3D seismic imaging and geological modeling of the Hontomin CO_2 storage site, Spain

Juan Alcalde Martín

Interactions between fish farming, wild fish populations, local fisheries and society: a case study in Catalonia, Spain

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Interactions between fish farming, wild fish populations, local fisheries and society: a case study in Catalonia, Spain

Interacciones entre acuicultura marina de peces y poblaciones de peces salvajes, pesca local y sociedad: un caso de estudio en Cataluña, España

Memoria presentada por **Kathrin Bacher** para optar al título de Doctor por la Universitat de Barcelona, bajo la dirección de Dra. Ana Gordoa Ezquerra

Centro de Estudios Avanzados de Blanes (CEAB)
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Für mini Eltere

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ABSTRACT

The overarching goal of this doctoral thesis was to advance the understanding of the interactions between marine fish farming, wild fish populations, the local small-scale fishery and the society. This thesis was designed as a multi-disciplinary study and is divided into three different sections: ecology (*chapter 1 and 2*), fisheries (*chapter 3*) and social science (*chapter 4*).

In the ecological part we examined the spatial and temporal extent of the attraction effect of wild fish at an Atlantic bluefin tuna and a Gilthead seabream farm. At both farms wild fish aggregated closely to the cage structure, revealing an abrupt decline of fish abundance rather than a gradient. The intensity of the cage effect varied according to farm, season and depth. At the seabream farm, the cage effect persisted year round, whereas at the tuna farm, the effect was restricted to summer and spring.

The variability of wild fish aggregations within the Gilthead seabream farm was analyzed because it can be a distorting factor in estimating the farm attraction effect. Our findings showed that at the surface, fish abundance was significantly higher during feeding compared with non-feeding periods. Moreover, the distance from the feeding vessel significantly influenced fish aggregations in the water column. At the bottom, substrate type was the dominant factor explaining aggregation variability.

The effect of fish farming on the small-scale fishery was evaluated in order to determine whether farms act as protection zones or as traps for wild fish populations. The findings revealed a relevant amount of commercial and recreational fishing effort in farm vicinity. However, the results showed no benefit or difference of

fishing in close proximity to the farm compared to areas away from the farm (in terms of yield, income, and catch composition). Yet, farm-aggregated fish are vulnerable to hidden fishing practices inside the farm.

The analysis of the perception of marine fish farming in Catalonia was performed with five key stakeholder-groups (NGOs, local fishermen, fish farming industry, scientists and regional administration). Four perceptions were identified; two represented divergent views and two intermediate positions. Environmental impacts were not perceived as a high risk by the majority of the participants. The major weaknesses were attributed to economic (e.g. price competition with other producer countries) and social issues (e.g. lack of credible information about farmed products).

Overall, this thesis provides new information about the complex dynamics of wild fish aggregations at marine fish farms and investigates how this attraction effect influences the local small-scale fishery. Moreover, an understanding of the different perceptions on marine fish farming can help to secure a social, economic and environmental sustainable activity.

General introduction and objectives

GENERAL INTRODUCTION AND OBJECTIVES

I. 1 Development and current state of marine fish farming

Coastal areas contain some of the most divers and productive ecosystems that sustain a wide range of services including food production, economic development, tourism and recreation. As a consequence of population growth coastal ecosystems are increasingly being impacted by a wide variety of land- and marine-based human activities. In order to sustain these ecosystems, the benefit of economic development has to be balanced against the need for preservation within an integrated management plan (Frankic 2003). Marine aquaculture, as part of the coastal zone, plays an important role in ensuring the sustainable use and development of marine and coastal resources (Stead et al. 2002).

During the past 25 years new production technologies have allowed the marine aquaculture sector to expand rapidly and farmed fish became an important segment of the world fish market (Tacon & Halwart 2007). At the same time, landings of wild fish from capture fisheries have been stagnant or in decline, whilst demand for fish and seafood has increased from an average per capita consumption of 9.9 kg in the 1960s to 19.2 kg in 2012 (FAO 2014). This increase in per capita consumption can partly be explained by the rise of aquaculture production, which accounts for 42.2% of the total fish produced worldwide in 2012 (FAO 2014) (Fig. 1). Within the aquaculture sector, the farming and production of marine organisms cultured in floating cages is one of the segments having a higher rate of growth worldwide (Tacon & Halwart 2007). Commercial cage culture was pioneered in Norway in the 1970s with the development of salmon farming (Beveridge 2004) and expanded rapidly to the countries of southern Europe, especially Greece and Spain. The marine fish farming industry in the

Mediterranean is mainly characterized by the production of Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*). Moreover, capture-based aquaculture of Atlantic bluefin tuna (*Thunnus thynnus*) have developed rapidly and today are present in the waters of 10 Mediterranean countries (www.ICCAT.int) (Fig. 2). Although this is a fattening activity rather than aquaculture, it has increased the net revenue generated in the fishery by deseasonalisation of tuna supply. Spain is the third largest producer of marine fish aquaculture in the EU after the United Kingdom and Greece (APROMAR 2013) and the third largest importer of fish products worldwide (FAO 2014).

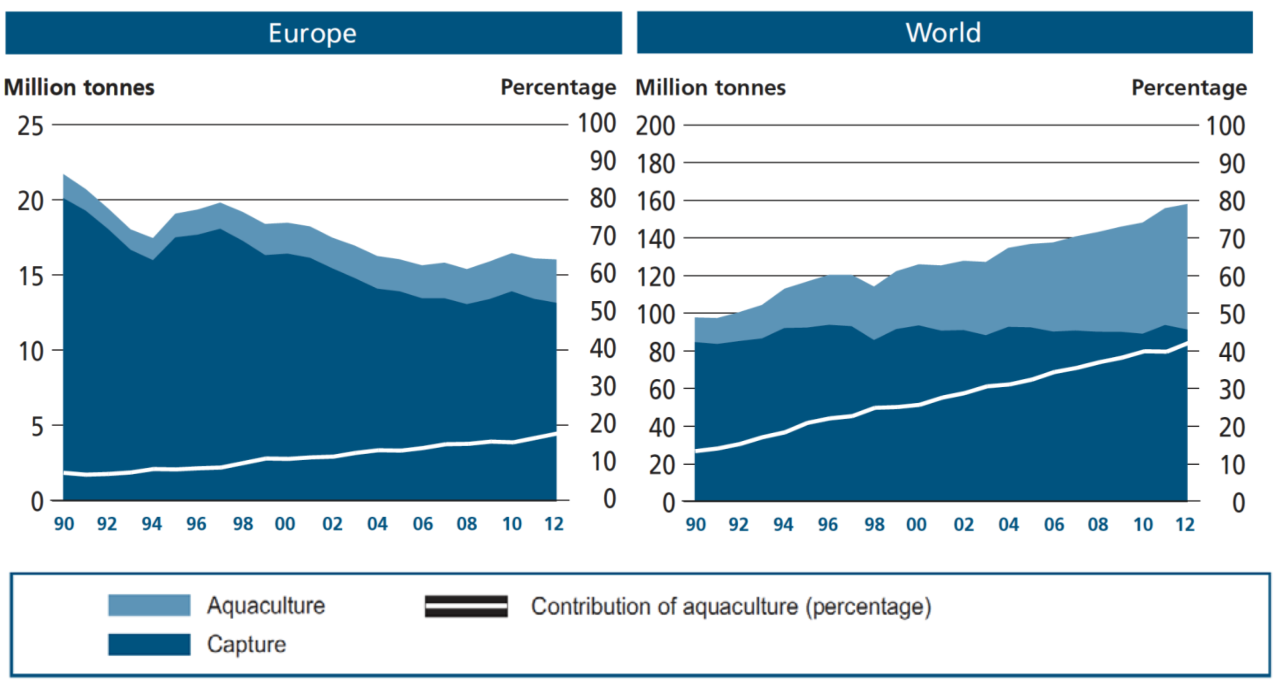

Figure 1 Share of aquaculture in total fish production in Europe and worldwide (FAO 2014).

Nevertheless, responsible for the continuous growth of the global aquaculture sector are the developing countries, particularly in Asia, whereas annual growth rates in the European Union (EU) have been minimal since 2000, averaging only 2.9% (FAO 2014)

(Fig. 1). The EU seafood market is currently supplied for 25% from EU fisheries, 65% from imports and 10% from EU aquaculture (EU Commission 2013). In 2010 the production of marine fish aquaculture in Spain has decreased 9.4%. Despite a slight increase in 2012, the production volume still remains 8.8% below the level of 2009 (APROMAR 2013).

Figure 2 Typical structure of a coastal fish farm used for farming Gilthead seabream (*Sparus aurata*) and Atlantic bluefin tuna (*Thunnus thynnus*) with circular floating cages made with HDPE pipes. Photo credit: Atlantic bluefin tuna: Greenpeace; Gilthead seabream: Internet

In the autonomous region of Catalonia (NE Spain) industrialized marine fish farm production started at the beginning of the 1990s (Jordana 1999). Catalonia used to be the second most important region for marine fish farm production in Spain, however, 60% of the Catalan fish farming installations had to close over the past decade (APROMAR 2013).

Even though the EU aquaculture sector is believed to have a significant growth potential (EU Commission 2013), there are many social, economic and environmental issues that influence the sustainable development of marine fish farming. The future success of this industry will depend on knowledge and skills from different disciplines to create an integrated framework to better plan and manage the marine aquaculture sector as part of coastal development. This thesis is an example of such a multi-disciplinary approach that applies ecological field studies, fishery science and social research techniques to investigate the effects of marine fish farming.

I. 2 Effects of marine fish farming

Marine aquaculture affects the environment and interacts with other coastal resource users in various ways. Concerns about negative environmental effects are particularly associated with marine sea-cage fish farming. Potential impacts on the environment involve various effluents (e.g. waste feed, feces, pesticides and medications) (e.g. Karakassis et al. 2000; Primavera 2006). Additionally, this activity might have direct negative effects on wild fish populations, through genetic contamination from fish that have accidentally escaped from farms (Hindar et al. 1991; Naylor et al. 2005; Jensen et al. 2010) and disease and parasite amplification and possible transfer to wild stocks (Heggberget et al. 1993; Diamant et al. 2000). Furthermore, indirect impacts should also be considered, in particular those on distant fish resources due to aquaculture’s high dependence on fish meal and fish oil in order to cultivate carnivorous fish (Naylor et al.

2000; 2009). This dependence on fisheries is an argument used to declare the unsustainability of this activity and to preclude it as an alternative to industrial fishing. Furthermore, fish farming might generate competence with other economic sectors. The access to and use of coastal resources of fish farms can lead to conflicts with other users of the coastal zone (Hoagland et al. 2003; Halwart et al. 2007; Nimmo et al. 2011). Although the increased production of farmed fish can impact the markets and prices for wild fish (Asche et al. 2001); the low prices of farmed products can make fish more accessible for consumers. The acceptance of the fish farming sector and its products may be especially low in areas where other traditional users are already settled (e.g. fishing industry, tourism) and valued by the local population. Yet, in some regions marine aquaculture has been shown to improve the economic development of rural coastal communities (Burbridge et al. 2001; Katranidis et al. 2003).

I. 3 Effects on wild fish populations

A well known effect of introducing sea-cage fish farms into the marine environment is the attraction of wild fish (Fig. 3). Particularly, in oligotrophic temperate systems, such as the Mediterranean Sea, where primary production is limited by low nutrient levels, fish farms generate new feeding sources and grounds for wild fish in the littoral zone. Farm-associated fish feed on uneaten pellets falling through the cages (Fernandez-Jover et al. 2007; Fernandez-Jover et al. 2008), while juvenile fish use the farm structure as shelter (Fernandez-Jover et al. 2009) and carnivorous species are attracted due to the aggregation of smaller prey fish (Sanchez-Jerez et al. 2008). Attraction of wild fish to fish farms is a global phenomenon and has been documented in Spain (Dempster et al. 2002; Boyra et al. 2004; Tuya et al. 2006), Croatia (Šegvić Bubić et al.

2011), Greece (Machias et al. 2005), Turkey (Akyol & Ertosluk 2010), Scotland (Carss 1990), Norway (Bjordal & Skar 1992; Dempster et al. 2009), USA (Oakes & Pondella 2009), Canada (Goodbrand et al. 2013), Indonesia (Sudirman et al. 2009), and also in neotropical reservoirs in Brazil (e.g. Demétrio et al. 2012; Ramos et al. 2013). The ecological and biological consequences of this aggregation effect at farms have received increasing interest in recent years and are being examined by a growing number of studies covering a wide range of topics.

The constant food supply at farms may alter natural distribution patterns of fishes in a given area (e.g. Dempster et al. 2002; Boyra et al. 2004). Moreover, the consumption of food pellets increases the body fat content and changes the fatty acid composition of aggregated fish (Skog et al. 2003; Fernandez-Jover et al. 2007; Dempster et al. 2011;

Figure 3 A dense shoal of *Diplodus sargus*, Mugilidae and *Sarpa salpa* aggregated underneath a sea-cage fish farm.

Fernandez-Jover et al. 2011). The biological consequences of this diet shift are not entirely clear. It has been suggested that waste feed could increase the reproductive potential of wild fish (Dempster et al. 2011), yet, changes in biochemical compositions may negatively affect egg quality and thus reproductive success (Salze et al. 2005; Lanes et al. 2012). In parallel, wild fish play an important role in minimizing the environmental impact of marine fish farming. The consumption of lost food by wild fish has been reported to reduce the organic waste that reaches the benthos underneath farms up to 40-80% (Vita et al. 2004; Felsing et al. 2005). In order to fully benefit from this recycling function, it has been argued that fish harvesting should be avoided in the vicinity of farms (Dempster et al. 2006). In order to protect farm-associated fish, their aggregation patterns need to be understood. Studies based on underwater visual surveys have shown that fish assemblages at farms strongly vary depending on the season (Valle et al. 2007; Fernandez-Jover et al. 2008; Šegvić Bubić et al. 2011) and depth (Dempster et al. 2005; Dempster et al. 2009), reflecting species-specific behaviour. Yet, no integrated study to assess the spatial and temporal extent of the attraction effect has yet been undertaken. An understanding of whether this attraction persists across seasons and what spatial distances and depths are reached is essential for future regulatory measures to be implemented for fish farms (addressed in *chapter 1*).

Even though the farm attraction effect on wild fish has been widely studied, the magnitude of this effect will depend on factors influencing within-farm variability. As wild fish are mainly attracted by the farm waste food (Tuya et al. 2006), substantial variation within farms associated with the daily pattern of feeding activity can be expected. Nevertheless, to date visual surveys have always been performed during the feeding activity, when wild fish are more likely to be attracted by waste food falling from cages (e.g. Valle et al. 2007; Fernandez-Jover et al. 2008). This generalized sampling protocol leaves uncertainty about whether fish are attracted during non-feeding periods and may therefore capture a biased or limited picture of the farm attraction effect (addressed in *chapter 2*).

I. 4 Effects of fish farming on the local fishery

The effects on wild fish around fish farms, such as changes in distribution patterns and the shift away from a natural diet may directly affect the local fishery, since many farm-associated species are of commercial interest (Fernandez-Jover et al. 2008; Šegvić Bubić et al. 2011). The diet switch from natural prey to fish feed pellets, that contain relatively large amounts of both marine and terrestrial fats, may influence flesh quality (Guillou et al. 1995). In Norway, this effect of fish farming is in conflict with the interests of the commercial fishery, because the quality of gadoid fish that have been feeding on waste feed is perceived inferior compared to fish with a natural diet (Skog et al. 2003; Otterå et al. 2009). Moreover, the close aggregation of wild fish in the vicinity of fish farms may reduce the availability of fish to the local fishery, since wild fish cannot be caught while aggregated, due to fishing restrictions within farm leasehold areas. This has led to the hypothesis that fish farms may act as small marine protected areas (Dempster et al. 2002; Dempster et al. 2006). Nevertheless, based on information from acoustic transmitters (Uglem et al. 2009; Arechavala-Lopez et al. 2010) and gut contents of previously farm-associated fish caught by fishermen (Arechavala-Lopez et al. 2011), displacements out of farm leasehold areas have been demonstrated for certain species. Therefore, it has been suggested that fish farms are beneficial for local fisheries by acting as “population sources” (Arechavala-Lopez et al. 2010; Dempster et al. 2011).

However, in recent years, an increase in commercial and recreational fishing activity at fish farms has been observed in various countries (e.g. Machias et al. 2006; Fernandez-Jover et al. 2008; Šegvić Bubić et al. 2011) (Fig. 4). Consequently, it has been argued that instead of small protection zones, fish farms may act as “ecological traps”, by increasing the catchability of attracted fish as they are concentrated in smaller areas

Figure 4 Small-scale fishing vessels fishing at the border of the leasehold area of a Gilthead seabream farm

than in a natural situation (Fernandez-Jover et al. 2008; Arechavala-Lopez et al. 2010). Yet, to date no information on the fishing effort at fish farms exists and its potential benefit for the local fishery remains unclear (addressed in *chapter 3*).

I. 5 Social perception of marine fish farming

The successful development of the marine fish farming sector not only depends on the carrying capacity of the marine system but also on its acceptance in the society. Previous findings in Greece showed that the acceptance of aquaculture decreases where local concerns about environmental damage from aquaculture are high and perceived socio-economic benefits are low (Katranidis et al. 2003). Hugues-Dit-Ciles (2000) demonstrated that the aquaculture sector in Mexico is more likely to be socially acceptable, economically viable and environmentally friendly, if the values and needs of local communities are incorporated into the planning process prior to development. The recognition of the range of perceptions that exist on marine aquaculture's economic, social and environmental benefits and costs is therefore a central aspect towards a sustainable development of this industry (Burbridge et al. 2001; Kaiser & Stead 2002; Mazur & Curtis 2008). It is now widely accepted that a more competitive and sustainable future aquaculture industry has to be based on an integrated approach (GESAMP 2001; Fezzardi et al. 2013), representing an interdisciplinary framework that combines knowledge from natural resource management and social sciences (Stead et al. 2002). There is a small but increasing number of social science studies on marine aquaculture. However, most of them focus on consumer attitudes (Verbeke et al. 2007; Altintzoglou et al. 2010; Fernández-Polanco & Luna 2010; Fernández-Polanco & Luna 2012) or the opinions of the general public (Katranidis et al. 2003; Shafer et al. 2010; Freeman et al. 2012), rather than perceptions of aquaculture-related key stakeholder groups (Whitmarsh & Palmieri 2009; Chu et al. 2010). Developing an overview of the different perspectives can increase stakeholders' awareness of other perceptions

(Raadgever et al. 2008) and inform about what stakeholder groups consider the most important issues (Mazur & Curtis 2008). Moreover, this type of studies allows identifying the main limitations, challenges and opportunities in an environmental, social and economic context, which can help governments and the aquaculture sector to develop a more sustainable industry (addressed in *chapter 4*).

Dissertation modality

This thesis is organized as a compilation of articles. It includes four articles that are described in chapter 1 to 4.

List of published and submitted articles

Chapter 1
Spatial and temporal extension of wild fish aggregations at *Sparus aurata* and *Thunnus thynnus* farms in the north-western Mediterranean
Bacher K[1], Gordoa A[1], Sagué O[2] (2012)
Aquaculture Environment Interactions *2*(3): 239-252, Impact Factor: 2.2

Chapter 2
Feeding activity strongly affects the variability of wild fish aggregations within fish farms: a sea bream farm as a case study
Bacher K[1], Gordoa A[1], Sagué O[2] (2013)
Aquaculture Research DOI: 10.1111/are.12199, Impact Factor: 1.4

Chapter 3
Does marine fish farming affect local small-scale fishery catches? A case study in the NW Mediterranean Sea
Bacher K[1], Gordoa A[1]
Under revision: Aquaculture Research, Impact Factor: 1.4

Chapter 4
Stakeholders' perceptions of marine fish farming in Catalonia (Spain): A Q-methodology approach
Bacher K[1], Gordoa A[1], Mikkelsen E[3] (2014)
Aquaculture, 424: 78-85, Impact Factor: 2.0

I.6 Dissertation objectives and contents of the thesis

The overarching goal of this doctoral thesis was to advance the understanding of the interactions between marine fish farming, wild fish populations, the local small-scale fishery and the society. This thesis was designed as a multi-disciplinary study and is divided into three different sections: ecology, fisheries and social sciences. *Chapter 1 & 2* investigate ecological aspects of fish farming on wild fish populations by direct observations in the field. *Chapter 3* analyzes fisheries data to examine the effect of fish farming on the local small-scale fishery. *Chapter 4* is a social science study that investigates the perceptions of different stakeholder groups on marine fish farming. This thesis has been developed within the regional frame of Catalonia (NW Mediterranean).

