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A multimetric approach to evaluate offshore mussel aquaculture effects on the taxonomical and functional diversity of macrobenthic communities

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ABSTRACT

A multimetric approach was used to detect structural, compositional, and functional shifts in the underlying macrobenthic communities of an offshore mussel (*Mytilus galloprovincialis*) farm in a Portuguese Aquaculture Production Area. Sampling stations distributed inside and outside this area were used to evaluate sediment descriptors and macrobenthic samples collected before (April and September 2010) and after (June and September 2014) the initiation of mussel farming. Sediment fine fraction, organic matter content, and trace element concentrations were found to increase with depth, independently from the mussel farm. Moreover, the structure and composition of the macrobenthic communities were likewise structured by depth. Turnover was the dominant temporal and spatial pattern of beta diversity for all communities. Furthermore, the functional diversity of these communities was unaffected by the mussel farm. These results suggested that an offshore profile allowed hydrodynamic conditions to weaken the impact of mussel farming and highlighted the importance of conducting an integrative multimetric analysis when studying aquaculture impacts on benthic communities.

1. Introduction

Aquaculture has been identified as one of the key contributors to future food security (Anderson et al., 2017). Indeed, more than 3 billion people rely on it as a major source of dietary protein (Fulton et al., 2018), requiring its rapid development to meet the ever-increasing demand for food (Salin and Ataguba, 2018). Yet, due to a growing concern for the well-being of the marine environment, its expansion has pushed for the need to evaluate and reduce the impact of conventional production activities (Cao et al., 2007; Ellis et al., 2016; Ottinger et al., 2016). At present, environmental concerns focus on the efficiency of natural resource use and the risks that aquaculture byproducts pose towards biodiversity (Valenti et al., 2018). These risks are progressively addressed by the advancement of technology, which has paved the way for aquaculture activities to take place increasingly away from calm coastal zones (Bostock et al., 2010; Shainee et al., 2012) where environmental impacts and competition with other uses may be heightened (Gentry et al., 2016).

Offshore aquaculture is rapidly gaining acceptance (Froehlich et al., 2017; Jansen et al., 2016; Thomas et al., 2019) as a form of food production aligned with the environmental, economic, and social objectives of many coastal nations (Gentry et al., 2017). However, its effects remain to be a subject of investigation as choice of location (Silva et al., 2011), hydrodynamic forces (Henderson et al., 2001; Pérez et al., 2003), species characteristics (Gentry et al., 2017; Oyinlola et al., 2018), and spatial conflicts influence the suitability of offshore sites and their capacity for impact neutralization (Sanchez-Jerez et al., 2016). Principal concerns for offshore farms are associated with organic enrichment as a result of farm additives and biological waste (Cancemi et al., 2003; Holmer, 2010), the spread of diseases via interaction with wild stocks (Lafferty et al., 2015), and the genetic impact of species escapees (Jackson et al., 2015; Naylor et al., 2005). Taking into account

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Organic enrichment of sediments from salmon farming in Norway: environmental factors, management practices, and monitoring techniques

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Abstract

Environmental impacts of salmon cage aquaculture resulting from deposition of organic-rich particulate matter to the sea bottom have been thought to be a function of the local environmental conditions and management practices. However, testing of these suppositions have been limited by (1) widely varying monitoring methods employed, and (2) lack of data comparability resulting from the absence of standardized national monitoring schemes.

In order to determine the sensitivity of different monitoring methods in detecting benthic environmental effects, a comparative analysis was undertaken of four methods commonly employed in Norway that vary in cost and expertise required: (1) visual diver surveys, (2) faunal analysis, (3) sediment chemistry, and (4) Sediment Profile Imagery (SPI). Results indicate that all methods agreed in the common "impact zone" under and immediately next to the cages. However, each of the methods differed in their sensitivity in detecting more subtle effects at greater distances from the cages.

