light-trap technique provides selective sampling, since results are biased towards photophilic species. However, it has traditionally been used for various purposes, generally aimed at capturing zooplankton species, most frequently early life-stages of fish (e.g. Floyd et al., 1984; Doherty, 1987). Additionally, it is useful in studies at places with difficult access or where habitual sampling methods such as plankton hauls are inconvenient. Specifically, oblique hauls may become logistically problematic. Researchers that still decided to deploy nets between the cages had to limit sampling to vertical hauls or small purse seines (McConell et al., 2010); light traps thus seem an appropriate alternative for sampling in logistically difficult habitats (Chicharo et al., 2009).

Traps were suspended at approx. 20 m above the sea bottom, at 4 m below an anchored buoy (Fig. 1B). They were deployed after sunset for approximately 1 h, recording deployment and retrieval times to the nearest minute (for later standardisation to individuals per traps per hour), and their contents then removed. Due to logistical constraints we were only able to sample one site during one single night (*i.e.* all samples from Control 1 and Farm 1 were sampled on one specific night and Control 2 and Farm 2 on a different night). Every night two traps were deployed approximately at the same time at the cages and two at control site and every one of them was retrieved three times during the whole night, making a total of six control and six farm samples considering each as one replicate. Traps were moved 20–30 m after retrieval, and a period of at last 30 min was allowed prior to next deployment. At recovery time, traps were raised slowly to allow filtration of the chamber content through the 250 μm-mesh bottom of the collection cup. Material retained was preserved in 4% formalin seawater solution. In the laboratory, samples were sorted, counted and the main plankton groups identified. Fish individuals were measured to the nearest 0.1 mm and identified to family level using published literature (Russell, 1976; Sabatés, 1988; Arias and Drake, 1990; Fahay, 2007; Ré and Meneses, 2008; Lecaillon et al., 2012).

Environmental variables were obtained or measured *in situ* in order to include them in the design as covariables with the objective of inferring if their fluctuations had a significant influence on the zooplankton assemblages studied, and thus cope with the environmental variability inherent to a study that spanned five months. They were: Water temperature, Day of lunar month (DLM), Moon illumination, State of the sea (wave height in m), Time to moonrise, Time since sunset, Time between sunset and moonrise, Time from the nearest high tide, and Cloud cover. The exact rising and setting times for the moon and sun and the percentage of moon illumination were taken from http://www.timeanddate.com/. Current direction and velocity were also added as predictor variables. The average direction and velocity during the previous 24 h before every sampling night was obtained from the historical data recorded by the national government in the region (http://www.puertos.es). Hourly current data, which was provided as magnitude and direction vectors were averaged for the previous 24 h prior to sampling and then simplified into four vectors corresponding to main current directions NNE-SSW, ENE-WSW, ESE-WNW and SSE-NNW, taking positive and negative values for every direction (e.g. positive values for currents with direction NNE, between 45 and 90°, and negative for currents towards SSW between 180 and 225°).