The detailed objectives and the structure of the thesis are given below:

Chapter 1

Chapter 1 uses an integrated approach to assess the spatial and temporal extent of the attraction effect of wild fish at two different farming systems of the Mediterranean: an Atlantic bluefin tuna *Thunnus thynnus* (ABT) fattening farm and a Gilthead seabream *Sparus aurata* (SB) farm. The following specific objectives have been identified:

1. Characterize the wild fish assemblages at farms in terms of abundance, biomass and species composition
2. Determine the horizontal spatial attraction range along a distance gradient away from the farm at three different depths
3. Examine how the attraction effect varies with season

4. Analyze the potential interactions between the three factors: spatial extent, depth and season
5. Compare aggregation patterns at the ABT and the SB farm

Chapter 2

Chapter 2 investigates the within-farm variability of wild fish aggregations through a closer examination of the potential driving factors of variability at a SB farm: feeding activity and bottom substrate type. This was approached through the analysis of the following objectives:

6. Investigate whether fish aggregations differ between feeding and non-feeding periods
7. Examine if the distance of the feeding vessel influences the distribution pattern of aggregated fish
8. Analyze whether the effect of the feeding activity changes with depth
9. Evaluate how different bottom substrate types affect fish aggregations within farms

Chapter 3

Chapter 3 investigates the interactions between fish farms, farm-aggregated wild fish and the small-scale fishery. The main goal is to assess whether fish farms increase the catchability of farm-aggregated fish or whether farms act as a protection zone for wild fish. The following objectives were investigated:

10. Estimate the commercial and recreational fishing effort in farm vicinity

11. Assess differences between fishing in farm vicinity and away from the farm (in terms of yield, income, and catch composition)
12. Estimate the biomass removal from fishing activities inside the farm leasehold area

Chapter 4

The main objective of chapter 4 is to identify the different perceptions of key stakeholder-groups on marine fish farming in Catalonia (Spain). This study aims to contribute to the scarce social science research on marine aquaculture. The specific objectives were as follows:

13. Identify the different perceptions of marine fish farming in Catalonia held by five key stakeholder-groups: fishery, fish farming sector, environmental NGOs, regional administration and scientists
14. Detect which stakeholder groups share the same perception
15. Identify the major areas of agreement and disagreement between perceptions
16. Identify the limitations, challenges and opportunities of marine fish farming in an environmental, social and economic context, as seen by major stakeholder groups in Catalonia

I.7 REFERENCES

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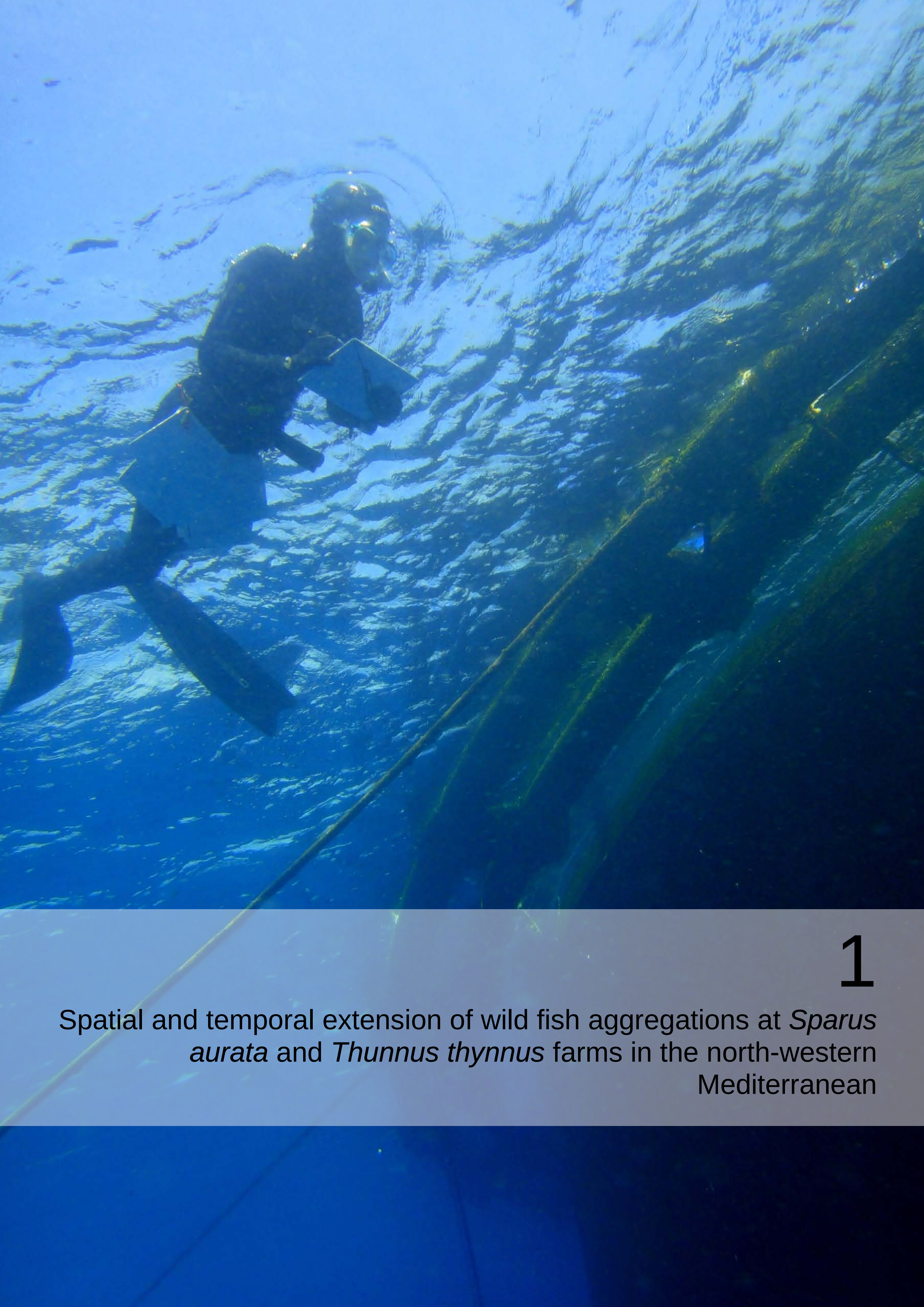

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Spatial and temporal extension of wild fish aggregations at *Sparus aurata* and *Thunnus thynnus* farms in the north-western Mediterranean

Bacher K., Gordoa A. & Sagué O. (2012) Spatial and temporal extension of wild fish aggregations at *Sparus aurata* and *Thunnus thynnus* farms in the north-western Mediterranean. *Aquaculture Environment Interactions 2*(3): 239-252

ABSTRACT

Fish farms cause wild fish to aggregate nearby and thus act to modify their distribution, but the spatial and temporal extent of the attraction effect around farms is still poorly understood. This study has examined attraction using an integrated approach combining three factors, spatial extent, depth, and season. We analysed an Atlantic bluefin tuna (ABT) (*Thunnus thynnus*) and a Gilthead seabream (SB) (*Sparus aurata*) farm off the north-eastern coast of Spain which represent different fish farming models in the Mediterranean. Underwater visual counts were conducted from summer 2010 to spring 2011. We recorded 39 species at the SB farm and 17 species at the ABT farm. The analysis of fish abundance and biomass at three stations located along a distance gradient from the farm (SB: 0 m, 30 m, 200 m; ABT: 0 m, 100 m, 200 m) showed significantly higher values next to the cages than at more distant stations, revealing that the spatial extent of the attraction effect was mainly restricted to the cage rather than following a gradient. The intensity of the cage-effect varied according to farm, season, and depth, reflecting species-specific behaviours. At the SB farm the cage-effect persisted year round, varying with depth, whereas at the ABT farm the effect was only detected in summer and spring. These distinct spatial and temporal aggregation patterns suggest that implementation of fishery regulatory measures to protect wild fish should be farm-specific. This study emphasizes the importance of using an integrated approach to study wild fish aggregations at farms.

1.1 INTRODUCTION

The impact of human activities on marine ecosystems extends around the world. A recent global study revealed that no area is unaffected by human influences and that a considerable proportion (41 %) is heavily affected by multiple drivers (Halpern et al. 2008). Coastal areas in particular are being impacted by a wide variety of human activities as a consequence of the pressures of population growth (Burbridge 1999). Aquaculture is an activity that has been expanding rapidly in recent years due to the world-wide demand for seafood. This anthropogenic activity generates new feeding grounds for wild fish populations in the littoral zone. Several studies have shown that fish farms attract wild fish in their near vicinity, thereby altering natural distribution patterns (e.g. Carss 1990; Dempster et al. 2002; Boyra et al. 2004). Apart from high food availability, the presence of an artificial structure, and the chemical attraction to farmed fish, have been put forward as influences contributing to this aggregation effect (Tuya et al. 2006). The physiological consequences of this new food source on local fish populations are still unclear (Fernandez-Jover et al. 2011). A recent study has shown that farms do not seem to negatively affect wild fish species like saithe (*Pollachius virens*) and Atlantic cod (*Gadus morhua*), but rather act to enhance the body condition of farm-associated fish (Dempster et al. 2011). In parallel, consumption of lost food by wild fish may buffer the environmental impact on the benthos underneath farms (e.g. Lupatsch et al. 2003; Vita et al. 2004). Therefore, it has been argued that fish harvesting should be avoided in the vicinity of farms (Dempster et al. 2006), in order to fully benefit from the recycling function of wild fish. However, the spatial extent of fish aggregations around farms has been poorly studied to date. Previous work has examined differences between farms and distant control locations (e.g. Dempster et al. 2002; Boyra et al. 2004) and only recently has the distance factor been examined in the vicinity of Norwegian salmon farms (Dempster et al. 2010).

The natural distribution of fish populations in the littoral zone is influenced by different factors, such as depth (Bell 1983; García-Charton & Pérez-Ruzafa 1998) and habitat structure (Letourneur et al. 2003; Lombarte et al. 2011), which influence the type and distribution of food and shelter (García-Charton & Pérez-Ruzafa 2001). Depth has also been identified as an important factor determining spatial patterns of fish aggregations at fish farms (Dempster et al. 2005; Sudirman et al. 2009). In addition, previous studies have shown that the species composition of fish aggregations at farms changes with the season (Valle et al. 2007; Fernandez-Jover et al. 2008), indicating species-specific residence times at farms. Although the spatial and temporal variability of farms has been studied previously, no systematic approach to assess the spatial and temporal extent of the attraction effect has yet been undertaken. An understanding of whether this attraction persists across seasons, how it changes with time, and what spatial distances and depths are reached is essential. Despite the growing number of publications on the variability of wild fish aggregations at fish farms which have taken different factors into account (Table 1), an integrated analysis is currently lacking. This study is intended to begin filling this gap by putting forward a comprehensive approach that analyses and combines the main factors known to influence wild fish aggregations, namely, spatial extent, depth, and season. Determining these factors has implications for future regulatory measures to be implemented for fish farms. The specific objectives of this study were to examine the horizontal spatial attraction range along a distance gradient away from the farm for each depth, and to investigate temporal variability.

Sampling was carried out at two fish farms that represent different fish farming models in the Mediterranean Sea: an Atlantic bluefin tuna (ABT) (*Thunnus thynnus*) farm and a Gilthead seabream (SB) (*Sparus aurata*) farm. Gilthead seabream has been cultured extensively for many years throughout the Mediterranean (FAO 2008), and ABT capture-based aquaculture, known as fattening farms, have developed rapidly and today are present in the waters of 10 Mediterranean countries (see www.ICCAT.int).

Table 1 Summary of studies that have investigated different factors influencing variation in fish aggregations at marine fish farms. Farm types: GR/RA: mixed groupers (*Epinephelus fuscoguttatus* and *Cromileptes altivelis*) and rabbitfish (*Siganus* spp.), SB/ESB: mixed Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*), WSB: White seabass (*Atractoscion nobilis*), ABT: Atlantic bluefin tuna (*Thunnus thynnus*), AS: Atlantic salmon (*Salmo salar*). Depths: S: surface, M1: intermediate cage depth, M2: between the cage and the sea bottom, AB: above bottom, B: bottom.

References	Study location	Nº Farms	Factors	Farm type	Sampling sites	Sampling depths	Sampling period
Dempster et al. 2002	Spain	9	distance between farms	SB/ESB	cage, 200 m	integrated (5-10 m)	Sep/Oct
Dempster et al. 2005	Spain	5	depth	SB/ESB	cage	S, M1, M2, B	Oct/Nov
Dempster et al. 2009	Norway	9	depth	AS	cage, 1-2 km	S, M1, M2, AB, B	Summer
Sudirman et al. 2009	Indonesia	1	depth, day time	GR/RA	cage	1-3, 3-6, 6-9, >9 m	Dec–Apr
Oakes & Pondella 2009	USA	1	depth, season	WSB	cage, 200 m	S, M1, B	1 year
Valle et al. 2007	Spain	1	season	SB/ESB	cage, 200 m	integrated (5-10 m)	1 year
Fernandez-Jover et al. 2008	Spain	3	season	SB/ESB	cage	integrated (5-10 m)	2 years
Boyra et al. 2004	Canary Iss.	2	season	SB/ESB	cage, 500 m - 1 km	integrated	1 year
Šegvić Bubić et al. 2011	Croatia	2	season	ABT	cage, 200 m	integrated (0-15 m)	1 year
Dempster et al. 2010	Norway	9	spatial extension	AS	cage, 25, 50, 200 m	integrated (5 m-B)	Jul/Oct
This study	Spain	1	extension, depth, season	ABT	cage, 100, 200 m	S, M1, M2	1 year.
This study	Spain	1	extension, depth, season	SB	cage, 30, 100 m	S, M1, B	1 year

1.2 MATERIAL AND METHODS

Study site and farm characteristics

The selected farms are located in the littoral area influenced by the Ebro River in the north-western Mediterranean Sea (Fig. 1) off their common home port of L'Ametlla de Mar (40°53′10″N 0°48′13″E). The SB farm is located about 1 km from the coast over a rocky-sandy bottom with a bottom depth of 20 m. The farm started operating in 1993, consists of 30 circular cages (each 19 m in diameter) with a net depth of 10 m, and covers a leased area of 400 000 m^2.

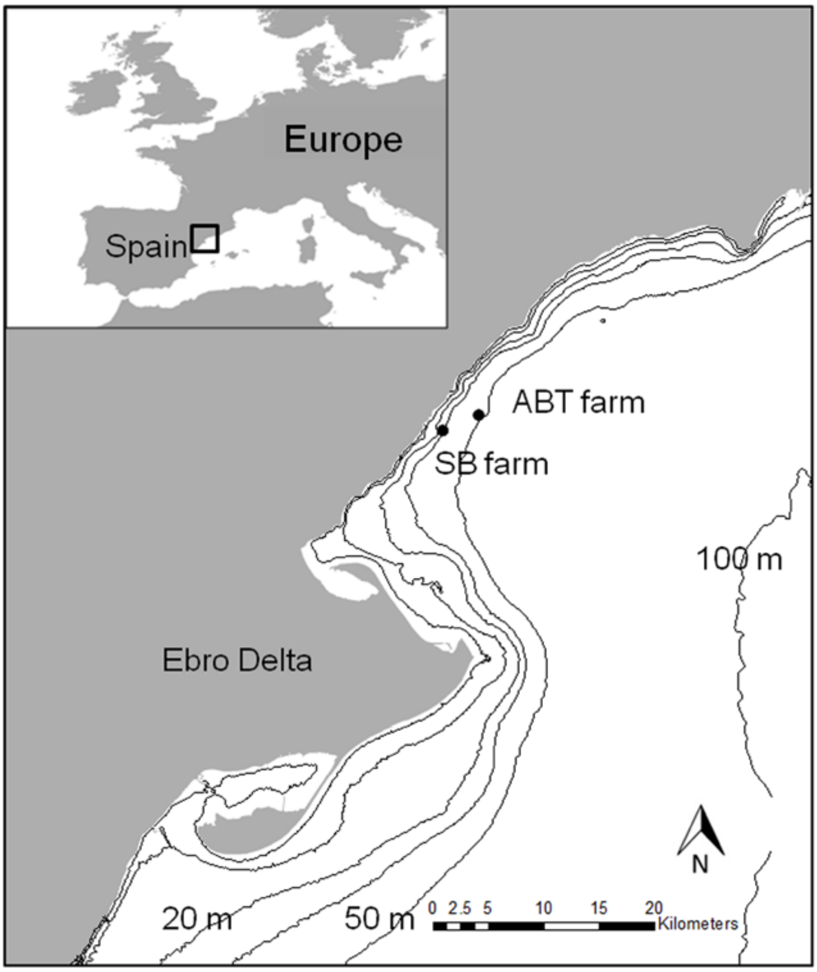

Figure 1 Study stations adjacent to the Ebro River Delta off the north-eastern coast of Spain. SB: Gilthead seabream, ABT: Atlantic bluefin tuna

On average the farm contains 850 t of stocked fish biomass and produces 800 t of *Sparus aurata* annually. Farmed fish are fed 2 500 t yr^{-1} of dry food pellets based on fish meal and vegetable oil. The ABT farm is located further offshore (4.5 km) over a mixed gravel-mud-sand bottom with a bottom depth of 45 m. The farm started operating in 2004, and the total leased area is 300 000 m^2. During the study, two oval cages (each 120 x 60 m) and four round cages (each 50 m in diameter) with a net depth of 30 m were in use. On average the farm stocks 700 t of wild adult *Thunnus thynnus* caught in the western Mediterranean spawning grounds and reaches an annual production of about 990 t. The tunas are exclusively fed with frozen fish (5700 t yr^{-1}), such as Atlantic mackerel (*Scomber scombrus*), Round sardinella (*Sardinella aurita*), European pilchard (*Sardina pilchardus*), and Atlantic herring (*Clupea harengus*).

Water temperature and visibility

Temperature and underwater visibility displayed high variability during the study period. Water temperature at the two farms ranged from a minimum of 12.3 °C in winter to a maximum of 25.5 °C in summer. Underwater visibility varied greatly from one day to another, and values were often low, which was expected due to the influence of the Ebro River runoff (Cruzado et al. 2002; Gordoa et al. 2008). The minimum and maximum visibility over the year ranged from 5 to 20 m, with lowest visibilities near the bottom during cold months and highest visibilities at the surface and midwater in summer and spring. Sampling was only conducted on days with at least 5 m of visibility.

Sampling design

Wild fish at both fish farms were counted by means of underwater visual census (UVC). The spatial horizontal design at each farm comprised three fixed sampling stations located along a distance gradient from the farm within each farming concession area. The three sampling stations were chosen according to the different spatial dimensions of the cages (Fig. 2). Stations were: (1) cage: right next to one of the cages (distance 0 m), (2) border: off the edge of the cages (distance: SB farm 30 m, ABT farm 100 m) and (3) limit: at the boundary of the leasehold area (distance: 200 m).

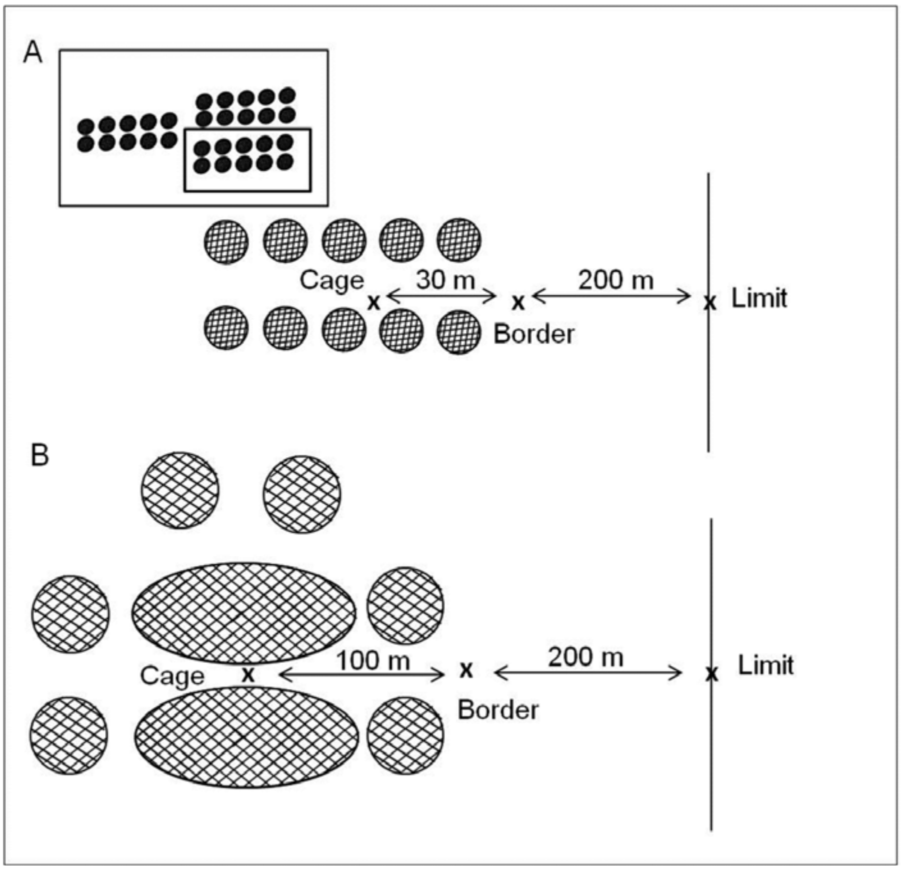

Figure 2 Layout of the (a) Gilthead seabream (SB) farm and (b) the Atlantic bluefin tuna (ABT) farm with corresponding sampling stations. Xs indicate the positions of the 3 types of sampling stations (cage, border, limit).

The three stations at each farm had the same ecological features: depth, bottom type and distance to the shore. Visual surveys at each station were performed in three distinct depth strata: surface (0-3 m), midwater (8-12 m) and deep/bottom (18-20 m). Bottom depths varied greatly between the two farms, hence the deep depth stratum was representative of the bottom at the SB farm but not at the ABT farm. Due to logistical constraints associated with no-decompression diving limits, we chose 20 m, i.e. the bottom depth at the SB farm, as the depth limit for the UVC.

Sampling was carried out from summer 2010 to spring 2011 on three randomly selected days per season. At each station we performed one count per day and per depth, resulting in a total of 108 fish counts at each farm. All surveys were performed during morning hours (8:30-12:00). The UVC counts were carried out using a method developed by Dempster et al. (2005) which is robust for comparisons of counts at different depth levels and at different visibilities. The method depends on stationary timed counts during which the diver rotates through 360°. To standardize the counts, fish are only counted from 1 m above to 1 m below eye-level out to a radius of 5 m. Bottom counts at the SB farm were conducted kneeling on the seafloor and spanned the zone from the substrate to 2 m above. Counts lasted 7 min at each depth. All UVCs were performed by two divers. While the first diver concentrated on estimating the abundance of the dominant species, the second diver looked for more cryptic species. During the seven minutes the maximum number of individual fish of each species observed at any one time was recorded. This made it more unlikely to count the same fish twice. For schools of up to 20 fish, individual fish were counted; for larger shoals estimates were obtained by subdividing the shoals into imaginary subgroups of equal size, counting the individuals in one of the subgroups and multiplying that count by the number of subgroups. The total length of individuals was recorded, and the biomass was calculated based on published length-weight relationships for each species. Mugilidae species could not be identified visually to species level and were therefore recorded at the family level. Similarly, *Trachurus mediterraneus* and *Trachurus trachurus* were recorded as *Trachurus* spp.

Statistical analysis

The assumptions of normality and homogeneity of variance can often be difficult to fulfil with biological data. A good alternative is the analysis of variance based on permutations (PERMANOVA), as it allows multivariate data to be analyzed in the context of complex experimental designs and provides a robust approach to deal with skewed data and many zero counts (Anderson 2001). Therefore, all univariate and multivariate statistical analyses were carried out using the PRIMER V6.1.13 computer program (Clarke & Gorley 2006) with the PERMANOVA+ V1.0.3 add-on package (Anderson et al. 2008).

Univariate analysis

A univariate PERMANOVA with three factors (station, depth, season, all fixed) was performed to test differences in total fish abundance and biomass for each site. The similarity matrix was computed using the Euclidean distance on square root-transformed data, and post-hoc pairwise comparisons were used to investigate significant results. In addition, the number of species per station, depth and season was estimated. For direct comparison between the SB and ABT farms, the deep stratum at the SB farm, which represents the bottom community unreachable at the ABT farm, was excluded.

Multivariate analysis

Permutational multivariate analysis of variance was used to test the differences in wild fish aggregations at the different stations, depth strata, and seasons (PERMANOVA, Anderson 2001; Anderson et al. 2008). Prior to analysis the data were fourth-root transformed in order to downweight the influence of more abundant species, whilst preserving information on relative abundance (Clarke & Green 1988). Since the Bray-Curtis similarity measure is undefined for two empty samples, we used the zero-adjusted Bray-Curtis for which a ‘dummy species’ is added to the original abundance matrix in order to generate meaningful nMDS displays (Clarke et al. 2006). Non-metric multidimensional scaling (nMDS) ordinations averaged by season were produced to depict the multivariate patterns of fish aggregations. Statistical significance was tested using 9999 permutations of residuals under a reduced model (Freedman & Lane 1983) and Type III (partial) sums of square (SS, Anderson et al. 2008). Significant terms were further examined by applying appropriate post hoc pairwise comparisons. We applied the Similarity Percentage Analysis (SIMPER) routine to examine species contributions to within-group similarity for the most important factor at each farm.

1.3 RESULTS

Composition of wild fish species

A total of 14 475 individual fish were counted at the SB farm and 5 627 at the ABT farm, belonging to 47 species and 23 families (Appendix 1). The vast majority of the species were osteichthyes, only four being chondrichthyes, including three species of rays and one blue shark (*Prionace glauca*). In all, 39 species (17 families) were recorded at the SB farm and peripheral stations, the most common families being Sparidae (8 species) and Labridae (7 species). At the ABT farm and peripheral stations, 17 species belonging to 9 different families were observed, the most common being Sparidae (4 species) followed by Clupeidae (3 species) and Carangidae (3 species). The censuses included two unusual sightings in the Mediterranean, the barrelfish/driftfish (*Hyperoglyphe perciformis*), and the blue shark. Forty of the observed species are targeted by local fishermen. The number of species was higher at the cage than at the border and limit stations at both farms (Appendix 1).

SB farm

Fish were significantly more abundant at the cage compared to the border and the limit (average abundance; cage: 240 ± 30, border: 73 ± 20, limit: 97 ± 28; Table 2, Figure 3a). Similarly, biomass values were substantially higher at the cage compared to the border and the limit (average biomass (kg); cage: 73.4 ± 16.6, border: 2.7 ± 1.2, limit: 1.3 ± 0.4; Table 2, Fig. 3b).