Data from 168 environmental survey samples located at various distances from working Norwegian salmon cage farms collected using similar methodology between 1996 and 1998 were analyzed to determine the relationship between environmental variables, management regimes, and levels of environmental impact. Total organic carbon (TOC) levels in sediments were significantly higher immediately adjacent to cages compared to reference sites, and approximately 32% of the samples under the cages showed significant degradation. At intermediate distances (50–100 m), influences from fish farming are not clearly detected by TOC analysis. Further, while neither depth nor current speed alone are good predictors for environmental management, the results suggest

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Assessing large-scale macrobenthic community shifts in the Aegean Sea using novel beta diversity modelling methods. Ramifications on environmental assessment

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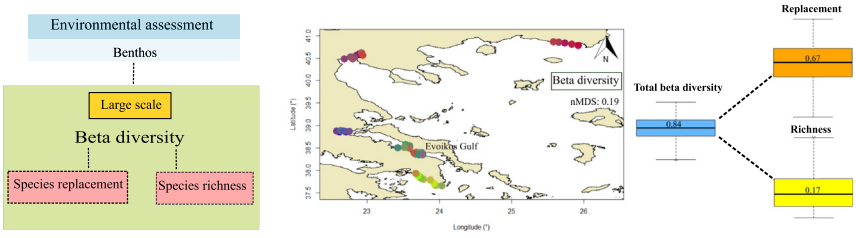
HIGHLIGHTS

- Beta diversity metrics detect large-scale macrobenthic community shifts.
- Species replacement is the main driver for the Aegean benthic community structure.
- Novel modelling framework can detect macrobenthic community turnover.
- Beta diversity provides a promising tool in large-scale environmental assessment.

GRAPHICAL ABSTRACT



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Macrobenthic communities
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Modelling
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ABSTRACT

The effects of large-scale environmental gradients on the spatial patterns of macrobenthic communities used in marine health assessment were evaluated using beta diversity methods. In this work, beta diversity partitioning and relevant ecological modelling methods revealed clear patterns between the northern and the southern parts of the Aegean Sea (Greece). A community turnover point was observed in the Evoikos Gulf marking the transition between the northern and the southern communities. The increased beta diversity in this work was due to species replacement driven mainly by the latitudinal gradients of bottom temperature and salinity whereas species richness did not present substantial differences between the Aegean macrobenthic communities. These findings are attributed to the ability of beta diversity methods to detect the environmental filtering that occurs in these marine provinces through the assessment of biotic interactions in respect to geographic distance. We propose a new standpoint of using beta diversity measures for benthic environmental assessment on a large spatial scale and in marine areas characterised by environmental gradients.

1. Introduction

Understanding how biodiversity is partitioned on a large spatial scale and quantifying the differences in community structure between sites remains at the heart of ecosystem management practices (Pearman et al., 2018). Beta diversity methods are suitable for assessing

Abbreviations: GDM, Generalized Dissimilarity Modelling.

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Rapid bioassessment of macroinvertebrate communities is suitable for monitoring the impacts of fish farm effluents

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ABSTRACT

Development of the fish farming industry in Iran in an environmentally and economically sustainable manner requires an effective and low-cost means of regularly monitoring receiving environments. Biomonitoring using macroinvertebrates is known to be effective for assessing water quality. The problem, however, is that biomonitoring can be labour intensive and analyses can have a long turnaround time. Rapid bioassessment methods have been developed to overcome these limitations, but it is not known whether they are as sensitive to changes in water quality as are their more time-consuming counterparts. To answer this question, we compared three methods for sampling and measuring macroinvertebrates. We refer to these as the quantitative method, semi-quantitative method, and qualitative method respectively. The quantitative method was a single habitat method with taxonomic identification of macroinvertebrates to genus level that counted all taxa. The semi-quantitative method involved multi-habitat sampling with identification to family level and quantification as relative abundance. The qualitative method was the same as the semi-quantitative method except that incidence (presence/absence) was recorded instead of abundance. The study was carried out at three fish farms in Iran with sampling done once per season for a year from the outfall of each farm as well as from the receiving rivers, with one sample taken upstream of the effluent discharge and two samples downstream. Analysis by permutational multivariate analysis of variance (PERMANOVA) revealed that the effects of three variables of season, farm, and site on macroinvertebrate communities were significant for all three methods. Qualitative sampling was the only method that showed a statistically significant interaction between farm and season as well as a difference among the sites within each farm. Although the results of a BEST (Bio-Bio) analysis showed that different families were responsible for the differences between the sites, all three methods were able to detect the differences between the sites within each farm. However, pairwise comparisons between sites within farms indicated some differences between the three methods. The quantitative method revealed fewer differences than did the other two methods. The qualitative method did not lose any important information and had the added advantage of saving considerable time and effort in sampling and enumerating. These results suggest that rapid bioassessment could be used to effectively monitor the receiving waters of fish farm effluents.