Table 2 Gilthead seabream (SB) farm: summary of results of permutational univariate and multivariate analysis of variance comparing abundance, biomass and species community for the factors station (ST), depth (DE) and season (SE) and post hoc tests for significant factors and interactions. C: cage, B: border, L: limit; D: deep water, M: midwater, S: surface; SU: summer, AU: autumn, WI: winter, SP: spring. Significant at *p < 0.05, **p < 0.01, ***p < 0.001

Source	df	Total abundance		Total biomass		Species community	
		MS	*F*	MS	*F*	MS	*F*
ST	2	703	21.95***	337130	29.34***	7963	9.23***
DE	2	887	27.70***	10073	0.88	56209	65.15***
SE	3	12	0.36	16191	1.41	2533	2.94***
ST x DE	4	72	2.24	45226	3.94**	4002	4.64***
ST x SE	6	65	2.02	16692	1.45	2055	2.38***
DE x SE	6	26	0.80	11495	1.00	1664	1.90**
ST x DE x SE	12	79	2.46*	12323	1.07	1143	1.32*
Residuals	69	32		11490		863	

Post hoc comparisons	Abundance/Biomass		Species community
ST	C ≠ B = L	ST x DE	S: C ≠ B = L
DE	D ≠ M = S		M: C ≠ B ≠ L D: C = B ≠ L
	Biomass		
ST x DE	S: C ≠ B = L	ST x SE	SU/WI/SP: C ≠ B = L
	M: C ≠ L ≠ B		AU: C = B; C = L; B ≠ L
	D: C = B ≠ L	DE x SE	AU/WI/SP: D ≠ M = S
			SU: D ≠ M ≠ S

However, the fish distribution was not homogeneous across depths. Significant differences in abundance and biomass at the cage compared to the border and the limit were only observed in the midwater and surface strata. At the bottom, abundance and biomass did not vary between the cage and the border but were significantly higher than at the limit (Fig. 3a-b).

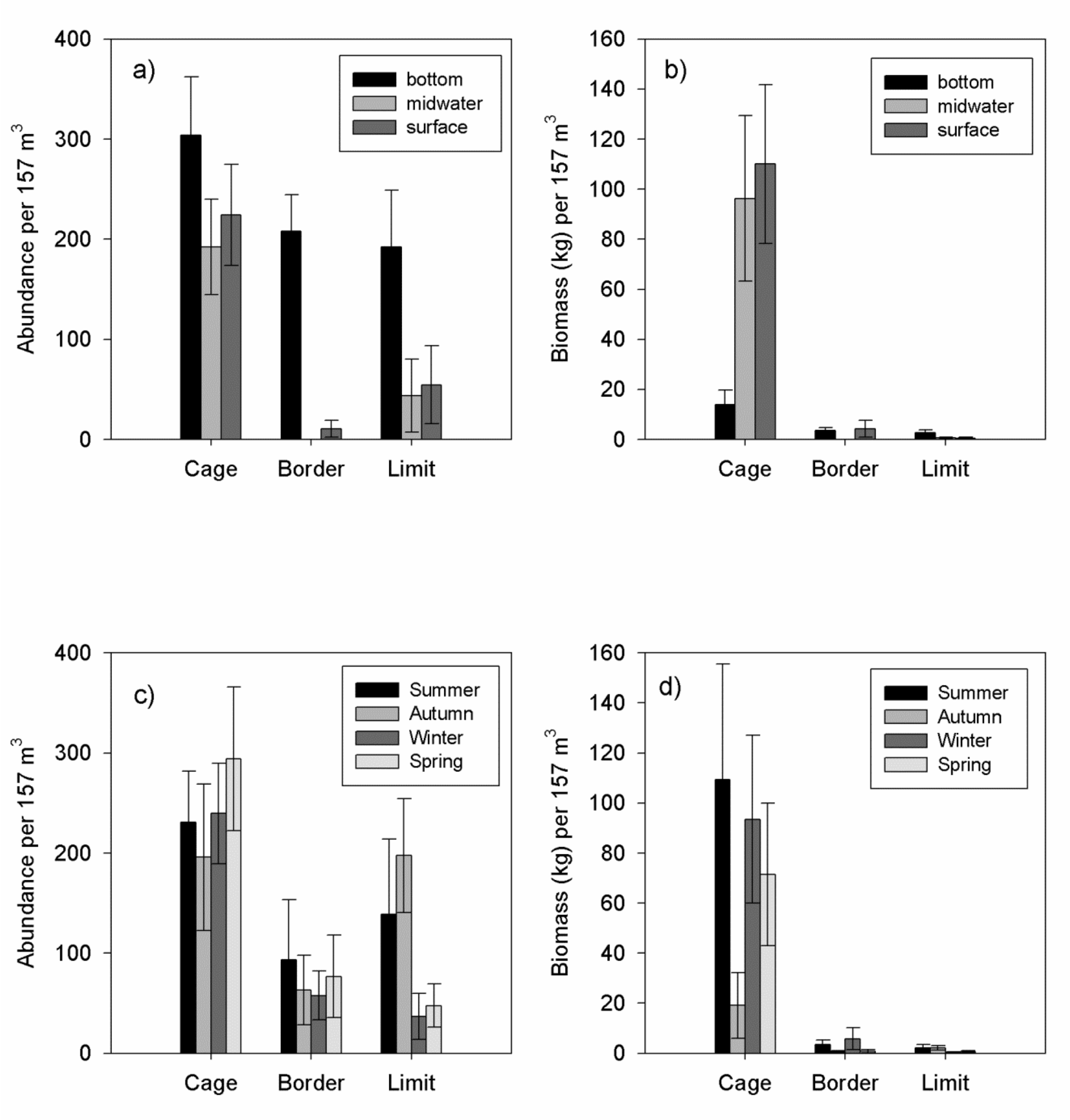

Figure 3 Total abundance and biomass (kg) of wild fish at the Gilthead seabream (SB) farm (a, b) by sampling station and depth and (c, d) by sampling station and season. Bars are mean ± SE of 12 underwater visual counts in a volume of 157 m^3.

Overall, fish were more abundant at the bottom compared to the midwater (3 times; $p < 0.001$) and surface strata (2.4 times; $p < 0.001$; Table 2), although total fish biomass did not differ among depths (Fig. 3a-b). Fish abundance and biomass at the cage did not vary by season except in autumn, when small species were most abundant, resulting in significantly lower biomass values at that time of year. The higher abundance and biomass observed at the cage was constant all year round, except in autumn, when fish abundance at the cage was not significantly higher than at the limit (Fig. 3c-d, Table 2, triple interaction). Fish abundance at the limit revealed a different seasonal pattern compared to the other stations, attaining the highest values in summer and autumn and the lowest values in winter and spring (Fig. 3c). At the cage, the species composition differed significantly from those at the border and the limit (Table 2). However, variability in the fish community was heavily depth-dependent, with a clear separation between the bottom and the water column (midwater and surface strata) all year round (nMDS ordination; Fig. 4).

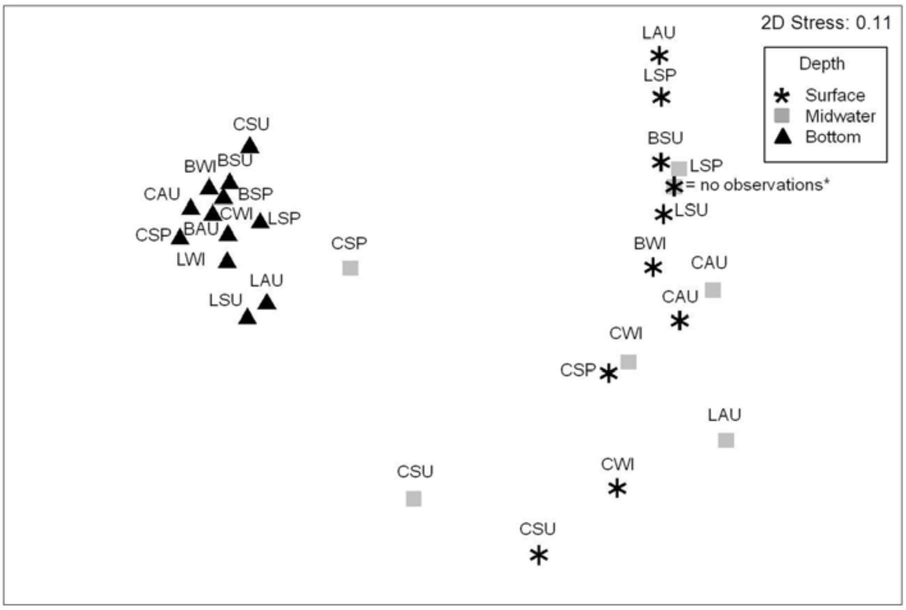

Figure 4 Non-metric multidimensional scaling ordination plot of wild fish assemblages at the Gilthead seabream (SB) farm based on a Bray-Curtis similarity matrix of fourth-root transformed abundance data, averaged per season (C: Cage, B: Border, L: Limit; SU: summer, AU: autumn, WI: winter, SP: spring). * Samples without fish observations ('no observations') were placed together; surface: BSP, LWI, BSU; midwater: BSU, LSU, BSP, BAU, BWI, LWI. Stress = 0.11.

Midwater and surface aggregations differed from each other only in summer (Table 2). SIMPER analysis showed that assemblages at the bottom were stable over time at all stations and were largely (> 50%) represented by three species (*Chromis chromis*, *Coris julis* and *Serranus cabrilla;* Table 3). In contrast, cage-aggregations in the water column differed significantly from those at the border and the limit, mirroring the spatial and seasonal aggregation patterns found for abundance and biomass (Table 2).

Table 3 Gilthead seabream (SB) farm. Results of the similarity percentage analysis showing the species contribution to within-group similarity (%) by sampling station and depth stratum. Full species names are listed in Appendix 1

	Cage	%	Border	%	Limit	%
Surface	*O. melanura*	83.0	All similarities are zero		*S. pilchardus*	100.0
	B. boops	10.1				
Midwater	*C. chromis*	39.3	No species observed		*B. boops*	100.0
	Mugilidae	27.5				
	O. melanura	23.8				
Bottom	*C. chromis*	32.0	*C. chromis*	33.1	*C. chromis*	34.0
	S. cabrilla	17.1	*C. julis*	19.4	*C. julis*	23.7
	C. julis	16.9	*S. cabrilla*	14.0	*D. vulgaris*	16.1
	G. xanthocephalus	7.4	*S. scriba*	12.8	*S. cabrilla*	12.9
	P. pilicornis	7.1	*D. vulgaris*	8.0	*O. melanura*	3.9
	S. scriba	5.0	*G. xanthocephalus*	4.3		
	P. rouxi	4.1				
	D. vulgaris	4.1				

This aggregation pattern was stable over time, except in autumn, when fish assemblages at the cage did not differ from those at the border and the limit (Table 2). Cage-aggregations in the water column were dominated by six species which accounted for 94 % of total abundance (Fig. 5). Abundance values for these taxa varied by season, each season being characterised by a different combination of species (summer: *Oblada melanura*, Mugilidae, *Trachinotus ovatus*, *C. chromis,* and *Sarpa salpa*; autumn: *Boops boops*; winter: *O. melanura*, *B. boops*; spring: *C. chromis*, *O. melanura*, Mugilidae; Fig. 5).

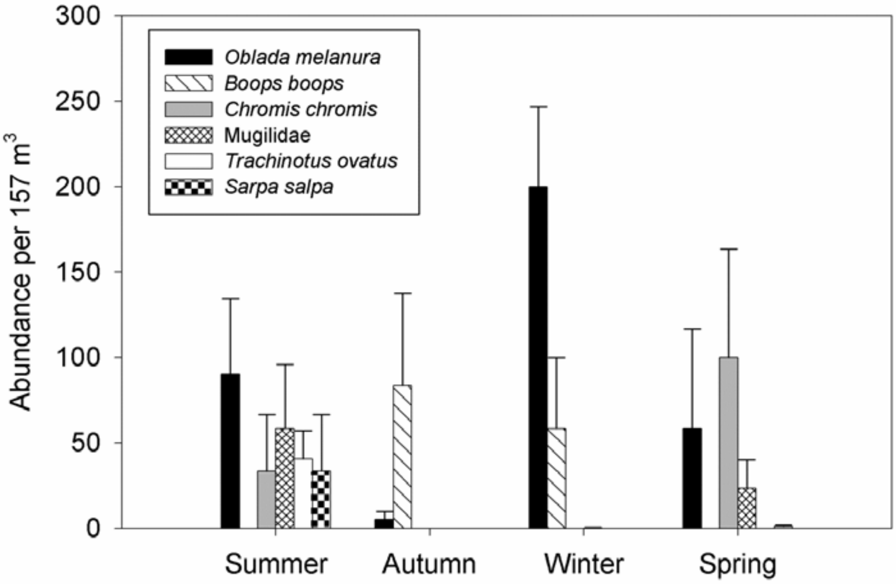

Figure 5 Total abundance (mean ± SE) of the six most abundant species at the Gilthead seabream (SB) farm in the midwater and surface strata at the cage by season.

ABT farm

The majority of fish were observed at the cage, where abundance values were higher than at the border and the limit (average abundance; cage: 113 ± 28, border: 12 ± 4, limit: 31 ± 10; Table 4). Likewise, fish biomass was substantially higher at the cage compared to the border and the limit (average biomass (kg); cage: 424.8 ± 158.4, border: 4.2 ± 2.3, limit: 5.1 ± 4.3; $p < 0.001$, Table 4, Fig. 6a-b). Abundance and biomass at the cage varied significantly with season (Table 4), with higher values in summer and spring compared to autumn and winter (Fig. 6c-d). Indeed, fish biomass was strongly affected by seasonality, and as a consequence higher biomass values at the cage compared to the border and the limit were only detectable in summer and spring (Fig. 6d) and were restricted to the deep and midwater strata (significant interactions, Table 4, Fig. 6b). Overall, the highest fish biomass was recorded for the deep and midwater strata. However, these high values only occurred in summer, due to the presence of wild *T. thynnus* which contributed 94.3 % to the total fish biomass recorded in this season. During the rest of the year no differences were recorded among depths (Table 4).

Table 4 Atlantic bluefin tuna (ABT) farm. Summary of results of permutational univariate and multivariate analysis of variance comparing abundance, biomass and species community for the factors station (ST), depth (DE) and season (SE) and post hoc tests for significant factors and interactions. C: cage, B: border, L: limit; D: deep water, M: midwater, S: surface; SU: summer, AU: autumn, WI: winter, SP: spring. Significant at *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ns = non-significant

Source	df	Total abundance		Total biomass		Species community	
		MS	*F*	MS	*F*	MS	*F*
ST	2	293.99	10.20***	1195600	30.83***	6757	7.08***
DE	2	47.45	1.65	434790	11.21***	5507	5.77***
SE	3	97.1	3.37*	602830	15.54***	5411	5.67***
ST x DE	4	71.03	2.47	301250	7.77***	3484	3.65***
ST x SE	6	31.65	1.10	379900	9.79***	1934	2.03**
DE x SE	6	12.1	0.42	169150	4.36***	2217	2.32***
ST x DE x SE	12	14.8	0.51	116090	2.99**	1241	1.30
Residuals	72	28.81		38785		954	

Post hoc comparisons				Biomass	Species community
	Abundance/ Biomass		ST x DE	S: C = B = L	S: C ≠ B = L
ST	C ≠ B = L			M: C ≠ B = L	M: C ≠ B = L
DE	ns	D ≠ M = S		D: C ≠ B = L	D: C ≠ B ≠ L
SE	SU = SP ≠ WI = AU		ST x SE	SU/SP: C ≠ B = L	SU/SP: C ≠ B = L
				AU/WI: C = B = L	AU/WI: C = B = L
			DE x SE	SU: D = M ≠ S	SU: D ≠ M ≠ S
				AU/WI/SP: D = M = S	AU/WI/SP: D = M = S

Wild fish communities at the cage differed significantly from those at the border and the limit in all three depth strata (Table 4). SIMPER analysis revealed that cage-assemblages consisted mainly of four species (*Thunnus thynnus*, *Oblada melanura*, *Sarpa salpa,* and *Sardina pilchardus*), which accounted for 91 % of the group similarity. By contrast, fish aggregations at the border and the limit were dominated by *Trachurus* spp. (59 %), *Hyperoglyphe perciformis* (22 %) and *Seriola dumerili* (10 %). The separation of the cage-aggregations from the border and limit aggregations was confirmed by the nMDS ordination, but there was no clear interpretation for samples by depth and season (Fig. 7).

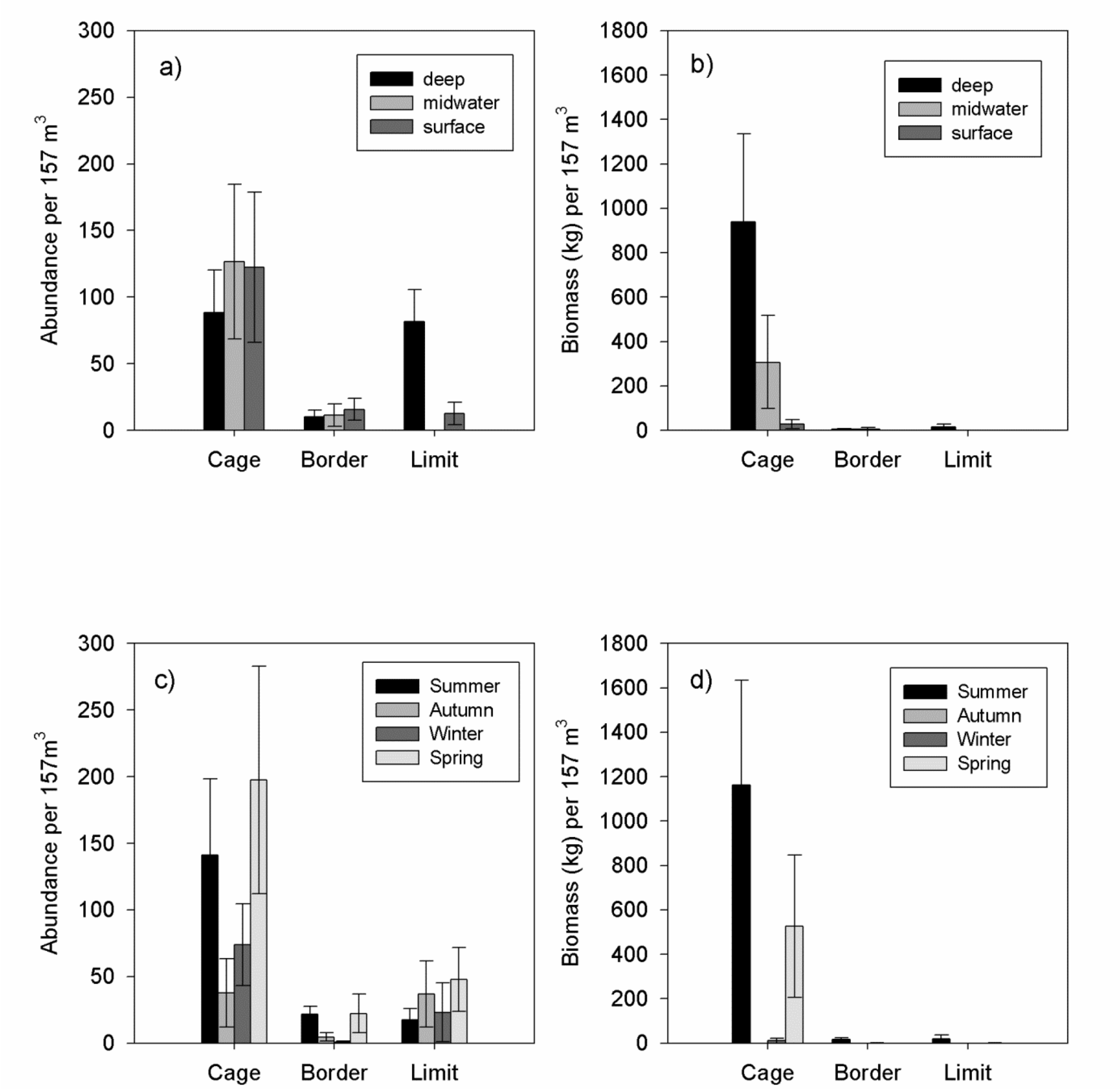

Figure 6 Total abundance and biomass (kg) of wild fish at the Atlantic bluefin tuna (ABT) farm (a, b) by sampling station and depth and (c, d) by sampling station and season. Bars are mean ± SE of 12 underwater visual counts in a volume of 157 m^3.

Differences in fish aggregation patterns were only observed during summer and spring, while in autumn and winter fish assemblages were station-independent (Table 4). Assemblages at the cage in summer and spring were clearly dominated by *T. thynnus*. Conversely, *T. thynnus* was never recorded at either the border or limit stations (Table 5). In autumn and winter fish assemblages at the three stations were mainly composed of different species (Table 5).

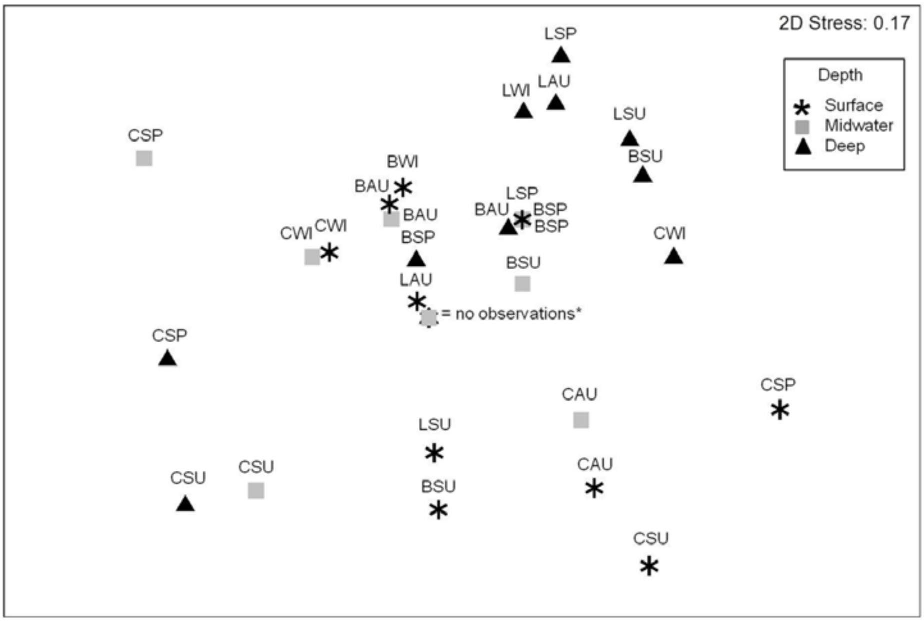

Figure 7 Non-metric multidimensional scaling ordination plot of wild fish assemblages at the Atlantic bluefin tuna (ABT) farm based on a Bray-Curtis similarity matrix of fourth-root transformed abundance data, averaged per season (C: Cage, B: Border, L: Limit; SU: summer, AU: autumn, WI: winter, SP: spring). Samples without fish observations ('no observations') were placed together; surface: BSP, LWI, LSP; midwater: BWI, BSP, LSU, LAU, LWI, LSP; deep: CAU, BWI. Stress = 0.17.

Table 5 Atlantic bluefin tuna (ABT) farm. Results of the similarity percentage analysis showing the species contribution to within-group similarity (%) by season at the three sampling stations. Full species names are listed in Appendix 1

	Summer	%	Autumn	%	Winter	%	Spring	%
Cage	*T. thynnus*	81.1	*O. melanura*	100.0	*S. salpa*	100.0	*T. thynnus*	58.5
	S. dumerili	9.6					*S. pilchardus*	35.0
Border	*S. dumerili*	52.6	*B. capriscus*	58.6	*H. perciformis*	100.0	*Trachurus* spp.	100.0
	S. sarda	30.8	*H. perciformis*	41.4				
	Trachurus spp.	16.7						
Limit	*S. sarda*	41.5	*Trachurus* spp.	100.0	*H. perciformis*	100.0	*Trachurus* spp.	94.9
	S. dumerili	35.9						
	Trachurus spp.	22.6						

Assemblages at different depths did not differ by season except in summer, when there was a different predominant species at each depth (surface: *S. dumerili*, midwater: *T. thynnus*, deep: *Sarda sarda*). At the cage, each season exhibited a different species prevalence (summer: *O. melanura*, *Scomber japonicus*, *T. thynnus*; autumn: *O. melanura*; winter: *O. melanura*, *S. salpa*; spring: *O. melanura*, *S.*

pilchardus, *S. japonicus*, *S. salpa*, *Sardinella aurita*, *T. thynnus*), which together accounted for 91 % of total fish abundance (Fig. 8).

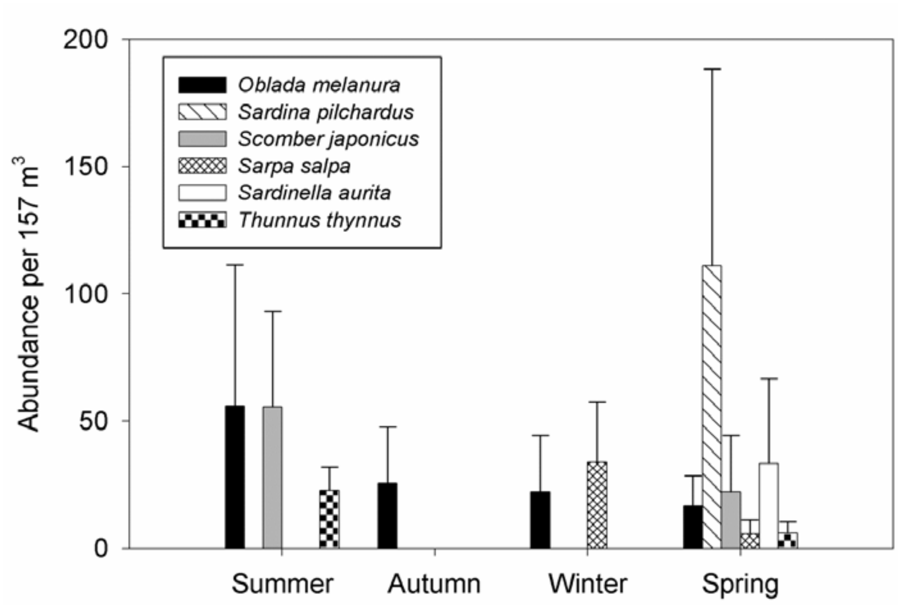

Figure 8 Total abundance (mean ± SE) of the six most abundant species at the Atlantic bluefin tuna (ABT) farm at the cage by season.

Inter-farm differences

The greater species diversity and fish abundance recorded at the SB farm was ascribable to the bottom community (27 species, see Appendix 1), which was excluded from the comparative analysis performed here (see 'Material and methods'). The results of previous statistical analyses carried out in the present study showed that attraction at both farms was restricted to the cage station, though with significant differences by season. Taking into account only the cage sampling station at both farms, we recorded a total of 5 001 individual fish (10 species) at the SB farm and 4 053 fish (16 species) at the ABT farm. The total sampled fish biomass at the cage during the study period was 6 times higher at the ABT farm (15.3 t yr^{-1}) compared to the SB farm (2.5 t yr^{-1}). Species diversity at both farms was highest in spring and summer. The seasonal variations in abundance at both farms notwithstanding, differences between the farms were recorded all year long except in spring (Fig. 9).

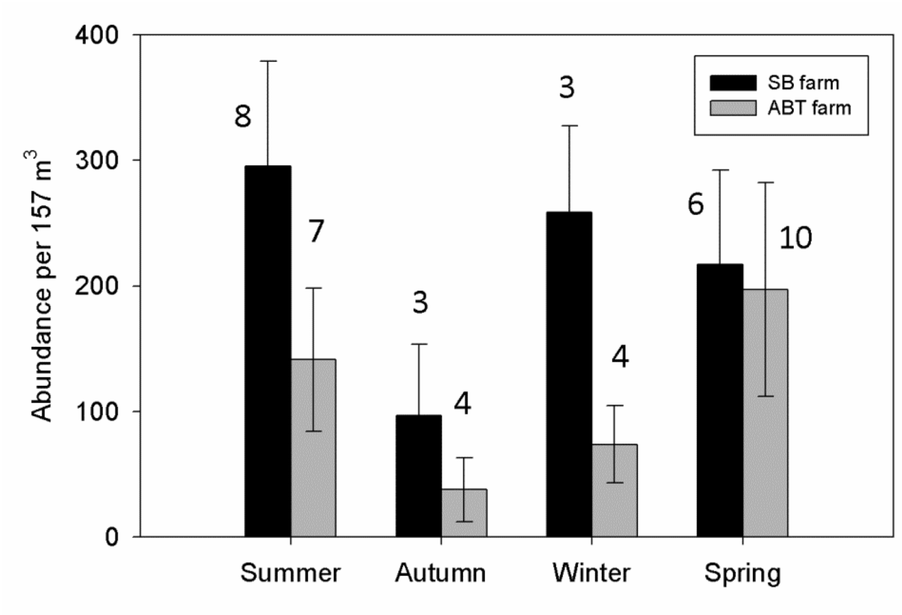

Figure 9 Total abundance (means ± SE) and number of fish species (on top of bars) at the cage by season at the Gilthead seabream (SB) and Atlantic bluefin tuna (ABT) farms. Values for the SB farm include counts from the midwater and surface strata only (see 'Material and methods').

1. 4 DISCUSSION

The study revealed a strong attraction effect for wild fish at both investigated fish farm facilities. Cage-aggregations differed from those at the border and limit stations in abundance, biomass, and fish community, revealing an abrupt decline in aggregated fish at a distance from the cage rather than a gradient. However, the spatial and temporal extent of the cage attraction effect was different at each farm type. Different species exhibited species-specific spatial and seasonal aggregation patterns, depending on their ecology.

The SB farm attracted large aggregations of wild fish throughout the year, and no seasonal variability in abundance was recorded, indicating that this aquaculture facility provides a permanent habitat for local fish populations. There were two depth-specific fish assemblages: a bottom community characterized by high diversity (35 species) and a water-column community composed mainly of 6 species. The total number of species recorded was more than twice the maximum previously reported at SB farms in the Mediterranean (Dempster et al. 2002). We attribute this difference to the absence of any analysis of the bottom community in most previous studies, with the exception of Dempster et al. (2005), in which the sandy bottom type may have been responsible for the lower diversity (14 species), fish abundance and biomass being higher in the water column than on the bottom. Contrary to the abundance pattern, our biomass results corroborated the findings of Dempster et al. (2005) because of species size differences at the different depths.

SB community composition on the bottom was represented by the typical Mediterranean reef fish species (e.g. Dufour et al. 1995; García-Charton & Pérez-Ruzafa 2001; Gordoa 2009a) at all three sampling stations and was very stable over time. Differences in abundance were observed only at the limit of the leasehold area, probably caused by lower abundance of just a few benthic species, such as blennids and gobiids. This difference suggests that bottom fish species are also attracted to the high food availability around the cages. Moreover, this shows that the SB farm did not exert a negative effect on the fish community on the rocky bottom underneath the farm. At farms that aggregate both pelagic and demersal species, unconsumed food and faeces from farmed fish will be consumed in the water column and at the bottom. It thus follows that the mitigating influence of wild fish on farm effluent dispersal should be considered, and it has been suggested that farms may be better sited over artificial reefs (Angel et al. 2002) that could increase consumption of waste particles. Similarly, mixed rocky-sandy bottoms, which sustain a more numerous and diverse fish community than sandy bottoms, may have the potential to increase waste particle consumption. Still, the impact on other rocky bottom organisms needs to be taken into account.

The fish community in the water column at the cage was dominated by a relatively small number of taxa (*Oblada melanura*, *Boops boops*, *Chromis chromis*, Mugilidae, *Trachinotus ovatus*, and *Sarpa salpa*) which, except for *C. chromis,* have been reported to dominate fish aggregations in previous SB farm studies (e.g. Dempster et al. 2002; Fernandez-Jover et al. 2008). Due to the rocky-sandy bottom, we observed high abundances of *C. chromis* all year round, which indicates that bottom type also exerts an influence on the water column community. Larger individuals of *C. chromis* frequently moved from the bottom to a depth of 10 m and fed actively on uneaten food pellets. The seasonal aggregation patterns of the most abundant species *O. melanura* (all year long) and *B. boops* (higher abundance in autumn and winter) were consistent with the results of previous studies (Valle et al. 2007; Fernandez-Jover et al. 2008). Strikingly some species such as *Diplodus sargus* and *Pomatomus saltatrix* were observed when we entered the water before starting the survey but scarcely recorded during counting. Thus, we presume that these species avoid divers and are underestimated with the scuba diving methodology. These limitations of underwater visual counts have been described in previous studies (e.g. Thresher & Gunn 1986).

The ABT farm attracted large aggregations of wild fish, though this effect exhibited strong seasonal variability. Our censuses recorded 17 species compared to the 20 species recorded at two Croatian ABT farms (Šegvić Bubić et al. 2011). Substantial differences in the species composition between the Croatian farms and the Spanish farm would appear to be caused by the presence of littoral reef-associated species at the Croatian farms as a result of ecological differences between the farm locations. In both studies the farms were situated over similar bottoms and depths. The most relevant difference between the locations was the distance from shore, 200 m for the Croatian farms and 4 500 m for the Spanish farm, with the associated difference in slope steepness and the proximity of the continental shelf. These bathymetrical features at the Croatian farms were conducive to the presence of both littoral reef-associated and oceanodromous species. At the Spanish ABT farm the seasonality of such pelagic species as *Sardina pilchardus*, *Scomber japonicus*, *Sardinella aurita, Sarda sarda, Seriola dumerili*, and *Thunnus thynnus* strongly influenced the seasonality of the cage-effect, limiting it to summer and spring. Although the Croatian farms were also subject to the seasonality effects of oceanodromous species, the permanent high abundances of *Boops boops* and *Belone belone* resulted in a year-long attraction effect at the Croatian farms (Šegvić Bubić et al. 2011). The seasonal variability of the cage effect in the present study was mainly attributable to the seasonal occurrence of *T. thynnus*. The presence of this species during summer-spring and its absence in autumn-winter can be explained by its spawning season and migratory pattern (Rooker et al. 2007). Nevertheless, the presence of *T. thynnus* around the ABT farm continued at least until December in 2011 (personal observation outside the study period). The attraction of wild *T. thynnus* to ABT farms is beginning to elicit a new scientific topic, namely, whether farms could alter *T. thynnus* migration patterns. At the ABT farm investigated in this study no escapement ever occurred and the closest ABT farm facilities are at a distance of about 550 km (Cartagena, Spain), hence the possibility that the observed individuals of *T. thynnus* were feral animals that escaped from a farm was considered very small. This study also yielded certain additional information from the ABT farm which has not been expressly analysed but which we believe worth mentioning. Specifically, only small individuals of the species *Oblada melanura,* Mugilidae, *Sarpa salpa*, *Seriola dumerili*, *Trachinotus ovatus*, and *Sardina pilchardus* were recorded; in total 65 % of cage-aggregated fish were smaller than 11 cm. Individuals of that size are not likely to feed on whole baitfish and may feed on very small particles of baitfish and/or living organisms that cover the cage ropes. It is therefore reasonable to assume that these small individuals are attracted not only to the available food but also to the farm structures in search of shelter, as has been suggested by other authors (Fernandez-Jover et al. 2009; Šegvić Bubić et al. 2011). In addition, at the beginning of July 2011 during monitoring of *T. thynnus* spawning in captivity that our group has been carrying out since 2008 (Gordoa et al. 2009b), we collected, two types of eggs inside the ABT cage that could be genetically determined as *T. thynnus* and *Trachurus mediterraneus*. Thus, ABT farms may act as new spawning grounds with unknown viability for larvae, but they at least have the potential to provide eggs as food for aggregated species.

Further, we observed the unexpected presence of the barrelfish/driftfish (*Hyperoglyphe perciformis*) at the ABT farm all year round, except in summer. This species, which typically has an Atlantic distribution, has only been observed once in the Mediterranean (Karrer 1986). In addition, we made the first sighting of a blue shark (*Prionace glauca*), circling the farm near the surface in spring.

Our results revealed differences and similarities between the two fish farm models considered here. At both farms the attraction effect was mostly constrained to the cage station. The seasonal occurrence of pelagic species restricted the attraction effect to summer and spring at the ABT farm, whereas the SB farm attracted fish all year long. Nevertheless, the cage attraction effect, compared to border and limit stations, was considerably stronger at the ABT farm. Differences in fish abundance and species composition recorded at the SB and ABT farms may be related to the type of food used and/or the type of habitat at each farm. Whole baitfish differ substantially in their nutrient composition, food size, and settling velocity from the food pellets used at SB farms (Vassallo et al. 2006). Šegvić Bubić et al. (2011) suggested that the pellets and their fine particulates may attract a more diverse fish community and can be more easily consumed than baitfish. In addition, the ABT farm is located four times as far from shore over deeper, muddy bottoms, compared to the shallower mixed rocky-sandy seafloor of the SB farm. The exposed situation of the ABT farm compared to the SB farm attracts more mobile pelagic species, from small plankton feeders (e.g. *Sardina pilchardus* and *Sardinella aurita*) to big species such as *Thunnus thynnus* whose diet is mostly based on small pelagics.

Fishing near fish farms is a common practice that has been reported in Spain (pers. obs., Fernandez-Jover et al. 2008; Arechavala-Lopez et al. 2011), Croatia (Šegvić Bubić et al. 2011), Greece (Machias et al. 2006), Norway (Maurstad et al. 2007) and even within farms in Turkey (Akyol & Ertosluk 2010). The farms studied here are located in waters within the jurisdiction of the local government, which has not implemented any fishing restrictions in their vicinity. Nonetheless, the cages are located in the centre of the farm leasehold area and their distance from the perimeter acts as a protective zone for wild fish. The potential for farms to protect wild fish highly depends on the behaviour of each particular species. The results of the current study show that the majority of aggregated fish concentrated in close proximity to the cage and suggest that they are to some extent protected. The territorial species recorded at the SB farm all year long reap the greatest protection. In contrast, pelagic and semipelagic species that conduct seasonal movements away from the farm (e.g. *Thunnus thynnus*, *Scomber japonicus, Sarda sarda*, and *Sardina pilchardus*) are only partly protected by the farm area. In addition, daily movements could substantially increase fish vulnerability. A study by Arechavala-Lopez et al. (2010) recorded rapid and repeated movements of grey mullets (*Chelon labrosus* and *Liza aurata*) to other farms and to nearby fishing areas. To date no data on the efficiency of fishing near farm boundaries exist. The presence of a species of such high commercial value as *T. thynnus* at such a short distance from the coast could trigger illegal fishing activities from fleets that do not have any quota allocation (Spanish Mediterranean artisanal fleet) or only a very limited allocation with a short fishing period (recreational fleet). During the study, large numbers of recreational fishing vessels were observed gathering at the concession boundary to presumably target this species. Further, the potential of farms to attract rare species, such as the blue shark (*Prionace glauca*) and the barrelfish/driftfish (*Hyperoglyphe perciformis*) requires the implementation of conservation actions.

Our work emphasizes the importance of applying an integrated approach to study wild fish aggregations at farms. The spatial extent of fish attraction is a key item of information for determining the effective size of an appropriate protection zone around farms. Data on the seasonal aggregation pattern provides knowledge of periods when exploited species are especially vulnerable at farms. As demonstrated here, different farm types exhibit distinct fish aggregation patterns which may require different regulatory measures. Without such measures, the proliferation of fish farming facilities along the coast might result in the decline of a number of highly targeted fish species.

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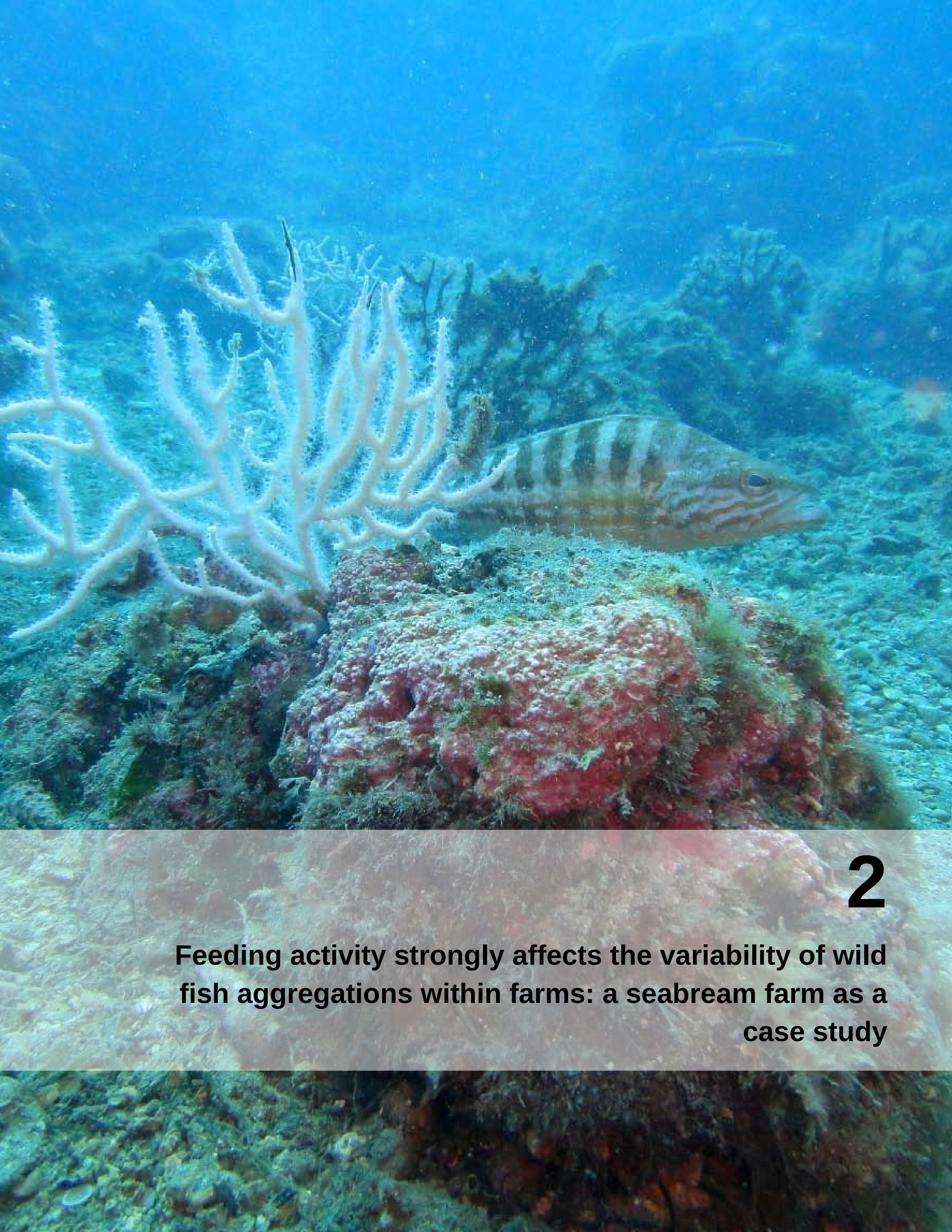

2

Feeding activity strongly affects the variability of wild fish aggregations within farms: a seabream farm as a case study

Bacher K., Gordoa A. & Sagué O. (2013) Feeding activity strongly affects the variability of wild fish aggregations within fish farms: a sea bream farm as a case study. *Aquaculture Research* DOI: 10.1111/are.12199.

ABSTRACT

Factors influencing within-farm variability of wild fish aggregations have not been systematically studied. We tested the hypothesis that fish abundance and species composition vary between feeding and non-feeding periods and different bottom substrates within a *Sparus aurata* farm. Sampling took place during feeding and non-feeding periods on six consecutive days in July 2011. Visual censuses were carried out at three different depths and at three sampling stations over rocky-sandy and sandy substrates, respectively. In all, 33 species belonging to 17 families were observed. Total fish abundance, biomass and species community significantly differed between feeding and non-feeding periods. Each depth was represented by a distinct species community and was therefore affected differently by the feeding activity. At the surface, fish abundance was significantly higher during feeding compared to non-feeding periods. The distance from the feeding vessel significantly influenced fish aggregations in the water column, indicating that planktivorous species learned to associate the boat noise with food availability through classic conditioning. At the bottom, substrate type was the dominant factor explaining aggregation variability. The current study provides new information about the dynamics of fish aggregations within farms, emphasizing the importance of considering the different sources of variability in future study designs.

2.1 INTRODUCTION

Marine fish farming is expanding worldwide creating new artificial structures and feeding grounds in the littoral system. These new habitats attract a wide variety of fish species in high numbers from its surroundings (e.g. Carss 1990; Thetmeyer et al. 2003; Boyra et al. 2004), thereby altering natural distribution patterns. The ecological and biological consequences of this aggregation effect at farms have received increasing interest in recent years and are being examined by a growing number of studies covering a wide range of topics. Fish farms influence local fish populations through effects on distribution (Uglem et al. 2009; Arechavala-Lopez et al. 2010), abundance and biomass (Dempster et al. 2002), species composition (Tuya et al. 2006), transmission of disease and parasites (e.g. Saunders 1991; Johnsen & Jensen 1994; Fernandez-Jover et al. 2010), genetic contamination (Hindar et al. 1991), physiology (Dempster et al. 2011) and feeding habits (Fernandez-Jover et al. 2007). The intensity of the farm attraction effect has been shown to be highly variable changing with season (e.g. Valle et al. 2007; Fernandez-Jover et al. 2008; Šegvić Bubić et al. 2011) and depth (Dempster et al. 2005, 2009; Bacher et al. 2012), reflecting species-specific behaviour.

To determine the effect of marine fish farm installations on wild fish populations, it is essential to obtain representative estimations of abundance and species composition of fish aggregations. Even though the farm attraction effect on wild fish has been widely studied, the magnitude of this effect will depend on factors influencing within-farm variability. At present, there is an absence of studies analyzing patterns of variability of fish aggregations within farms. This lack of knowledge represents a critical gap, as this information would represent a crucial contribution to achieve a more complete image of the adaptive feeding response of wild fish and within-farm dynamics. Variability of fish aggregations within farms has been discussed in two previous studies (Boyra et al. 2004; Dempster et al. 2005), but no further approach was developed to search for patterns of variability and associated factors. Since wild fish are mainly attracted by the farm waste food (Tuya et al. 2006), substantial variation within farms associated with the daily pattern of feeding activity can be expected. In addition, habitat heterogeneity within farms may have a marked effect on wild fish spatial distribution.

Sampling surveys in previous studies have always been performed under the effect of the feeding activity, when wild fish are more likely to be attracted by waste food falling from cages (e.g. Valle et al. 2007; Fernandez-Jover et al. 2008). This common criterion of sampling during feeding periods is valuable as it makes the results of different studies directly comparable, but leaves uncertainty about whether fish leave the farm during non-feeding periods. This approach is therefore biased towards feeding periods and may not capture the global picture of the farm attraction effect. An additional source of within-farm variability, also associated with feeding, might be caused by the distance of the feeding vessel from the sampling locations. This subject was already highlighted by Dempster et al. (2005), who suggested that the spatial distribution pattern of aggregated fish during the feeding period might be a direct response to where feeding is occurring within the farm. Hence, variability in the distance of the feeding vessel at different sampling events can add a great amount of uncertainty about the magnitude of the farm attraction effect. Furthermore, the response of wild fish to the feeding activity is likely to vary between distinct species and life history stages. Fish species vary at distinct depth strata within farms, reflecting species-specific distribution patterns (Dempster et al.

2005; Sudirman et al. 2009; Bacher et al. 2012) associated with differences in feeding ecology. Consequently, the feeding activity may affect distinct depths differently.

In natural systems the habitat type modulates fish communities, greater structural complexity supporting richer communities and higher abundances (e.g. Jenkins & Wheatley 1998; Guidetti 2000). Likewise, higher abundance of certain fish species were recorded at farms located over rocky bottoms compared to those on sandy bottoms (Dempster et al. 2009; Bacher et al. 2012). Thus, the presence of different types of bottom substrates within a farm may significantly influence the spatial variability of fish aggregations.

Analyzing the variability within fish farms will provide an in-depth view on the interaction between species-specific feeding ecologies and their adaptive response to farming activities. Moreover, the identification of significant factors will be highly valuable to weigh the potential bias of previous estimations and to optimize future sampling programs aimed at estimating fish aggregations at farms.