Statement of relevance: This manuscript compares three methods of sampling which are quantitative, semi-quantitative and qualitative methods in order to find the most efficient and cost-effective method of sampling. There is no apparent consensus on the appropriate method of collecting and measuring macroinvertebrates, in particular for investigating the effect of fish farms on the rivers. Our manuscript revealed that rapid bioassessment method as a cost-efficient and effective method can be used in order to develop aquaculture in a sustainable manner, both environmentally and economically. Therefore, authors believe that this manuscript is appropriate for publication by the Journal of Aquaculture.

1. Introduction

Aquaculture, once considered an environmentally friendly practice, is now recognised as a potential polluter of aquatic environments (Pillay, 2008). As fish farming intensifies and the size of farms increases, so does the potential impact on aquatic ecosystems (Boyd, 2003; F.A.O., 2000). Higher production rates result in an elevated production of waste materials including uneaten feed and metabolic waste products (Viadero et al., 2005) that may have a negative impact on the quality of the receiving water (Camargo, 1992; Schulz et al., 2003). In order to develop aquaculture in a sustainable manner, both environmentally and economically, cost-efficient

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Temporal variation on environmental variables and pollution indicators in marine sediments under sea Salmon farming cages in protected and exposed zones in the Chilean inland Southern Sea

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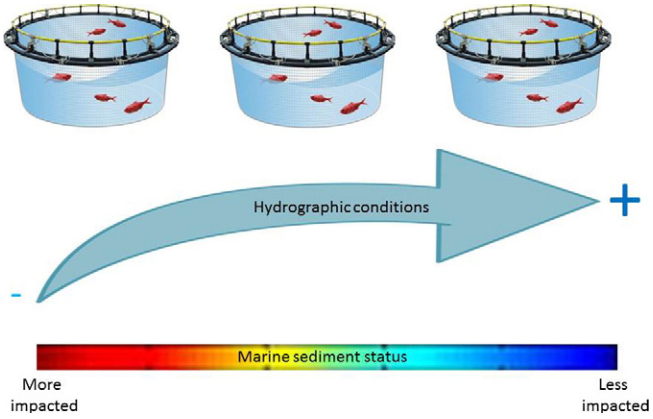
HIGHLIGHTS

- Salmon farming impacts vary depending on the hydrodynamic characteristics.
- The impacts on the sediments varied in magnitude and temporally between exposed and protected zones.
- Redox potential, sulphurs and phosphorus are the best to reflect the impacts in both protected and exposed zones.
- Organic carbon in the sediments is not an accurate predictor of the salmon farming impacts.
- Oxygen availability in the sediments seems to be a major driver of the impacts.

GRAPHICAL ABSTRACT



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Salmon farming
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ABSTRACT

The impacts of any activity on marine ecosystems will depend on the characteristics of the receptor medium and its resilience to external pressures. Salmon farming industry develops along a constant gradient of hydrodynamic conditions in the south of Chile. However, the influence of the hydrodynamic characteristics (weak or strong) on the impacts of intensive salmon farming is still poorly understood. This one year study evaluates the impacts of salmon farming on the marine sediments of both protected and exposed marine zones differing in their hydrodynamic characteristics. Six physico-chemical, five biological variables and seven indexes of marine sediments status were evaluated under the salmon farming cages and control sites. Our results identified a few key variables and indexes necessary to accurately evaluate the salmon farming impacts on both protected and exposed zones. Interestingly, the ranking of importance of the variables and the temporality of the observed changes, varied depending on the hydrodynamic characteristics. Biological variables (nematodes abundance) and environmental indexes (Simpson's dominance, Shannon's diversity and Pielou evenness) are the first to reflect detrimental impacts under the salmon farming cages. Then the physico-chemical variables such as redox, sulphurs and phosphorus in both zones also show detrimental impacts. Based on the present results we propose that the hydrodynamic regime is an important driver of the magnitude and temporality of the effects of salmon farming

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Impact of cage farming of cobia (*Rachycentron canadum*) on the benthic macrofauna in a tropical region

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ABSTRACT

This study assessed the environmental impact of the cage culture of cobia (*Rachycentron canadum*) off the coast of Recife, northeastern Brazil. Fifteen thousand juveniles were reared in four 1200 m^3 floating cages for 9 months and fed with a 42% protein commercial feed. Sampling campaigns were held at the beginning, during and after harvest (February, August and December of 2011, respectively). Seven sampling stations were established transverse to the coastline, and a control was placed 200 m to the southeast of the cages. Local hydrodynamics had an important role in dispersing the farming residues, which favored dispersion northeastwards. The area of direct impact of settling particles was estimated to be from 10 to 129 m from the cages. A significantly higher concentration of total nitrogen in the intermediate and final sampling campaigns and lower dissolved oxygen levels in the final sampling were observed. Significant changes in the structure of the macrobenthic community (decreased diversity and evenness parallel to an increase in density) reinforce that a process of organic enrichment took place in the area surrounding the fish farm. These changes, however, occurred only in a temporal, not spatial, fashion and were likely due to the organic enrichment of sediment by wastes from fish farming.

1. Introduction

The rapid expansion of cage fish farming has amplified the need to consider the possible environmental impacts of this activity. One of the most commonly reported impacts is the release of organic matter and dissolved nutrients (Dean et al., 2007; Sanz-Lazaro and Marin, 2011). In intensive aquaculture systems, it is estimated that only 25% of the nutrients in feeds are incorporated by fish. The rest remains in the environment, with the largest amount ending up in the sediment (Holmer et al., 2013; Morata et al., 2015). The increased availability of nutrients usually boosts primary production, increases turbidity and may eventually cause the death and decomposition of the algal biomass, which in turn, may lead to decreased concentrations of dissolved oxygen (La Rosa et al., 2002). Given that most of the residues end up deposited around and below the cages, the impact of cage fish farming is frequently more noticeable in the sediment than in the water column (Vita and Marin, 2007; Yucel-Gier et al., 2007). For this reason, the structure of the benthic community has been widely used as a tool to assess environmental impacts of aquaculture (Karakassis and Hatziyanni, 2000; Vita and Marin, 2007).

To ensure the sustainability of cage fish farming, there is a need to assess possible environmental imbalances caused by this activity and, based on that, find ways to minimize impacts. Most of the currently available data on the environmental impacts of marine fish farming is derived from studies in temperate regions (Chen et al., 1999; La Rosa et al., 2002; Apostolaki et al., 2007; Dean et al., 2007; Sutherland et al., 2007; Yucel-Gier et al., 2007; Borja et al., 2009; Fernandez-Gonzalez and Sanchez-Jerez, 2011; Martinez-Garcia et al., 2013; Morata et al., 2015). This study, therefore, assessed the impact of the cage farming of cobia (*Rachycentron canadum*) on water quality variables and the structure of benthic macrobiota of a tropical area off the northeastern Brazilian coast.

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Seasonal and spatial variations of macrobenthic community in intertidal *Sargassum* field off Naozhou Island, South China Sea