The aim of the current study was to investigate the within-farm variability of wild fish aggregations at a gilthead seabream (*Sparus aurata*) farm. This farm was chosen as a case study, due to the profound knowledge of its dynamics acquired by the authors in a previous study (Bacher et al. 2012). The specific objectives were: (1) to analyze whether fish aggregations differ between feeding and non-feeding periods, (2) to investigate if the distance of the feeding vessel influences the distribution pattern of aggregated fish, (3) to evaluate how different bottom substrate types affect fish aggregations within farms and (4) to test whether the effect of the feeding activity changes with depth. In addition, all known factors influencing variability at farms and their effects are summarized in a conceptual diagram combining the results of the present study and previous publications.

2.2 MATERIAL AND METHODS

Study site and farm characteristics

The investigated gilthead seabream farm is located in L'Ametlla de Mar (40°53′10″ N, 0°48′13″ E) in the littoral zone influenced by the Ebro River in the north-western Mediterranean Sea (Fig. 1). The farm is located about 1 km from the coast over a mixed rocky-sandy and sandy bottom with a bottom depth of 18-20 m. The farm started operating in 1993, and consists of 30 circular cages (each 19 m in diameter) with a net depth of 10 m, and covers a leased area of 400 000 m^2. On average, the farm contains 850 t of stocked fish biomass, and fish are fed 2 500 t yr^{-1} of dry food pellets based on fish meal and vegetable oil.

Underwater visual census

Previous counts of wild fish at fish farms in warm temperate ecosystems have been conducted using an open-circuit scuba system (e.g. Dempster et al. 2002; Boyra et al. 2004). In this study it was decided to count fish by free-diving, for two reasons. First, sampling effort is not restricted to the non-decompression limits associated with scuba diving, facilitating an intense sampling scheme during a short temporal window as required in this study. Second, observations made during previous counts in 2011 (Bacher et al. 2012) at the same farm suggested that certain fish species, such as *Diplodus sargus* and *Dentex dentex* were hardly ever recorded during fish counts taken by scuba diving. Nevertheless, these species were regularly spotted on the dive down before starting the survey counts, but immediately disappeared thereafter. Certain fish species are known to have a tendency to avoid scuba divers (e.g. Stanley & Wilson 1995; Schmidt & Gassner 2006), behaviour thought to be triggered mainly by breathing and related noises produced by the demand valve (Chapman & Atkinson 1986). Our intention was therefore to employ the free-diving technique to minimize underestimation of species that avoid the disturbance caused by scuba gear.

Sampling design

To examine the variability associated with feeding and non-feeding periods, an intense sampling during a short temporal window was chosen to minimize other sources of variation, such as oceanographic conditions or the previously described seasonal variability of this specific farm (Bacher et al. 2012). Thus, sampling was carried out on six consecutive days in July 2011 in the morning (8:00-11:30 hours) and in the afternoon (4:30-8:00 hours).

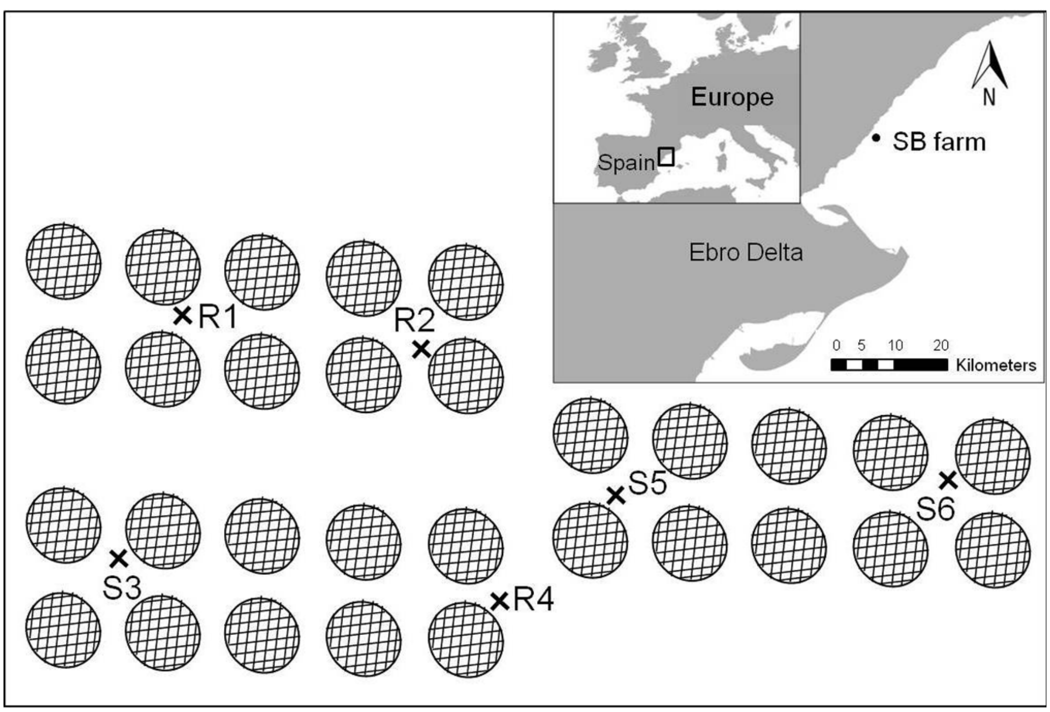

Figure 1 Map of the Gilthead seabream (SB) farm location in L'Ametlla de Mar (Spain) and the six sampling stations. R: rocky-sandy substrate, S: sandy substrate.

To analyze the influence of bottom substrate type, six stations were selected within the facility, namely, three stations over a rocky-sandy substrate and three stations over a sandy substrate (Fig. 1). At each station, underwater visual censuses (UVCs) were performed in three distinct depth strata: surface (0-2 m), midwater (9-11 m) and bottom (18-20 m). Hence, at each station two counts per day and depth were performed over six consecutive days, yielding a total of 216 fish counts. Fish counts were conducted by two divers. The first diver, professionally qualified in free-diving, carried out the UVCs in the midwater and bottom strata, while the second diver stayed at the surface, recording the fish observed by the first diver and surveying the surface. Fish counts lasted a total of 5 min at each depth. To complete the 5-min counts, the free-diver made three dives to the bottom and two dives to the midwater at each station.

The UVC counts were carried out using the method developed by Dempster et al. (2005), which is robust for comparing counts at different depth levels and under differing conditions of visibility. The method consists of stationary timed counts during which the diver rotates through 360°. To standardize the counts, fish are counted only from 1 m above to 1 m below eye-level out to a radius of 5 m. Bottom counts spanned the zone from the substrate to 2 m above the bottom. The maximum number of individual fish of each species observed at any one time was recorded, to reduce the likelihood of counting the same fish twice. For schools of up to 20 fish, individual fish were counted; for larger shoals estimates were obtained by subdividing the shoals into imaginary subgroups of equal size, counting the individuals in one of the subgroups and multiplying that count by the number of subgroups. Individual length was recorded, and biomass was calculated based on published length-weight relationships for each species (www.fishbase.org). Mugilidae species could not be identified visually to species level and were therefore recorded as Mugilidae. Similarly, *Trachurus mediterraneus* and *Trachurus trachurus* were recorded as *Trachurus* spp. The species *Oblada melanura* and *D. sargus* were represented by two distinct size classes (*O. melanura*: 2-3 cm and 20-30 cm; *D. sargus*: 2-4 cm and 22-35 cm), and were therefore separated into small size class (SS) and large size class (LS) prior to analysis. This separation permits to distinguish between individuals of a few centimetres that are believed to use fish farm cages as a shelter (Fernandez-Jover et al. 2009) and larger individuals that are attracted due to the high food availability.

Influence of the feeding vessel

To determine whether fish systematically change their location in response to where feeding is occurring, the distance of the feeding vessel in relation to the sampling stations was recorded. It was not possible to integrate the influence of the feeding vessel as a predefined factor, because feeding at cages did not follow a clear schedule and/or order. Particularly for this specific study with 6 sampling locations, the timing of fish counts according to the vessel's distance to the cages was unfeasible. This factor was therefore subsequently included and analyzed independently for the valuable information it may provide. Three distances were defined for purposes of data analysis: nearby (at the cage where the census was being taken or at the cage adjacent to it), middle-distance (in the same group of cages where the census was being carried out), and distant (in another group of cages).

Statistical analysis

The assumptions of normality and homogeneity of variance can often be difficult to fulfil with biological data. A good alternative is the analysis of variance based on permutations (PERMANOVA), as it allows multivariate data to be analyzed in the context of complex experimental designs and provides a robust approach to deal with skewed data and many zero counts (Anderson 2001). Therefore, all univariate and multivariate statistical analyses were carried out using the PRIMER V6.1.13 computer program (Clarke & Gorley 2006) with the PERMANOVA+ V1.0.3 add-on package (Anderson et al. 2008). Statistical significance was tested using 9 999 permutations of residuals under a reduced model (Freedman & Lane 1983) and Type III (partial) sums of squares (SS, Anderson et al. 2008).

Univariate analysis

The univariate analysis considered three fixed factors: feeding vs. non-feeding (FE), substrate type (SU), depth (DE) and day (DA) as a random factor to test for differences in total fish abundance and biomass. To test the feeding effect on the most abundant fish species in the water column, univariate permutational one-way analysis of variance were carried out for the factors: feeding vs. non-feeding (FE) and distance from the feeding vessel (DI). The species considered in the analysis were as follows: *D. sargus* (LS), Mugilidae, *O. melanura* (LS), *S. salpa* and *Pomatomus saltatrix*. The later species was not included in the analysis on the distance from the feeding vessel, as *P. saltatrix* was almost absent during feeding periods. The number of samplings at different distances from the feeding vessel were unbalanced (nearby: 9; middle-distant: 10; distant: 17), due to the reasons already explained. However, an unbalanced design in a one-way case can be overcome by applying the most conservative Type III (partial) sums of squares (Anderson et al. 2008). The similarity matrix was computed on square root-transformed data using the Euclidean distance, and post-hoc pairwise comparisons were used to investigate significant results.

Multivariate analysis

Permutational multivariate analysis of variance was used to test the differences in wild fish aggregations for the same four factors as in the univariate analysis (PERMANOVA, Anderson 2001; Anderson et al. 2008). Prior to analysis the data were fourth-root transformed to downweight the influence of more abundant species while preserving information on relative abundance (Clarke & Green 1988). Significant terms were further examined by applying appropriate post-hoc pairwise comparisons. The Similarity Percentage Analysis (SIMPER) routine was employed to examine species contributions to within-group similarity for distinct depth strata at rocky-sandy and sandy stations.

Free-diving vs. scuba diving

The abundance and species composition data obtained by free-diving in this study was examined together with that recorded by scuba diving during a previous study (Bacher et al. 2012) with the purpose of identifying potential bias or differences between both sampling techniques. Consequently, only equivalent survey data were considered, fixing: season, number of sampling days, census duration, substrate type, and feeding periods. As census duration at each depth differed between the studies (7 vs. 5 min.), the counts were standardized to number of fish recorded per minute of sampling.

2.3 RESULTS

Composition of wild fish species

Overall, 33 different species belonging to 17 different families were observed (Appendix 2). The most common families were Sparidae (7 species) followed by Labridae (4 species) and Gobiidae (4 species). Counts included the two ray species *Myliobatis aquila* and *Pteromylaeus bovinus*. The most abundant species were *D. sargus* (LS)*,* followed by *Chromis chromis,* Mugilidae*, O. melanura* (LS)*, O. melanura* (SS) *and Sarpa salpa*, which together made up 86.4 % of total abundance. For all stations combined, the highest species diversity, 30 species, was recorded at the bottom compared with 8 species in the midwater and 7 species in the surface. Substantially more species (30) were observed at rocky-sandy stations than at sandy stations (10), whereas differences between feeding (32 species) and non-feeding (30 species) periods were small.

Feeding vs. non-feeding periods

Total fish abundance, biomass and species community significantly differed between feeding and non-feeding periods (Table 1). Even though the feeding interaction with depth was not significant for total abundance and biomass, post hoc results revealed that fish abundance significantly differs at the surface between feeding and non-feeding periods (Fig. 2a, Table 1). The feeding effect at the surface was also observed at the species community level (Table 1).

Table 1 Summary of results of permutational univariate and multivariate analysis of variance (PERMANOVA) comparing abundance, biomass and species community for the factors feeding vs. non-feeding (FE), substrate (SU), depth (DE) and day (DA) and post-hoc tests for significant factors and interactions. R: rocky-sandy substrate, S: sandy substrate, B: bottom, M: midwater, S: surface, F: feeding period, NF: non-feeding period. All multiple interactions with the random factor (DA) were not significant and are not shown. Significant at *p < 0.05, **p < 0.01, ***p < 0.001, ns = non-significant

Source	df	Total abundance		Total biomass		Species community	
		MS	*F*	MS	*F*	MS	*F*
FE	1	119	12.71*	26800	6.66*	4329	4.74*
DE	2	182	3.66	101310	1.77	51718	12.81***
SU	1	2368	74.13**	610370	10.29*	46114	19.53**
DA	5	74	2.14	93311	2.62*	3492	2.73***
FE x DE	2	43	1.25	16345	0.46	4530	3.72*
FE x SU	1	3	0.14	8136	0.96	1542	2.82
FE x DA	5	9	0.27	4026	0.11	913	0.71
DE x SU	2	396	19.01***	13782	0.35	27583	21.20***
DE x DA	10	50	1.43	57189	1.61	4037	3.15***
SU x DA	5	32	0.92	59323	1.67	2361	1.85*
FE x DE x SU	2	4	0.14	31499	1.00	1212	0.87
Residuals	144	35		35609		1280	

Post hoc	Total abundance	Total biomass	Species community
FE	F ≠ NF	F ≠ NF	F ≠ NF
FE x DE	B: F = NF	ns	B: F = NF
	M: F = NF		M: F = NF
	S: F ≠ NF		S: F ≠ NF
DE	ns	ns	B ≠ M ≠ S
SU	RS ≠ S	RS ≠ S	RS ≠ S
DE x SU	B: RS ≠ S	ns	B: RS ≠ S
	M: RS ≠ S		M: RS = S
	S: RS ≠ S		S: RS = S

These differences in species composition and abundance at the surface were primarily caused by the presence of *Sarpa salpa* and *O. melanura* (LS) during feeding periods, whereas at non-feeding periods aggregations were mainly composed of *O. melanura* (SS) and Mugilidae (Table 2). Except for four infrequent species, all species were present at the farm during both feeding and non-feeding periods (Appendix 2).

Nevertheless, some species showed a significant preference for certain periods of day. For instance, the frequency of *S. salpa* (Feeding: 96.1%, Non-feeding: 3.9%) and *O. melanura* (LS) (Feeding: 77.3%, Non-feeding: 22.7%) was clearly shifted to feeding periods. In contrast, *P. saltatrix* was much more abundant during non-feeding periods (Feeding: 5.5%, Non-feeding: 94.5%). The preferences of these three species were statistically confirmed, in contrast, the abundance of Mugilidae and *D. sargus* (LS) did not significantly differ between feeding and non-feeding periods (Table 3).

The random factor (day) does not account for daily differences in the feeding effect. Daily variability was only observed for species community at certain depths and substrates.

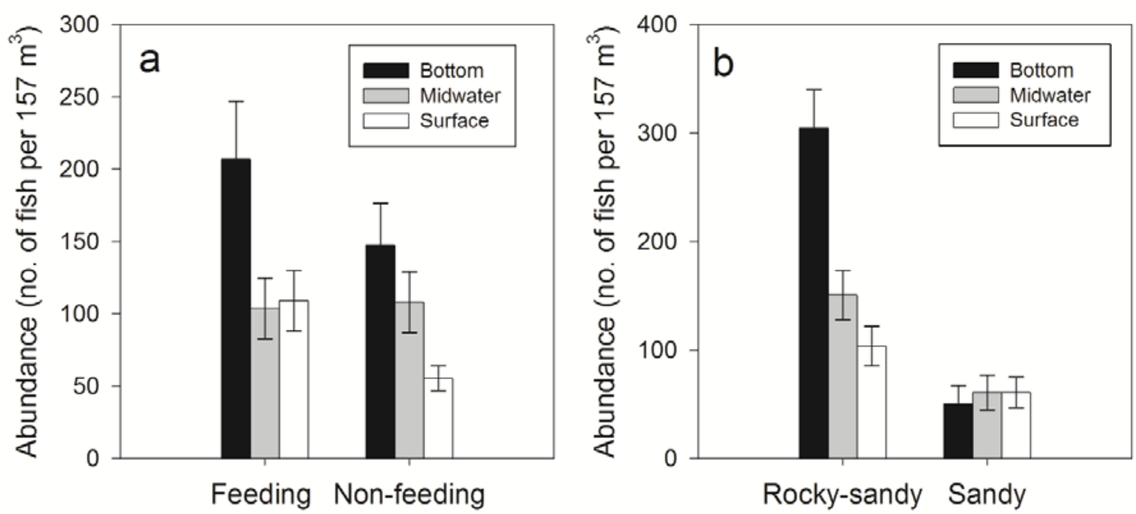

Figure 2 Total fish abundance at feeding and non-feeding periods (a) and at the two substrate types (b) by depth. Bars are mean ± SE of 36 underwater visual counts in a volume of 157 m^3.

Table 2 Accumulated species contributions (%) to total fish abundance at the surface over rocky-sandy and sandy substrates at feeding and non-feeding periods. Full species names are listed in Appendix 2.

Feeding		Non-feeding	
Species	%	Species	%
S. salpa	31.6	*O. melanura* (SS)	42.4
O. melanura (LS)	53.3	Mugilidae	74.0
O. melanura (SS)	74.3	*P. saltatrix*	84.6
D. sargus (LS)	88.4	*D. sargus* (SS)	93.0
D. sargus (SS)	97.8	*D. sargus* (LS)	100.0
B. belone	99.1		
Mugilidae	100.0		

Influence of the feeding vessel

The feeding vessel had a clear depth-dependent effect on wild fish aggregations. Fish abundance at the bottom was not influenced by the location of the feeding activity (Fig. 3). In contrast, fish abundance in the water column was significantly higher when the feeding vessel was nearby the cage where the census was being taken compared to when the feeding vessel was moderately distant or far off. Responsible for this effect were the most abundant species of the water column (*D. sargus* (LS), Mugilidae, *O. melanura* (LS) and *S. salpa*) whose total abundance significantly decreased with increasing distance from the feeding vessel (Table 3). The same gradual pattern was observed for each species separately (Fig. 4), but was not statistically significant (Table 3). Yet, post hoc analyses for *D. sargus* (LS) (p = 0.023) and Mugilidae (p = 0.048) revealed significant differences in abundance between nearby and far distances from the feeding vessel. In contrast, the small size classes of *O. melanura* and *D. sargus* were permanently in residence at the cages and insensitive to feeding vessel proximity (Fig. 4).

Table 3 Summary of results of permutational univariate analysis of variance on the abundance of the most abundant fish species in the water column for the factors: feeding vs. non-feeding (FE) and distance from the feeding vessel (DI). Significant at *p < 0.05, **p < 0.01

Source	df	*P. saltatrix*		*O. melanura*		*S. salpa*		*D. sargus*		Mugilidae	
		MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
Fe	1	19	5.17*	40	4.27*	53	6.44*	1	0.04	29	2.24
Residuals	142	4		9		8		27		13	
Source	df	Total abundance		*O. melanura*		*S. salpa*		*D. sargus*		Mugilidae	
		MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
DI	2	406	8.37**	49	0.20	56	2.11	114	3.07	54	3.17
Residuals	33	48		29		27		37		17	

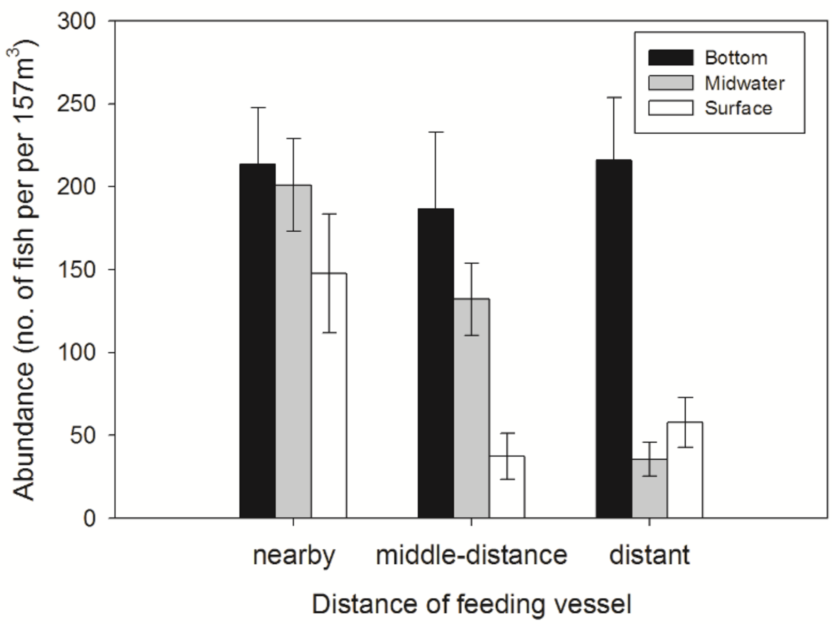

Figure 3 Total abundance (mean ± SE) of wild fish in relation to the distance of the feeding vessel from the sampling location. The data in this figure include fish counts from both substrate types. Number of samples for each distance: nearby: 9, middle-distance: 10, distant: 17.

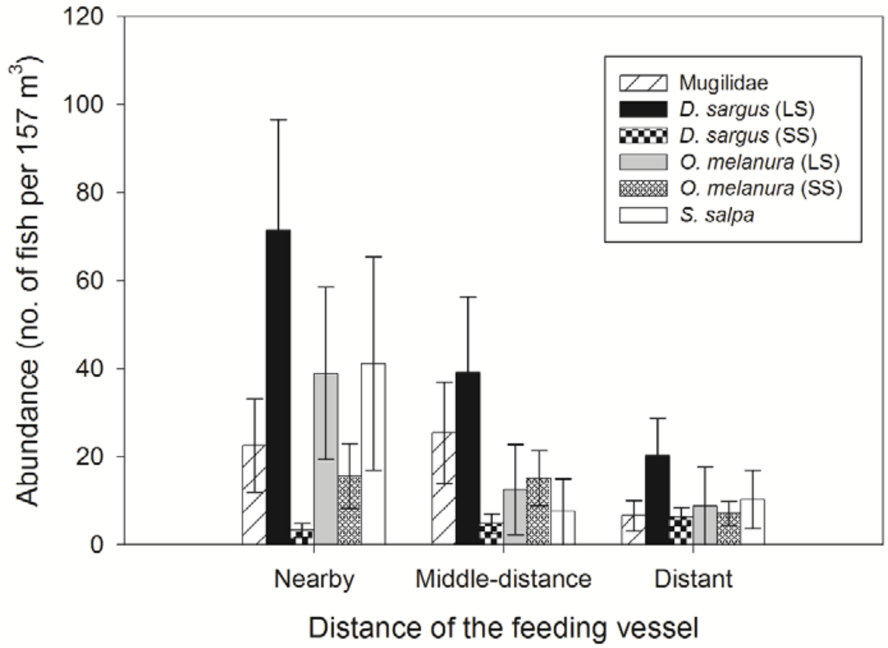

Figure 4 Abundance (mean ± SE) of the most frequent species in the water column in relation to feeding vessel distance. Full species names are listed in Appendix 2.

Bottom substrate and depth

Both fish abundance and biomass were significantly higher at stations over rocky-sandy substrates than at stations over sandy substrates (Table 1). Fish abundance was significantly higher at rocky-sandy substrate for each depth (Fig. 2b, Table 1), whereas biomass did not change with depth. At rocky-sandy substrates, fish abundance was significantly higher at the bottom than in the midwater and surface strata; in contrast, at sandy stations, abundance did not differ by depth (Fig. 2b). The species composition of the fish community significantly differed between different depths and substrate types (Table 1). Yet, the difference between substrate types was restricted to the bottom community. The rocky-sandy bottom was characterized by a diverse rocky-reef fish community dominated by *C. chromis*, *Coris julis* and *Serranus cabrilla*, whereas the sandy bottom was mainly populated by Mugilidae, Myliobatidae, *D. sargus* (LS) and *P. saltatrix* (Table 4). In contrast, species compositions at the midwater and surface did not differ between substrates (Table 1). The midwater was characterized by *D. sargus* (LS) and Mugilidae and the surface was represented by *O. melanura* (SS), *D. sargus* (SS), Mugilidae, and *D. sargus* (LS) (Table 4).