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Abstract

Seasonal and spatial variations in the macrobenthic community in an intertidal gulfweed field off Naozhou Island were investigated from April 2011 to January 2012. We identified 407 macrobenthic organism species: 64 macroalgae (15.72% of total species); 123 Arthropoda (30.22%); 107 Mollusca (26.29%); 67 Annelida (16.46%); 15 Cnidaria (3.69%); 14 Echinodermata (3.44%); 8 Porifera (1.97%); 4 Chordata (0.98%); 2 Urochorda (0.49%); and 1 each of Echiura, Sipunculida and Angiospermae (0.25%). Arthropods, mollusks, annelids, and macroalgae were four main groups in the benthic organism community and accounted for 88.70% of the total species. In terms of abundance of biomass, there were 15 dominant species, including 8 macroalgal, 5 mollusk and 2 arthropod species. The species diversity indices ranged from 1.21 to 4.42 with an average of 2.80; the annual average of evenness was 0.47. Species richness indices varied from 2.97 to 7.24 (average 4.97); and Simpson dominance indices varied from 0.20 to 0.92 in annual average of 0.75. Macroalgal distribution showed clear vertical zonation and seasonal changes. The number of macroalgal species found in the high tide zone, upper middle tide zone, middle tide zone, lower middle tide zone, low tide zone, and below low tide zone were 1, 8, 10, 16, 22, and 32, respectively. Biomass among the benthic organisms, macroalgae and crustaceans had significant positive correlation (P<0.05) with the coefficients of 0.802, 0.894, and 0.592, respectively. Macroalgal biomass showed a clearly negative correlation with the concentration of dissolved inorganic nitrogen (DIN) (R=0.486, P<0.05). During the winter and spring, when macroalgae were growing vigorously, DIN reached the lowest level in seawater and displayed a clear weak correlation between macroalgal growth and the nutrient concentration.

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Spatial and Temporal Variability of Benthic Respiration in a Scottish Sea Loch Impacted by Fish Farming: A Combination of In Situ Techniques

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- Per O. J. Hall[2],
- Anders Tengberg[2],
- Elin Almroth-Rosell[2],
- Anna Apler[3],
- Lois Calder[4],
- […]
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Aquatic Geochemistry **volume 18**, pages515–541(2012)Cite this article

Abstract

The effects of fish farm activities on sediment biogeochemistry were investigated in Loch Creran (Western Scotland) from March to October 2006. Sediment oxygen uptake rates (SOU) were estimated along an organic matter gradient generated from an Atlantic salmon farm using a combination of in situ techniques: microelectrodes, planar optode and benthic chamber incubations. Sulphide (H_2S) and pH distributions in sediment porewater were also measured using in situ microelectrodes, and dissolved inorganic carbon (DIC) fluxes were measured in situ using benthic chambers. Relationships between benthic fluxes, vertical distribution of oxidants and reduced compounds in the sediment were examined as well as bacterial abundance and biomass. Seasonal variations in SOU were relatively low and mainly driven by seasonal temperature variations. The effect of the fish farm on sediment oxygen uptake rate was clearly identified by higher total and diffusive oxygen uptake rates (TOU and DOU, respectively) on impacted stations (TOU: 70 ± 25 mmol O_2 m^{-2} day^{-1}; DOU: 70 ± 32 mmol O_2 m^{-2} day^{-1} recalculated at the summer temperature), compared with the reference station (TOU: 28.3 ± 5.5 mmol O_2 m^{-2} day^{-1}; DOU: 21.5 ± 4.5 mmol O_2 m^{-2} day^{-1}). At the impacted stations, planar optode images displayed high centimetre scale heterogeneity in

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Amelioration of marine farming impact on the benthic environment using artificial reefs as biofilters

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Benthic community
Biofiltration

ABSTRACT

An *in situ* monitoring of the sediment characteristics and macrobenthic communities was undertaken at a marine fish culture site in subtropical waters of Hong Kong before and after the deployment of biofilters which were made of cement concrete artificial reef (AR) structures. According to the distance to the boundary of the fish cages, 6 points were selected as sampling stations: 2 at the fish cages, 2 near the boundary of the fish culture area, and 2 reference sites further away from the culture area. Bimonthly sediment samples were collected for analysis of silt-clay fraction (SCF), moisture content (MC), total organic carbon (TOC), total Kjeldahl nitrogen (TKN) and total phosphorus (TP). The macrobenthos (>0.5 mm) present in the sediment were sorted, identified and enumerated. TOC, TKN and TP levels at the fish cage stations were consistently higher than those at the reference stations over the 1-year pre-AR and 2-year post-AR deployment monitoring period. The diversity of macrofauna was significantly reduced at the fish cage stations relative to the reference sites. The intermediary stations near the fish culture area showed a transitional state of disturbance. Over the 2-year post-AR deployment period, TOC, TKN and TP showed a decreasing trend at the fish cage and intermediary stations. More diverse macrofaunal communities were recorded at the fish cage stations, with species diversity H' increasing from 0–1 at the beginning of the AR deployment to $H' > 2$ at the end of the study. The present results demonstrated that artificial reefs can improve the benthic abiotic environment and biotic conditions beneath fish rafts which are deteriorated due to farming activities.