Table 4 Results of the similarity percentage (SIMPER) analysis showing the species contribution (%) to within-group similarity in different depth strata at rocky-sandy and sandy stations. Full species names are listed in Appendix 2.

	Rocky-sandy	%	Sandy	%
Surface	*O. melanura* (SS)	53.4	*O. melanura* (SS)	40.2
	D. sargus (SS)	82.7	*D. sargus* (SS)	70.6
	Mugilidae	90.6	Mugilidae	87.5
	S. salpa	94.1	*D. sargus* (LS)	99.3
	D. sargus (LS)	97.2		
Midwater	*D. sargus* (LS)	45.9	*D. sargus* (LS)	60.6
	Mugilidae	90.8	Mugilidae	96.1
	P. saltatrix	97.1		
Bottom	*C. chromis*	25.9	Mugilidae	59.5
	C. julis	44.0	Myliobatidae	75.6
	S. cabrilla	55.7	*D. sargus* (LS)	89.6
	P. pilicornis	67.1	*P. saltatrix*	95.8
	G. xanthocephalus	74.9		
	P. rouxi	78.6		
	D. sargus (LS)	82.0		
	Mugilidae	85.4		
	C. conger	88.7		
	G. cruentatus	91.5		

The results on mean abundances and species contributions obtained in the current study were similar to the findings obtained by the scuba diving technique (Table 5). Yet, more species were observed using free-diving (scuba diving: 19 species; free-diving: 24 species) and a remarkably higher abundance of *D. dentex and D. sargus* (LS) was recorded. These two species were hardly ever seen during surveys taken by scuba diving (Bacher et al. 2012).

Table 5 Average abundance (mean ± SE) and species' contributions (%) to total abundance recorded by free-diving (present study) and scuba diving visual census techniques (Bacher et al. 2012). The data shown here were collected over a rocky-sandy substrate at three different depths (surface, midwater, bottom) during feeding periods (see 'Material and methods'). Full species names are listed in Appendix 2.

Free-diving			Scuba diving		
Species	Abundance	%	Species	Abundance	%
C. chromis	21.1±12.1	46.9	*C. chromis*	9.4±4.9	28.4
Mugilidae	6.3±4.4	60.8	*O. melanura* (LS)	8.6±4.6	54.4
D. sargus (LS)	5.9±4.4	73.9	Mugilidae	5.6±3.7	71.3
O. melanura	4.4±4.4	83.8	*T. ovatus*	3.9±1.8	83.0
S. salpa	2.2±2.2	88.7	*S. salpa*	3.2±3.2	92.6

2.4 DISCUSSION

This study revealed complex patterns of variability within the investigated farm. The feeding activity exerted a strong effect on the abundance and distribution of species in the water column. The substrate type clearly influenced the species diversity, abundance and biomass of aggregated wild fish at the bottom between different sites within the farm.

In this study, most species were recorded in similar numbers throughout the day, suggesting that they did not leave the farm after feeding, corroborating the findings of Sudirman et al. (2009). Two exceptions were *O. melanura* (LS) and *S. salpa*; these two species dominated the surface during feeding periods and seemed to leave the farm on a daily basis in the afternoon after feeding. Conversely, *D. sargus* (LS) and Mugilidae, equally strongly affected by the proximity of the feeding vessel, were found to be very abundant at the farm throughout the day. The difference in daily aggregation patterns of these species is most likely a result of their different feeding ecologies. As a planktivorous species, *O. melanura* may benefit from the waste food while it is suspended in the surface layer, but may leave the farm after food is dispersed in favour of a more suitable habitat in search of other food sources. A recent tagging study of saithe (*Pollachius virens*), also a pelagic feeder, revealed a diurnal residence pattern around Norwegian salmon farms (Uglem et al. 2009). The response to feeding activity of an herbivorous species, such as *S. salpa* whose natural diet mainly consists of benthic algae and seagrass (Antolic et al. 1994) represents an adaptive and opportunistic feeding change. Individuals of this species have repeatedly been observed feeding on waste food next to the cages and their estimated body length of 50 cm is among the largest ever recorded (www.fishbase.org). This increase in body condition due to the fat and protein content of farm food has been observed in other farm-aggregated species (Fernandez-Jover et al. 2007; Dempster et al. 2011). The precise physiological consequences of this shift in the diet remain unclear; however, there is evidence for some species at Norwegian farms that the food supply of farms overrides other potentially negative effects (Dempster et al. 2011).

The demersal species Mugilidae and *D. sargus* (LS) exhibited a wider vertical distribution being opportunistic farm feeders often observed feeding on lost food pellets or grazing at nets along the cages. Our data suggest that these species spend longer residence times at the farm. In contrast, a recent tagging study investigating movements of the same Mugilidae species at Spanish fish farms (Arechavala-Lopez et al. 2010) revealed frequent movements among farms and to adjacent fishing areas. As visual census is limited to daylight hours, movements at night cannot be discarded. Regular movements away from the farm, at night or earlier in the afternoon, as was observed in the present study, may substantially increase vulnerability to fishing of aggregated wild fish (Dempster et al. 2002).

The location of the feeding vessel exerted a strong influence on the spatial distribution of fish in the water column, as fish were observed to actively follow the vessel around the farm. An experiment on learning behaviour in relation to feeding in fish (Fujiya et al. 1980) demonstrated that individuals of red sea bream (*Pagrus major*) could be conditioned to a sound source within a minimum of two days to a maximum of two weeks. The results of this study indicate that the planktivorous species *D. sargus* (LS), Mugilidae, *O. melanura* (LS) and *S. salpa* have learnt to associate the noise of the feeding vessel with food availability through classic conditioning. The year-round presence of *D. sargus* (LS), Mugilidae and *O. melanura* (LS) at the farm (Bacher et al. 2012) suggests that this effect of the feeding activity may extend throughout the year. Moreover, it is very probable that other planktivorous species that have been shown to dominate wild fish aggregations at farms in the Mediterranean (e.g. Dempster et al. 2002; Valle et al. 2007), Canary Islands (Boyra et al. 2004; Tuya et al. 2005), Norway (Dempster et al. 2009) and Indonesia (Sudirman et al. 2009) have acquired a similar adaptive behaviour.

In contrast, the small size classes of *D. sargus* and *O. melanura* did not follow the feeding vessel, but were permanently observed right next to the cage structures at the surface or concentrated on the bottom. This result, corroborates previous findings by Dempster et al. (2005) strengthening the hypothesis that close association with floating structures may be a natural behaviour of juveniles in search of shelter (Fernandez-Jover et al. 2009).

Bluefish (*P. saltatrix*) exhibited an aggregation pattern distinct from those of all the other species, as this species' presence was clearly shifted to the afternoon/evening, with only isolated sightings during the feeding period in the morning. These results revealed that bluefish enter the farm in shoals of hundreds of individuals in the afternoon, possibly to avoid vessels or human activities during feeding periods in the morning. This predator species does not feed on waste food, but is rather attracted to wild fish aggregations and is known to break into sea cages in the Mediterranean to prey on cultured fish (Sanchez-Jerez et al. 2008).

The bottom substrate type significantly affected the spatial variability of species diversity, abundance and biomass at different sites within the farm. This effect is explained by the fact that the more complex habitat structure of rocky bottoms results in greater species diversity and abundance (García-Charton & Pérez-Ruzafa 1998). As expected, differences between rocky-sandy and sandy habitat was most pronounced at the bottom. In contrast, the species community in the water column was mainly composed of five species: *O. melanura*, *D. sargus*, Mugilidae, *S. salpa* and *P. saltatrix* at every station and seemed to be independent of the bottom substrate type. Nevertheless, fish abundance at the water column was higher at rocky-sandy stations compared to sandy stations, indicating that substrate type also exerted an effect on the entire water column.

According to the results of this study, most species at the investigated farm did not seem to avoid scuba divers and were recorded in similar numbers by both sampling methods. Two exceptions were *D. sargus* (LS) and *D. dentex*, which were underestimated by scuba diving, indicating that these species associated the noise produced by scuba divers with a potential danger. The present findings revealed that far from being an infrequent visitor (Bacher et al. 2012), *D. sargus* is actually the most abundant species at the farm. The noise of the open-circuit scuba system potentially influences fish behaviour over a much larger distance compared to the silent free-diving technique. Still, both underwater census techniques are subject to limitations. When using scuba diving, the number of dives and diving time are restricted by non-decompression diving limits. Although free-diving is more depth-restricted, this technique permits a higher sampling effort, more dives per day (e.g. more stations) and consequently more factors to be examined under the most similar environmental conditions, thereby reducing undesirable natural variability.

In conclusion, the feeding activity leads to three sources of variability which future studies should take into account. First, it may not be possible to extrapolate the farm attraction effect to non-feeding periods, as fish abundance, biomass and species composition significantly differed between feeding and non-feeding periods. Second, the feeding vessel strongly influences the distribution of wild fish aggregations in the water column during feeding periods and may mask other factors under analysis. Although it is not possible to entirely control for this factor, fish counts taken close and further away from feeding events should be balanced. Third, predator species such as *P. saltatrix* may avoid farming activity and will thus be absent or underestimated in fish counts during feeding periods. Moreover, habitat heterogeneity within farms directly affects fish estimations and should be accounted for in future study designs.

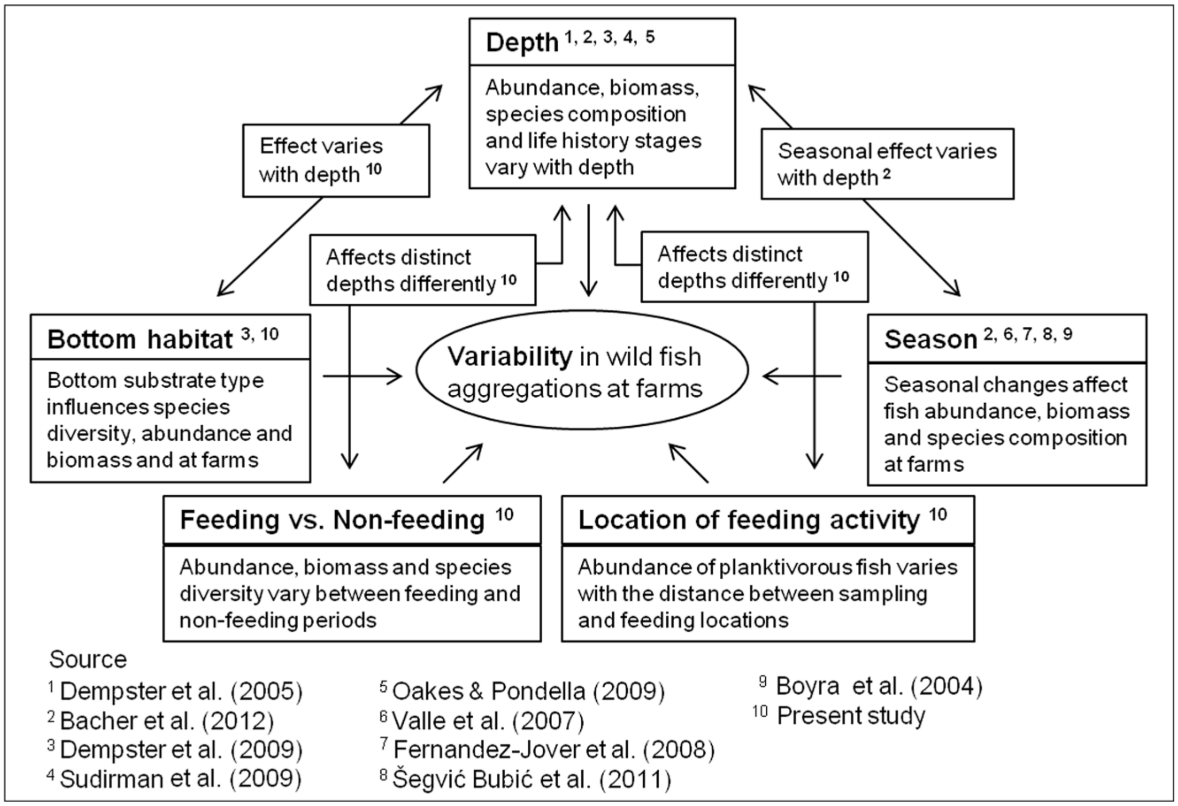

Figure 5 Conceptual diagram reviewing the factors influencing the variability of wild fish aggregations at marine fish farms.

This study provides new information about the dynamics of fish aggregations, revealing a system of high complexity within farms that has previously not been addressed. The effects and interactions of different sources of variability influencing wild fish aggregations are summarized in a conceptual diagram (Fig. 5), combining the results of the present study and previous publications. This synopsis clearly shows that several factors have received little or no attention to date. Although it is unfeasible to control for all the different factors, future studies should be aware of the different sources of variability. The conceptual diagram can be a useful tool for the design and interpretation of future work in this field of research.

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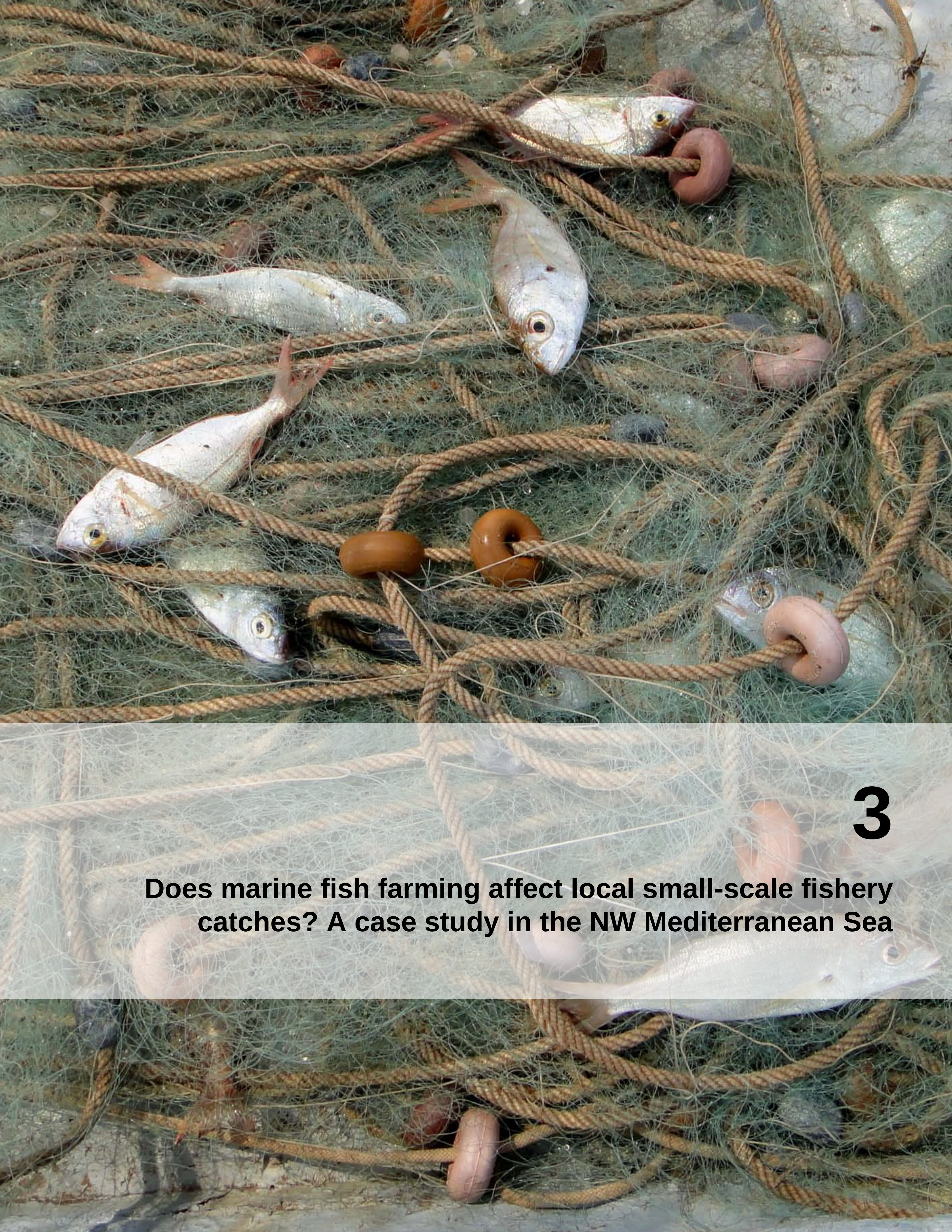

3

Does marine fish farming affect local small-scale fishery catches? A case study in the NW Mediterranean Sea

Under revision at the Journal *Aquaculture Research:* Bacher K., Gordoa A. Does marine fish farming affect local small-scale fishery catches? A case study in the NW Mediterranean Sea

ABSTRACT

Fish farms have been shown to aggregate large numbers of wild fish in their surroundings. Although little is known about how this affects the local fishery, two hypotheses have been put forward; a trapping and a protecting effect on wild fish. This study provides the first monitoring of commercial and recreational fishing activity at a fish farm. We assessed the effect on the small-scale fishery analyzing the differences between fishing in farm vicinity and away from the farm (in terms of yield, income, and catch composition). Moreover, we estimated the biomass removal from fishing activities by farm employees inside the farm. The study was conducted from January 2011 to June 2012 at a Gilthead seabream farm in the NW Mediterranean. The findings revealed a relevant amount of commercial and recreational fishing effort in farm vicinity. Yet, the results showed no benefit or difference of fishing in close proximity to the farm compared to areas away from the farm. Thus, we conclude that the farm-aggregated fish are protected from the commercial fleet by the farm leasehold area, but remain vulnerable to hidden fishing practices inside the farm, where farm employees harvest more than 4 t of wild fish annually.

3.1 INTRODUCTION

The marine fish farming sector is becoming increasingly important to compensate for the stagnating seafood supply from capture fisheries worldwide. Understanding how fish farming and nearby fisheries interact is important in terms of policy support (Natale et al. 2013), especially now that the reform of European Common Fishery Policy is assigning greater relevance to the growth of marine aquaculture (EU Commission 2013). In particular the small-scale fisheries, which have been the main users of marine living resources on the Mediterranean coast for many centuries (Maynou et al. 2011), have to compete for space and resources with other activities in the coastal zone (Griffiths et al. 2007; Guyader 2007; Akyol & Ertosluk 2010). In addition to competition over physical occupation of ocean space, interactions with marine fish farming may include effects through impacts on the chemical or ecological environment (e.g. Naylor et al. 2000; Hoagland et al. 2003; Mikkelsen 2006), as well as socio-economic interactions (Valderrama & Anderson 2008; Natale et al. 2013). Interactions may occur at many different levels and some are antagonistic, but there are also cases of cooperation between marine aquaculture and the small-scale fishery (Jordana 1999).

Studies based on underwater visual surveys have provided ample evidence that fish farms attract large numbers of wild fish in their surroundings due to the constant additional food supply (e.g. Dempster et al. 2002; Boyra et al. 2004; Bacher et al. 2012). These findings have been corroborated by reports of large catches of wild fish right beneath fish farm cages in Turkey (Akyol & Ertosluk 2010) and Norway (Bagdonas et al. 2012). Many of these farm-associated species are of commercial interest to coastal fisheries (Fernandez-Jover et al. 2008; Šegvić Bubić et al. 2011).

The aggregation of wild fish around sea-cage farms has led to opposite hypotheses on its potential effect. Some studies suggested that farms may act as small marine reserves, since wild fish cannot be caught while aggregated at the farm, due to fishing restrictions within farm leasehold areas (e.g. Dempster et al. 2002; 2006). Moreover, based on direct and indirect observations of fish movements in and out of the farm leasehold area (Uglem et al. 2009; Arechavala-Lopez et al. 2010; 2011), farms are considered as beneficial for local fisheries by acting as “population sources” (Arechavala-Lopez et al. 2010; Dempster et al. 2011). This hypothesis is supported by a study in Greece, which claimed that the presence of fish farms in two oligotrophic areas significantly increased fisheries landings (Machias et al. 2006). Moreover, Arechavala-Lopez et al. (2011) demonstrated that the local small-scale fishery captured Bogue (*Boops boops*), which had previously been aggregated at Spanish fish farms, implying displacement out of leasehold areas. Such behavior may also be expected from other farm-associated species, particularly those that are only present at the farm during feeding periods (Bacher et al. 2013), or species that conduct seasonal movements (Valle et al. 2007; Šegvić Bubić et al. 2011).

In recent years, an increase in commercial and recreational fishing activity at fish farms has been observed in various countries, such as Spain (Fernandez-Jover et al. 2008; Arechavala-Lopez et al. 2011), Croatia (Šegvić Bubić et al. 2011), Greece (Machias et al. 2006) and Norway (Maurstad et al. 2007). Consequently, it has been argued that instead of small protection zones, fish farms may act as “ecological traps”, continuously attracting fish from the surrounding waters and diminishing their local populations (Fernandez-Jover et al., 2008; Arechavala-Lopez et al., 2010). Nevertheless, to date neither fleet aggregation nor its potential benefit has ever been studied, and arguments speaking for or against a farm-effect on fishing have yet to be proven.

This case study aims at better understanding the interaction between fish farms, farm-aggregated wild fish and the small-scale fishery. The study was carried out at a Gilthead seabream (*Sparus aurata*) farm in the NE Mediterranean. The specific objectives were to 1) investigate the fishing activity in farm vicinity, 2) asses differences between fishing in farm vicinity and away from the farm (in terms of yield, income, and catch composition) and 3) to estimate the biomass removal from fishing activities inside the farm leasehold area.

3.2 MATERIAL AND METHODS

Study site

This study was conducted in L'Ametlla de Mar close to the Ebro River Delta in the north-western Mediterranean Sea (Fig. 1). The bathymetry of this area is characterized by a smooth slope and the habitat is dominated by sandy areas interspersed with rocky-sandy patches.

The Gilthead seabream (SB) farm is located about 1 km from the coastline over a rocky-sandy bottom with a bottom depth of 20 m. The farm started operating in 1993, consists of 30 circular cages (each 19 m in diameter) with a net depth of 10 m, and covers a leased area of 400 000 m^2. On average, the farm contains 850 t of stocked fish biomass and produces 800 t of *S. aurata* annually.

L'Ametlla de Mar is an important fishing port and has been linked to the fishing industry since its origin in 1775. During the study period in 2011, the small-scale fishing fleet comprised 24 vessels and used three different fishing gears: nets (trammel nets and gillnets), long-lines and octopus traps. The small-scale fishery is characterized as operating in small boats, exploiting areas near the coast, using a large number of gears and techniques (which change seasonally), typically manned by a single or a pair of fishermen and targeting a high diversity of species (e.g. Colloca et al. 2004; Tzanatos et al. 2005).

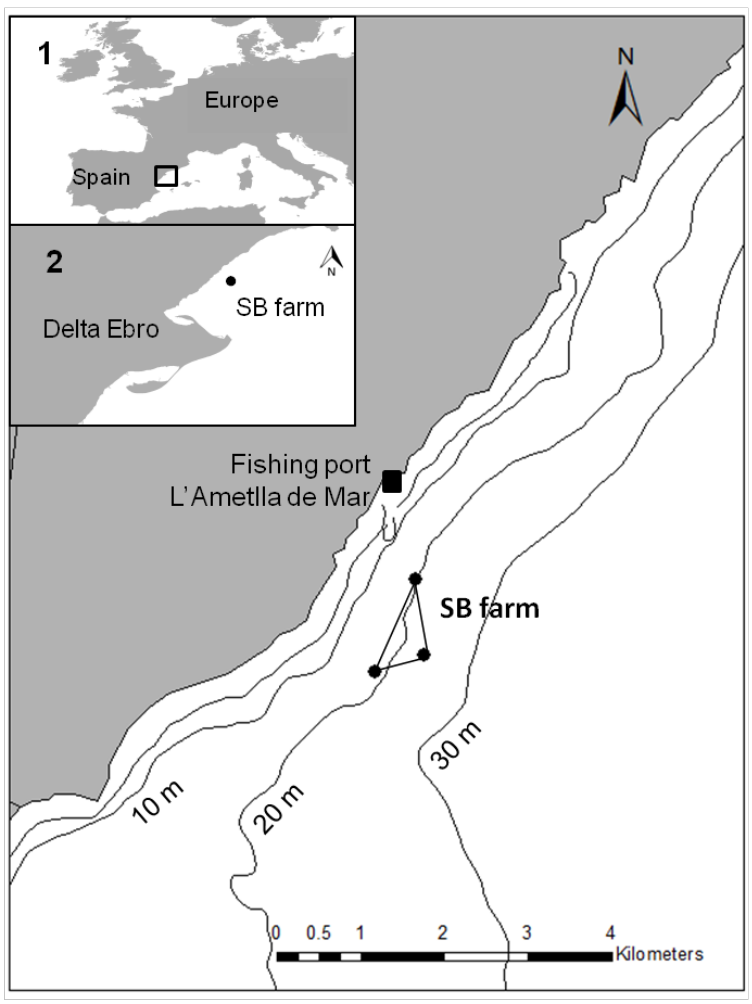

Figure 1 Study location. Fishing port in L'Ametlla de Mar and the leasehold area of the Gilthead seabream (SB) farm off the north-eastern coast of Spain. The map also indicates the bathymetry data of the area.

Data sources

We obtained the data of the daily catch per vessel of the small-scale fleet in L'Ametlla de Mar for the period from 1. January 2011 to 30. June 2012. Fishermen sell their catch through the fish auction of the Fishermen's Association which gathers the catch data and the results of the sale operations. This information is digitalized and stored in a database by the local fishing administration. This data included the daily catch (kg) and price (€ kg^{-1}) of each species sold at the fish auction by each fishing vessel. Yet, the data on daily landings do not report the fishing location from where the catch originates. For that reason, the fishing activity around fish farms was monitored and reported by an employee of the SB farm from 8:00 to 12:00 during the study period. The data included information on: the distance of fishing vessels to the farm, vessel type (commercial or recreational), vessel name (only for commercial vessels) and the fishing technique. This data was complemented with the daily information on total catches by species and income per vessel available from the database of the Fishermen's Association.

The SB farm employee who conducted the fishing vessel monitoring at the farm also carried out a self-monitoring of the fishing activities inside the farm. While feeding the cultivated seabream, farm employees target wild fish beneath the sea-cages using hand-lines, which represents an extra and hidden income to their salaries. In order to estimate the extent of this exploitation and the wild fish biomass that is systematically removed from the farm, we obtained the daily catch information (catch in number and weight per species) for 2011 and 2012. All species belonging to the family Mugilidae were recorded at the family level and *Trachurus mediterraneus* and *Trachurus trachurus* were recorded as *Trachurus* spp., because identification to species level is difficult.

Farm-effect

In order to analyze whether small-scale fishermen yield differential catches in the proximity of the farm compared to other areas, catch, income and species composition at different distances to the farm were compared. For this purpose, the fishing locations of small-scale vessels were grouped into three categories: inside (within the farm leasehold area), in close proximity (within 800 m of the farm boundaries) and away from the farm (> 800 m from the farm boundaries). The number of fishing days within the three distance categories substantially differed; hence, the analyses were done using subsets in order to match the number of fishing days for each distance and for each month of the year. Most small-scale vessels that had been observed fishing in the farm vicinity used nets (gillnets and trammel nets), whereas long-lines and octopus traps were not recorded often enough for statistical analysis. Consequently, the farm-effect was investigated by concentrating on netters.

Statistical analysis

We applied the analysis of variance based on permutations (PERMANOVA), as it provides a robust approach to deal with skewed data and many zero counts (Anderson 2001). All univariate and multivariate statistical analyses were carried out using the PRIMER V6.1.13 computer program (Clarke & Gorley 2006) with the PERMANOVA+ V1.0.3 add-on package (Anderson et al. 2008). Statistical significance was tested using unrestricted permutation of raw data, 9999 permutations and Type III (partial) sums of squares (SS, Anderson et al. 2008). To test for differences in total catch and income at different distances from the farm, univariate one-way analysis of variance was carried out. The similarity matrix was computed on square-root transformed data using the

Euclidean distance. Multivariate analysis of variance was used to test for differences in species composition of catches for the same distance factor. Prior to analysis, the data were fourth-root transformed to down-weight the influence of more abundant species while preserving information on relative abundance (Clarke & Green 1988). The Bray–Curtis dissimilarity measure was used for all multivariate analyses. To examine which species contribute most to the within-group similarity of the catch composition at the farm and away from the farm, the similarity percentage analysis (SIMPER) was applied.

3.3 RESULTS

In total, 895 fishing days were recorded in close proximity to the SB farm, 453 observations of small-scale fishing vessels and 442 of recreational vessels. Recreational effort was more intense during summer months (June – August), whereas the commercial effort varied throughout the year with highest intensity in September and October (Fig. 2). Fishing vessels were observed at different distances to the farm, however, 74% of the small-scale fleet and 95% of the recreational vessels were observed within 300 m of the fish farm installation (Fig. 3). Recreational vessels employed seven different fishing techniques, the most common method was trolling (47.7 %), followed by line-fishing (31.5 %) and spinning (9.4 %). The small-scale fishery used three fishing techniques: nets (67.8 %, gillnets and trammel nets), long-lines (17.9 %) and octopus traps (14.3 %).

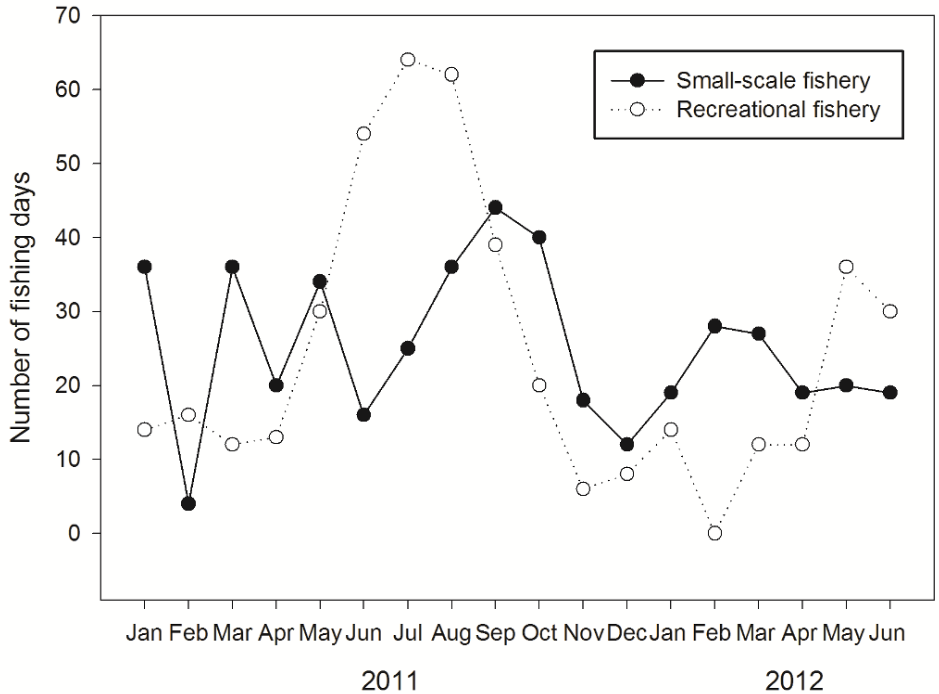

Figure 2 Total number of fishing days per month of small-scale and recreational fishing vessels in farm vicinity

In total, 18 out 24 fishing vessels of the small-scale fishery in L'Ametlla de Mar have been observed fishing in close proximity to the SB farm. Moreover, seven out of these 18 vessels have also repeatedly been recorded fishing inside the farm leasehold area. The fishing effort at the farm represented 9.5% (2011) and 8.3% (2012) of all reported fishing days. The cross-checking of observed and reported fishing days revealed that a total of 32% (2011) and 37% (2012) fishing days in the vicinity of the farm were not reported in the database of the Fishermen's Association of L'Ametlla de Mar. These results are indicative of an underreported activity and its corresponding catch.

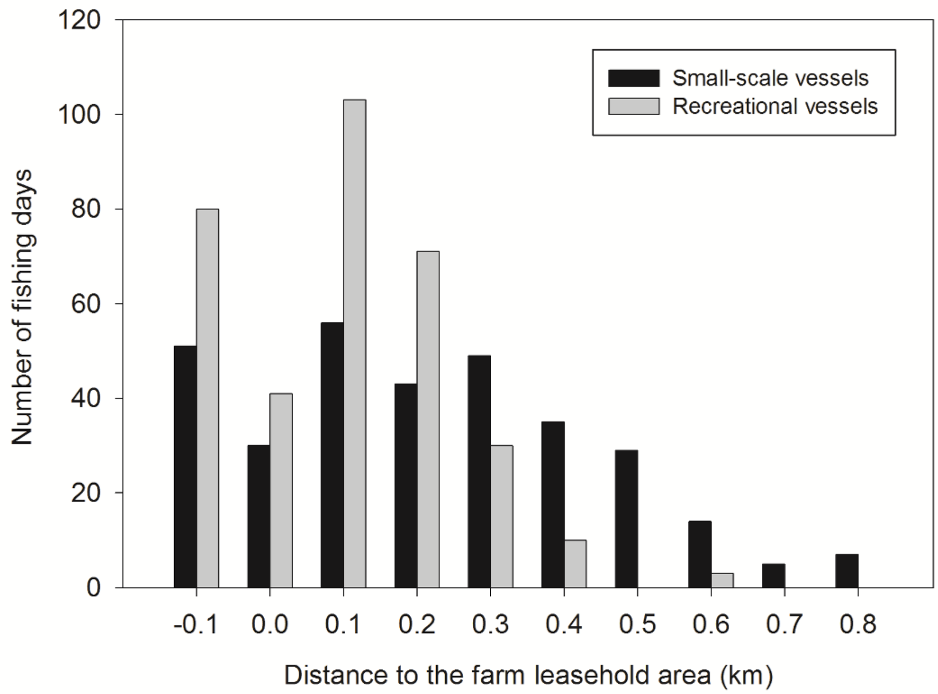

Figure 3 Total number of fishing days of small-scale and recreational vessels at different distances (km) to the SB farm in 2011

Farm-effect - Short distance

The results of the analysis of the catch, income and species composition significantly differed ($p < 0.001$) among the seven vessels that have been observed fishing inside, indicating differences in target species and fishing strategies. Consequently, the comparison between inside and the farm vicinity had to be conducted individually per vessel. Due to the underreporting, the catch information of several vessels was not available, therefore only two vessels could be included in the analysis (vessel 1: 58 fishing days, vessel 2: 28 fishing days). For both vessels, the results revealed no significant difference in terms of catch, income and species composition inside the farm compared to the farm vicinity ($p > 0.05$).

Farm-effect - Large distance

Given that the catch harvested inside and in farm vicinity did not significantly differ, the data was pooled for each vessel and compared to the catch harvested away from the farm. Combining the fishing days inside the farm and in close proximity allowed to include five vessels in the analysis, each with a minimum of 40 fishing days. No significant difference in catch, income and species composition was detected. The only exception was vessel 3, which showed significant differences in the catch composition and a higher income in fishing areas away from the farm (Table 1). The catch composition showed that the difference observed in vessel 3 is due to high catches of *Merluccius merluccius* and the commercially valuable *Solea vulgaris* (Table 2), revealing various fishing strategies. Average catch and income per day strongly varied between the five fishing vessels. Moreover, the SIMPER analysis revealed that the fishing vessels engaged in different fishing tactics. Vessel 1 and 2 targeted almost exclusively *Mullus surmuletus* and *Mullus barbatus* and to a lesser extent *Serranus cabrilla* and species of the family Scorpaenidae. No farm-effect on the catch level or species composition of these two vessels was identified. In contrast, the catch and daily income of the vessels 3, 4 and 5 is higher and more diverse (Table 1), revealing a variety of fishing strategies, targeting on *M. merluccius*, *S. vulgaris* and *Pagellus erythrinus.* These species are not characteristic of the wild fish community of this farm (Bacher et al. 2012) and the results shown in table 2 indicate that for those vessels, fishing at the farm is an additional strategy practiced simultaneously to their main fishing tactic. This issue is commented in detail in the discussion. Even though the statistical analysis did not detect an overall difference in the catch composition, it is worth noting that the catch of typical farm-associated species, such as Mugilidae, *Trachurus* spp. and *Diplodus sargus* was higher close to the farm (Table 2).

Table 1 Summary of results of permutational univariate and multivariate analysis of variance (PERMANOVA) comparing catch, income and species composition for the factor Distance. Average (mean ± SE) catch and income per day in farm vicinity and away from the farm. Significant at *p < 0.05

		Catch (kg day^{-1})		Catch		Income (€ day^{-1})		Income		Species composition	
Vessel	N	Farm	Away	MS	*F*	Farm	Away	MS	*F*	MS	*F*
V1	124	36.1 ± 3.6	36.4 ± 3.2	0.22	0.061	232.8 ± 19.7	229.7 ± 18.3	0.03	0.001	1251.1	0.674
V2	80	47.6 ± 4.6	44.8 ± 3.3	0.15	0.045	343.7 ± 33.7	358.5 ± 29.4	5.25	0.195	338.5	0.184
V3	40	58.8 ± 13.9	75.9 ± 17.9	12.35	0.935	321.3 ± 66.0	479.1 ± 76.4	223.34	3.98*	8231.1	2.70*
V4	40	119.4 ± 14.7	130.0 ± 14.9	2.46	0.281	511.8 ± 64.7	603.8 ± 61.4	43.77	1.151	2695.8	1.142
V5	44	96.6 ± 17.0	92.9 ± 16.0	0.38	0.029	492.0 ± 86.3	422.2 ± 46.3	8.71	0.186	3647.5	1.285

Table 2 Results of the similarity percentage analysis (SIMPER) showing the species contribution (%) to within-group similarity of the catch composition at the farm and away from the farm.

	Vessel 1		Vessel 2		Vessel 3		Vessel 4		Vessel 5	
Species	Farm	Away	Farm	Away	Farm	Away	Farm	Away	Farm	Away
Dentex dentex						6.90%		5.70%	7.30%	
Diplodus sargus					7.70%				15.90%	
Diplodus vulgaris							7.00%		9.60%	16.10%
Merluccius merluccius						31.20%	11.20%	24.60%		10.90%
Mugilidae					11.60%		11.20%	5.80%	9.60%	
Mullus surmuletus	25.00%	23.60%	31.80%	29.10%						
Mullus barbatus	33.60%	32.30%	26.30%	28.90%						
Pagellus erythrinus		5.30%				6.10%	9.60%	21.60%	20.90%	27.50%
Pagrus pagrus					5.90%					
Scorpaenidae	15.80%	17.80%	23.70%	22.80%						
Serranus cabrilla	8.80%	9.60%	14.00%	13.00%						
Solea vulgaris					11.40%	25.80%				
Sparus aurata										6.20%
Sphyraena sphyraena	5.60%									
Trachurus spp.					22.50%	4.70%	14.60%	8.80%		9.3%
Cumulative contribution	88.70%	88.70%	95.80%	93.80%	59.10%	74.80%	53.50%	66.60%	63.30%	70.00%

Fishing activities inside the SB farm carried out by farm employees

Throughout the study period a total of 10 fish species belonging to 4 families and 1 cephalopod, *Octopus vulgaris,* were caught beneath the sea-cages. The dominant species of the catch were *Trachurus* spp. (50.6 %) and *D. sargus* (35.2 %), followed by Mugilidae, *Pomatomus saltatrix*, *Trachinotus ovatus*, *Oblada melanura* and *Dentex dentex*. Other species of commercial interest, such as *Diplodus puntazzo*, *Diplodus vulgaris* and *P. erythrinus* were less frequently caught. The monthly average of daily catches (kg day^{-1}) varied significantly with season, highest catch rates were recorded around May, whereas minimum catches were observed in winter months (Fig. 4). Moreover, the species composition of the catch exhibited a seasonal pattern (Fig. 5). The dominant species *Trachurus* spp. and *D. sargus* were caught in high numbers throughout the year, but dominating different seasons, the sparid in autumn-winter and the carangid in spring-summer. Mugilidae were also abundant, but almost exclusively recorded in spring, whereas catches of *T. ovatus* were low and limited to the warmer months in summer and autumn (Fig. 5). During the two study years, a total of 11 224 individual fish with a total weight of 8.9 t (2011: 4.8 t, 2012: 4.1 t) were removed from beneath the sea-cages. This represents an additional annual income for the SB farm employees of a minimum of 18 615 €, considering first sale fish prices.

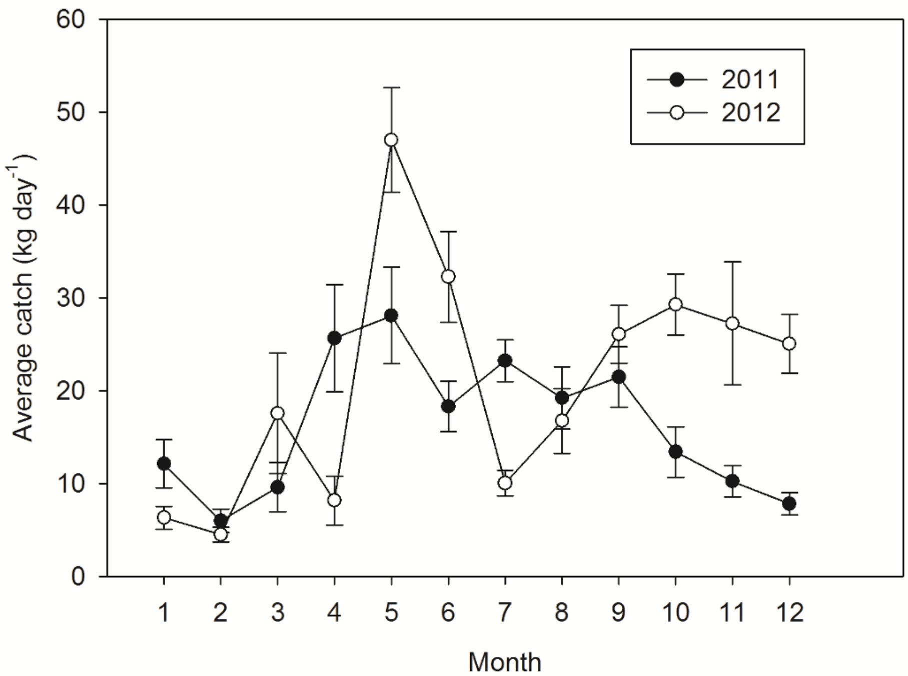

Figure 4 Average (mean ± SE) catch (kg day^{-1}) for each month in 2011 and 2012

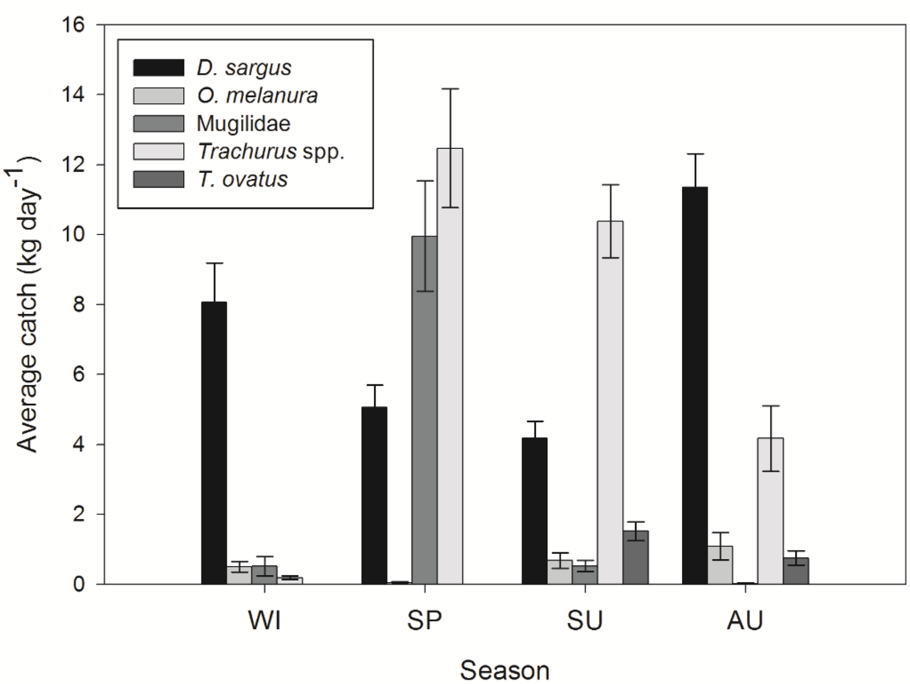

Figure 5 Average catch (kg day^{-1}) of the most dominant species caught by farm employees per season (WI: winter, SP: spring, SU: summer, AU: autumn) in 2011 and 2012

3.4 DISCUSSION

This study provides the first monitoring of commercial and recreational fishing activity at a fish farm. The findings revealed a relevant amount of commercial and recreational fishing effort in farm vicinity. Yet, our findings showed no benefit or difference of fishing in close proximity to the farm. Thus, we conclude that the farm-aggregated fish are protected from the commercial fleet by the farm leasehold area, but remain vulnerable to hidden fishing practices inside the farm.

The results revealed that the commercial and recreational fleets employ a wide range of fishing techniques in close proximity to the farm. As expected, the recreational fishing pressure was highest during summer months, due to the weather conditions and the holiday season, also evident in other Mediterranean regions (Rangel & Erzini 2007). Moreover, the peak of recreational fishing effort matches the seasonal peak of fish aggregation in the studied farm (Bacher et al. 2012). In contrast, the commercial fishing activity around the farm did not show any seasonal pattern. The recreational fishery does not have to report its fishing activity and landings; therefore, no data on catches is available. In view of the seasonal match between recreational effort and wild fish aggregation, future studies should take into account the catch of recreational vessels around farms to better understand the interaction between these two activities.

The overall annual commercial fishing pressure observed in farm vicinity is not negligible and represents about 9% of the total reported effort of the small-scale fishery based in L'Ametlla de Mar. Yet, in this study we found that around 30% of the fishing days of the small-scale fleet observed in farm vicinity were not reported in the data base of the Fishermen's Association. This figure is valuable to correct the number of expected annual fishing days (30% above the recorded). Although this study did not contemplate the estimation of the underreported catch of the small-scale fishery, these findings highlight a key issue, namely the amount of yield that is commercialized away from the official channels. In a recent study in a neighboring region, the fraction of underreporting declared by local fishermen was lower (< 10%) and justified by personal consumption (Maynou et al. 2011). The level of underreporting provided by Maynou et al. (2011) was based on what fishermen declared in the interviews, whereas in the current study, the percentage of underreporting has been estimated directly. To date there is no information available to asses if underreporting has increased as a consequence of the present crisis of the small-scale fishery in Catalonia/Spain and the rest of Europe (Guyader 2007; Maynou et al. 2013), and whether the crisis of the sector is magnified by a hidden economy.

The results of this study did not detect a farm-effect on the local small-scale fishery in terms of catch, income or species composition. Although the catch composition did not differ between fishing areas, close or away from the farm, the investigated vessels revealed different fishing strategies. The first group: vessel 1 and 2 targeted on the same species when fishing inside and away from the farm, indicating constant fishing techniques and strategies. Thus, it may be assumed that vessel 1 and 2 set their nets close to the farm, because the farm is located in the littoral zone, the natural habitat of their target species. The second group: vessel 3, 4 and 5 targeted on species of higher trophic levels and high commercial value (e.g. *M. merluccius*, *S. vulgaris* and *P. erythrinus*). From the daily reported catch composition (Table 2) one could wrongly interpret that these species are present in the vicinity of the farm. On the contrary, the depth range distribution of those species is above 20 m (Orsi Relini et al. 2002; Somarakis & Machias 2002; Mérigot et al. 2007), the depth at which the investigated farm is located. Thus, the catch composition of vessel 3, 4 and 5 around the farm results from practicing at least two different fishing tactics on the same day, setting nets around the farm simultaneously with sets at other habitat types (deeper waters). Still, vessel 3, 4 and 5 harvested generally higher catches of typical farm-associated species, such as *Trachurus* spp., *D. sargus* and Mugilidae in farm proximity. The high diversity of fishing tactics and the concurrent use of different fishing gears per day, as practiced by numerous Mediterranean small-scale fishermen (Forcada et al. 2010), complicates any investigation based on this fishery. Even though Spain censuses its small-scale fleet in the Mediterranean, the existing data does not provide information on 1) the fishing technique used, 2) the number of sets employed and 3) the fishing grounds from where the catch originates. This makes it difficult to obtain detailed data on the small-scale fishery, which may explain the absence of studies investigating the effect of fish farming on this fishery.