1. Introduction

Fish farming activities release a large amount of wastes in the form of feed residue, faeces and excreta. The wastes either suspend or dissolve in the surrounding waters at the beginning stage. A considerable part of such farming wastes, however, will eventually settle and be accumulated on the seabed beneath or near the fish culture zone. Subsequent decay of the deposited wastes consumes substantial dissolve oxygen and releases various substances harmful to the culture species, resulting in the deterioration of the farming environment (see Wu, 1995; Pearson and Black, 2001 for review).

Filter feeders, such as bivalves, sponges, hydrozoans, sea anemones, hydroids, anthozoans and polychaetes, dominating sublittoral benthic communities on hard substrata can capture large quantities of particles from the water column owing to their dense abundance and high filtration efficiency. During the feeding activities of these sessile organisms, suspended particulate matter is reassembled and re-processed, and the biodeposits produced by these organisms lead to changes in physico-chemical characteristics of the seabed sediment once settling from the water column (Jørgensen, 1990; Graf and Rosenberg, 1997). Jordan and Valiela (1982) investigated the nitrogen budget of the ribbed mussels *Geukensia demissa* in a marsh ecosystem and found that nearly half of the nitrogen filtered from the water column by the mussel population was absorbed. Thus *G. demissa* increased retention of nitrogen within the marsh by filtering particulate nitrogen from surrounding waters and stored nitrogen as biomass. Bivalves and other filter-feeding organisms can selectively absorb more nutritional constituents from the filtered matter, and transfer such nutrients as biodeposition on the seabed in the form of pseudofaeces and faeces (Gao et al., 2002).

In aquaculture zones, Angel et al. (2002) reported that resident organisms on artificial reefs which were deployed under finfish cages could effectively remove particulate matter from surrounding waters, resulting in marked reduction in chlorophyll *a* when water traversed the artificial reefs. In an integrated aquaculture system combining fish and filter-feeding mussels, the mussels can ecologically function as a self-regulator for cycling

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Stocking density and welfare of cage farmed Atlantic salmon: application of a multivariate analysis

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Abstract

The welfare of fish is receiving increasing attention and attempts have been made to control welfare in farmed fish through regulation of management practices, including stocking density. However, there is little published information on the influence of stocking density on welfare of fish in marine cages. This present study examined welfare in Atlantic salmon (*Salmo salar*) in cages on a commercial marine farm, exposed to densities ranging from 9.7 to 34 kg m^{-3}. On three occasions over a period of 10 months, fish were sampled from each cage, weighed and measured; their fin condition assessed and blood samples taken for measurement of glucose and cortisol. A multivariate analysis was used to combine four commonly used measures of fish welfare (condition of body and fins and plasma concentrations of glucose and cortisol) into a single welfare score. As well as objectively reflecting a coherence within the data, this score was consistent with the evaluation of welfare by experienced farmers. A generalized linear model indicated that the median welfare score for each cage was significantly related to sampling period, to stocking density (mean over the previous 3 months) and to location of the cage. A model with all the data from individual fish proved to be more robust and also identified sample period, stocking density (mean over 3 months) and position of the cage as significant predictors of the welfare score. There was no significant association between the welfare score and the length of time since grading or lice treatment. Further analysis of the relationship between stocking density and the welfare score suggested that there was no trend up to an inflection point ca. 22 kg m^{-3}, after which increasing stocking density was associated with lower welfare scores. This study suggests that, while stocking density can influence the welfare of Atlantic salmon in production cages, this is only one influence on their welfare and on its own cannot be used to accurately predict or to control welfare.

Keywords: Stocking density; Welfare; Atlantic salmon; Multivariate analysis

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