The average daily income differed among the investigated vessels, in particular vessel 1 and 2 earned substantially less compared to the other three vessels (Table 1). Moreover, concentrating on only one fishing tactic may be a risky strategy, since any disturbance in the littoral habitat puts this fishery at risk. Vessel 3, 4 and 5 employ a more diverse fishing strategy, which allows them to alternate the target species depending on their availability or commercial strategy (Table 2). Nevertheless, fishing in farm proximity does not provide any economic benefit, independent of the fishing tactic. In contrast, Machias et al. (2006) argued that the installation of fish farms increased fisheries landings in Greece. Yet, any inferences from landing fluctuations should be taken cautiously as there are many other factors that can affect fisheries production (e.g. fleet size, fishing power, fishing grounds), which could not be accounted for in the study by Machias et al. (2006).

The harvesting of large numbers of farm-aggregated wild fish by fish farmers has only been reported by one previous study (Akyol & Ertosluk 2010), however, it may be common practice in other regions as well. In Turkey, fish farmers argue that they need to remove predators (e.g. bluefish *P. saltatrix*, European conger *Conger conger*) and those fish infected with parasites. Farmers also claimed that shoals of bluefish sometimes attack and damage the cages, causing the escape of large numbers of cultivated fish, a phenomenon previously investigated by Sanchez-Jerez et al. (2008). These additional effects of fish farming are in conflict with the local small-scale fishermen in Turkey, since they do not get access to farm-associated wild fish (Akyol & Ertosluk 2010). In the present study, the fishing activity inside the farm is not an activity implemented by the farm owners, but by the employees who gain a substantial additional income from this practice. A negative impact of this activity for the small-scale fishery cannot be discarded in this particular case, because the main target species inside the farm (*Trachurus* spp. and *D. sargus*) are also targeted by part of the small-scale fishery in the vicinity of this facility. Yet, we have not observed a decrease in the catch rate inside the farm from one year to another; suggesting that the removed biomass is replaced by annual seasonal migration.

Most fish species aggregate in very close proximity to the sea-cages, with a steep decline in abundance just tens of meters away (Dempster et al. 2009; Dempster et al.

2010; Bacher et al. 2012), where they cannot be caught by the small-scale fishery. Inside-outside movements of some species have previously been reported (Uglem et al. 2009; Arechavala-Lopez et al. 2010), however, the results of the present study suggest that these displacements may not occur in large densities or synchronized enough to have an effect on fishing catchability. Yet, based on the results of Bacher et al. (2013) we cannot reject that this might be due to a temporal mismatch between daily fish movements and fishing practice. These authors found that fish density inside the farm varies during the day, because certain species leave the farm in the afternoon after farm feeding hours, when the small-scale fishermen return to the harbor, in order to sell their catch at the fish auction.

The species composition and abundance of wild farm-aggregated fish differ significantly among farms, depending on the farm characteristics and season (Fernandez-Jover et al. 2008; Bacher et al. 2012). Consequently, the effect of farms on the local fishery and local wild fish populations may equally vary. Further studies in different regions are needed to better understand the interaction between fish farming and the small-scale fishery, in order to improve management of areas where these two activities co-exist.

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4

Stakeholders' perceptions of marine fish farming in Catalonia (Spain): A Q-methodology approach

Bacher K., Gordoa A., Mikkelsen E. (2014) Stakeholders' perceptions of marine fish farming in Catalonia (Spain): A Q-methodology approach. *Aquaculture*, 424: 78-85.

ABSTRACT

Marine aquaculture production is becoming increasingly important to meet global seafood demands. Conversely, there are concerns about potential environmental impacts, especially associated with marine fish farming, and the access to and use of coastal resources. While only a small number of studies on social acceptability of fish farming exist, understanding the range of perceptions among social groups is a key challenge for successful management of aquaculture, and thus for sustainable development. The case study presented here uses the Q-methodology to explore the perceptions of five aquaculture-related key stakeholder groups (NGOs, local fishermen, fish farming industry, scientists and regional administration) towards marine fish aquaculture in Catalonia (NE Spain). The 30 participants were asked to sort 39 statements about environmental, social and economic aspects of marine fish farming, on a scale from strongly agree to strongly disagree. The factor analysis identified four distinct factors, each representing a different perception. While perception 1 regards fish farming as an activity with important socio-economic benefits and low environmental costs, perception 2 gives highest importance to environmental concerns. Perception 3 represents a more balanced view, valuing the socio-economic benefits and expressing moderate concern about environmental impacts, whereas perception 4 focuses mainly on economic aspects. Interestingly, the four perceptions were represented by various groups of stakeholders and not all respondents from the same sector shared the same perception. This study contributes to the scarce scientific information on social research on aquaculture, revealing limitations, challenges, and opportunities of the industry.

4.1 INTRODUCTION

The worldwide decline of capture fisheries (e.g. Myers & Boris 2003; Pontecorvo & Schrank 2012) and a simultaneous increase in seafood demand has triggered a rapid growth of marine aquaculture (FAO 2012). Responsible for this continuous growth are the developing countries, particularly in Asia, whereas annual growth rates in the European Union (EU) have been minimal since 2000, averaging only 0.4% (FAO 2012). The EU increasingly relies on fish originating from other regions, importing 65% of its finfish products (AIPCE-CEP 2012). The causes for the stagnation of the European aquaculture sector are believed to be numerous, e.g. limited access to space and licensing, price instability, pressure from imports, limited access to loans and stringent EU regulations (EU Commission 2002; 2009). Moreover, the social acceptability of the industry and its products has been identified as a key factor for the successful achievement of the sector's growth potential (Fezzardi et al. 2013; Kaiser & Stead 2002). The recognition of the range of perceptions that exist on marine aquaculture's economic, social and environmental benefits and costs is therefore a central aspect towards a sustainable development of this industry (Burbridge et al. 2001; Kaiser & Stead 2002; Mazur & Curtis 2008).

Marine aquaculture production is becoming increasingly important to meet global seafood demands, and is believed to improve the economic development of rural coastal communities (Burbridge et al. 2001; Katranidis et al. 2003; Varadi et al. 2001). Conversely, there are concerns about aquaculture's negative environmental effects, especially associated with marine sea-cage fish farming, due to its high dependence on fish meal and fish oil (Naylor et al. 2000; 2009). Potential impacts of fish farm production involve various effluents (e.g. waste feed, faeces, pesticides and medications) (Primavera 2006), negative interactions with wild fish populations (Diamant et al. 2000; Heggberget et al. 1993) and reduced amenity values (Read & Fernandes 2003). The access to and use of coastal resources of fish farms can lead to conflicts with other users of the coastal zone (Halwart et al. 2007; Hoagland et al. 2003; Nimmo et al. 2011). In addition, there are consumer concerns about the quality of farmed fish products (Verbeke et al. 2007).

Therefore, the range of perceptions of different stakeholders, as an important part of marine aquaculture management and planning, should be taken into account (Chu et al. 2010; Mazur & Curtis 2008; Robertson et al. 2002). Insufficient participation and consultation of relevant stakeholder groups could lead to mismanagement of resources and social conflict and/or decreased public support and trust (Buanes et al. 2004; Kaiser & Stead 2002; Shindler et al. 2002). Hence, there is a need to develop effective stakeholder involvement that aids communication and understanding on the many complex issues related to aquaculture (Stead et al. 2002). It is now widely accepted that a more competitive and sustainable future aquaculture industry has to be based on an integrated approach (Fezzardi et al. 2013; GESAMP 2001), representing an interdisciplinary framework that combines knowledge from natural resource management and social sciences (Stead et al. 2002).

There is a small but increasing number of social science studies on fish farming. However, most of them focus on consumer perceptions (Altintzoglou et al. 2010; Fernández-Polanco & Luna 2010, 2012; Verbeke et al. 2007) or the opinions of the general public (Freeman et al. 2012; Katranidis et al. 2003; Shafer et al. 2010), rather than perceptions of aquaculture-related key stakeholder groups (Chu et al. 2010; Rudell & Miller 2012; Whitmarsh & Palmieri 2009). Developing an overview of the different stakeholder perspectives can increase stakeholders' awareness of other perceptions (Raadgever et al. 2008) and may result in better mutual understanding and consensus between distinct groups and sectors (Pahl-Wostl & Hare 2004). Moreover, studies of the different perceptions inform about what stakeholder groups consider the most important issues (Mazur & Curtis 2008) and their attitudes towards measures for improvement. This can help governments and the aquaculture industry to develop a socially acceptable and sustainable aquaculture sector.

The present case study investigates the different perceptions on marine fish farming held by a diverse group of aquaculture-related key stakeholders in Catalonia (Spain). Spain is the third largest marine fish producer in the EU after the United Kingdom and Greece (APROMAR 2013) and the third largest importer of fish products worldwide (FAO 2012), with a per capita seafood consumption of 26.8 kg in 2011 (MAGRAMA 2011). Yet, in 2010 the production of marine fish aquaculture in Spain has decreased 9.4%. Despite a slight increase in 2012, the production volume still remains 8.8% below the level of 2009 (APROMAR 2013). In the autonomous region of Catalonia (NE Spain) industrialized marine fish farm production started at the beginning of the 1990s and has mainly focused on producing Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*). Most of the farm installations have been initiated in cooperation with fishermen's guilds. Catalonia used to be the second most important region for marine fish farm production in Spain and has been pioneering in the development of offshore farming systems (Jordana 1999). However, partially due to increasing national and international competition, the financial crisis and the price instability of aquaculture products (Fernández-Polanco 2012), 60% of the Catalan fish farming installations had to close over the past decade (APROMAR 2013). As a consequence, the total farmed fish production has decreased 22.3% from 2005 to 2012 (APROMAR 2013). Even though recent production numbers indicate a slight increase, the development of the aquaculture sector remains complex (APROMAR 2013).

This study aims at understanding the causes for the decrease of the present fish farming sector in Catalonia and to investigate the limitations, challenges and opportunities in an environmental, social and economic context. For this purpose, Q-methodology was applied, consisting of collecting and selecting statements directly from stakeholders, getting stakeholders to sort the statements according to their agreement or disagreement, factor analysis of the sorts, and finally analysis and interpretation of the factors identified.

The specific research questions were: (1) what are the distinct perceptions regarding the ecological, social and economic costs and benefits of fish farming in Catalonia, (2) which are the major areas of agreement and disagreement between perceptions, (3) which stakeholder groups share the same perception and (4) which are the most important issues and proposed measurements for improvement?

4.2 MATERIAL AND METHODS

Previous studies of social perception towards aquaculture (e.g. Freeman et al. 2012; Mazur & Curtis 2008; Robertson et al. 2002; Whitmarsh & Palmieri 2011) predominantly applied survey-based research methods. An alternative to such techniques is the Q-methodology. While the typical result of a survey-based study is a statistical analysis of pre-specified categories selected by the researcher, the outcome of a Q-study is a set of factors to explain the perceptions that exist among people (Addams & Proops 2000), allowing participants to raise their own topics rather than these being imposed by the researcher (Dryzek & Berejikian 1993). This method, developed by the British psychologist William Stephenson in the 1930s (Stephenson 1953), combines the benefits of both qualitative and quantitative research (McKeown & Thomas 1988; Stephenson 1953). Q-methodology does not require large population samples to obtain statistically valid results (Brown 1980), as it produces an in-depth view of different perspectives that exist in a given situation, but does not intend to generalize its results to a larger population (Steelman & Maguire 1999). Q-methodology is increasingly being used to explore perspectives of people involved in environmental issues (e.g. Bischof 2010; Frantzi et al. 2009; Mattson et al. 2006; Raadgever et al. 2008; Swedeen 2006), including aquaculture (Rudell & Miller 2012).

Collection and selection of statements

The first step of a Q-study is to generate a series of statements on the topic under investigation. In this study, semi-structured face-to-face interviews with 35 well-informed stakeholders were conducted during the period from April to June 2012. Participants were recruited on the basis of their relevance to the study aim and their knowledge of the aquaculture industry. The selected stakeholders included scientists, NGOs, fish farmers, fishermen and the regional fishing and aquaculture administration. The scientific sector included experts in fisheries economics (University of Barcelona), marine ecology (CSIC - Spanish National Research Council), aquaculture research (CSIC and IRTA - Institute of Food and Agricultural Research in Catalonia) and aquaculture-environment interactions (University of Alicante). The fish farming sector consisted of respondents from different fish farms in Catalonia, the Catalan Association of Aquaculture (ACA), the Spanish Fish Farmers Association (APROMAR) and a consultancy specialized in marine fish farming. The administration was represented by the fisheries and aquaculture administration, the environment department and the coast directorate from the regional administration in Catalonia. Environmental NGOs were represented by national and regional organizations (WWF Spain, Greenpeace Spain, Ocean2012, Oceana Spain, Fundació Mar and Nereo). Actors from the fisheries sector consisted of the presidents of the fishermen's guilds ("cofradía") at different ports (with and without fish farm installations nearby) along the Catalan coast. Participants were encouraged to speak freely about positive and negative aspects of fish farming in an environmental, social and economic context, and on measures to improve the sector's sustainability. A total of 356 statements were initially extracted from the interviews. Statements on similar aspects of aquaculture were combined, which considerably reduced the number of statements. To ensure that the whole range of perceptions is represented, the statements were sorted into the three categories of interest: environment, social and economic. In each category, statements were chosen that were representative of all the sub-themes that arose during the interviews. This process reduced the number of statements to a final list of 39 (13 statements from each category).

Sorting of statements

Out of the 35 participants that have been interviewed, 30 respondents (six from each sector) were asked to sort the 39 statements. Stakeholders were asked to sort the statements by how strongly they agreed or disagreed with them. The statements were provided to the participants on separate and numbered cards with the instruction to sort the statements using a 9 point chart ranging from -4, least agree to +4, most agree. In this way, a set of sorted data is collected for each participant, the pattern of the sort representing the individual perceptions. Respondents were encouraged to distribute their statements according to a quasi-normal distribution, yet, they were allowed to put more or less statements in a certain scoring category if it helped to better describe their perception. Respondents were asked to comment the scoring of the statements, which added valuable contextual information at the time of interpreting the results. The sorting was conducted face-to-face, however, to avoid long-distance travelling, five sorts were conducted by Skype.

Statistical analysis

The statistical analysis was conducted using the PQMethod software (Schmolck & Atkinson 2002). First, the software calculated a correlation matrix of all 30 sorts representing the level of similarity of the perceptions of individual participants (Van Exel & de Graaf 2005). The data were then factor analyzed using Principal Component Analysis (PCA). In this process, the sorts of participants that share similar perceptions grouped together and formed a factor. Factors were then varimax rotated in order to find the best solution maximizing the variance explained by the factors. The number of factors was determined by selecting factors with eigenvalues greater than two, meaning that each factor is defined by at least two significantly loading sorts (Brown 1980). The factor loading expresses the extent to which each sort agrees with a factor's viewpoint (Brown 2004). The sorts that loaded significantly (±0.41 or above, with $p<0.01$; for equation see Brown 1980) on a given factor were merged to form one single sort, configured to represent the perception of that factor. In other words, for each factor an idealized sort was constructed which is a weighted average of all the individual sorts that loaded on this factor (Watts & Stenner 2005). The resulting sort for each factor is then subject to interpretation.

Interpretation

The aim of a Q-study is to understand and explain the perceptions represented by each factor (Watts & Stenner 2012). During interpretation, particular attention was given to statistically distinguishing statements for each factor ($p < 0.05$). Moreover, the explanations gathered from respondents during the interviews and the sorting process added valuable information. Statements were identified as consensus statements when all factors agreed or when three factors agreed and one factor had a neutral rating.

4.3 RESULTS

In this study, four well defined factors were identified. The four factors explained 54% of the total variance between all 30 sorts. Table 1 shows which participants define and thus share a factor (perception). Factor sort values for each statement are listed in Table 2. The results section first describes the four perceptions represented by each factor, followed by areas of agreement among perceptions. Two participants loaded significantly on two different factors (“confounders”), as standard practice in Q-studies, their sorts were excluded from the construction of the factors’ viewpoints (Brown 1993). Possible explanations for their hybrid-views are discussed.

Table 1
Overview of the factor loadings for each sort ranging from 1 (complete agreement) to -1 (complete disagreement with the perception of that factor).

Q sorts	F1	F2	F3	F4
Factor 1				
Scientist (Fish biology)	**0.73**	0.04	-0.43	-0.01
Scientist (Aquaculture)	**0.68**	0.07	-0.04	0.32
Scientist (Aquaculture)	**0.75**	-0.06	0.09	-0.04
Fish farming sector (Producers association)	**0.73**	-0.23	0.22	0.18
Fish farming sector (Consultancy)	**0.43**	0.07	0.17	0.07
Fish farming sector (Producers association)	**0.74**	-0.21	-0.03	0.00
Fish farming sector	**0.84**	-0.29	-0.01	0.05
Fish farming sector	**0.48**	0.04	0.32	-0.18
Fish farming sector	**0.69**	-0.09	0.21	0.03
Administration (Fisheries and aquaculture)	**0.68**	0.29	-0.01	0.13
Administration (Environment)	**0.66**	0.06	-0.22	0.21
Administration (Coastal services)	**0.44**	0.04	0.09	-0.03
Factor 2				
Environmental NGO	0.22	**0.57**	-0.37	0.00
Environmental NGO	-0.25	**0.69**	-0.09	0.48
Environmental NGO	-0.16	**0.74**	0.22	-0.07
Environmental NGO	-0.31	**0.63**	-0.03	-0.13
Environmental NGO	0.21	**0.59**	0.19	0.29
Environmental NGO	0.06	**0.61**	0.45	0.03
Scientist (Aquaculture economics)	0.18	**0.41**	0.16	0.27
Administration (Fisheries and aquaculture)	-0.12	**0.51**	0.03	0.24
Factor 3				
Scientist (Marine ecology)	0.14	0.04	**0.74**	0.11
Fisherman (Aquaculture installations nearby)	0.04	0.23	**0.81**	0.08
Fisherman (Aquaculture installations nearby)	0.20	0.08	**0.65**	0.19
Factor 4				
Scientist (Aquaculture-environment interactions)	0.14	0.25	-0.17	**0.44**
Fisherman	0.09	0.03	0.34	**0.73**
Fisherman	-0.08	-0.07	0.23	**0.76**
Fisherman (Aquaculture installations nearby)	-0.03	0.02	0.01	**0.72**
Fisherman	0.19	0.25	-0.02	**0.61**
Confounded sorts				
Administration (Fisheries and aquaculture)	0.44	0.19	0.07	0.51
Administration (Fisheries and aquaculture)	0.46	0.39	-0.43	0.28
% explained Variance	**21%**	**12%**	**10%**	**11%**
Total defining Q sorts	**12**	**8**	**3**	**5**
Total Q-sorts	**13**	**8**	**3**	**6**

Table 2 Factor sort values for each statement

#	Statements	F1	F2	F3	F4
1	A more stringent environmental regulation applies to the fish farming sector compared to other coastal activities (e.g. ports, fishery, waste water discharge, etc.)	+3	-4	-3	+1
2	There is a high potential for improvement to reduce the economic risk associated with fish farming and to permit its economic viability	0	+1	-1	+2
3	The environmental impact of fish farms on the benthos is marginal and limited to the farm area	+3	-3	0	+2
4	Fish farms create new opportunities for economic activities (e.g. fishing, boating, gastronomy)	+1	0	+4	+3
5	There is a lack of a map that identifies appropriate zones for economic activities to reduce impacts and conflicts with other users	0	+4	+1	+3
6	There is no difference in quality or taste between wild caught and farmed fish	-1	-3	-4	-4
7	Fish farms are necessary to assure the provision of protein	+4	0	+1	-1
8	The fish farming sector creates a relevant amount of employment at a local level	-1	-1	0	0
9	The fish farming sector lacks a good business management	-1	+1	0	+1
10	Fish farms generate competition and conflicts with other users and activities of the coastal zone	-2	+3	-1	0
11	Fish farm feed generates overexploitation of fishery resources	-2	+4	+1	-3
12	The low prices of aquaculture products negatively impact the price of similar wild caught fish	-4	+3	+2	+1
13	Fish farming could contribute to the repopulation of overexploited species	0	0	+3	+2
14	Fish farming is an activity with low social appreciation	0	-1	+2	-2
15	The network for commercialization is deficient negatively affecting the final state and price of the product	-3	-2	-1	+2
16	Fish farming is an economic and not ecological activity therefore certain impact has to be accepted	+1	-3	-3	+3
17	The production of cultivated fish is environmentally more sustainable than the production of meat (e.g. poultry, beef)	+4	-4	-2	-2
18	There is a distrust concerning quality and condition of cultivated fish	+1	+1	+4	+1
19	Environmental NGOs promote a negative image of the fish farming industry	0	0	-2	-1
20	There is a high risk of biological contamination from fish farms (e.g. genetic contamination due to escapes and transmission of pathogens)	-2	+2	0	-1
21	The fish farming sector represents a potential job alternative for fishermen	-1	-2	+3	-3
22	The fish farming sector here cannot compete with other countries that produce at lower costs	+1	+1	0	+4
23	Fish farms generate new biotopes	0	0	+3	+1
24	The fish farming sector is undervalued by the regional administration compared to other consolidated activities	+2	-2	0	-3
25	Fish farms reduce the exploitation of local fish stocks by the local fishery	-4	-4	-3	-3
26	The low price of fish farm products is positive as it facilitates the access to fish	+3	+2	-3	-4
27	There is a high risk of negative impacts from the use of chemical products at fish farms	-4	+3	-2	-1
28	There is a great deficiency in the marketing of fish farming products	+2	0	-1	-1
29	Working conditions in the fish farming sector are better compared to the fishing sector	+2	+1	+2	0
30	The traceability of fish farm products is appropriate	+1	-1	-4	-2
31	The fish farming sector misleadingly concentrates on producing high fish quantity instead of quality	-2	+2	+1	+4
32	A sustainable development of the aquaculture activity requires Integrated Multi-trophic Aquaculture systems (IMTA)	-3	+3	+2	0
33	The fish farming sector is economically not viable and depends excessively on subsidies	-3	0	-4	+3
34	The fish farming industry should introduce certifications of quality	+4	+2	+3	+4
35	The fish farming sector should substitute the fish meal with vegetable proteins	-1	+4	-2	-2
36	The visual impact of fish farms is important	-3	-3	+1	-4
37	Marine fish farms promote the development and welfare of coastal communities	+2	-1	-1	0
38	The environmental impact of marine fish aquaculture is of a lower magnitude compared with other coastal activities	+3	-1	0	0
39	The fish farming industry promotes a diversification of the fish products in the market	0	-2	+4	0

Perception 1

Central to this perception is the belief that fish farms cause low environmental impacts (statements 3, 20 and 27). Unlike all other viewpoints, this perception regards the fish farming industry as environmentally more sustainable than other economic activities in the coastal zone (38), or terrestrial meat production (17). However, integrated multi-trophic aquaculture systems (IMTA, see for explanation e.g. Ridler et al. 2007) are not considered appropriate for the cultivation of marine fish in Catalonia (32).

This perception emphasizes the social importance of marine fish aquaculture for the supply of fish protein (7) and the development and welfare of coastal communities (37). Moreover, the low prices and the permanent availability of farmed products are considered to facilitate the access to fish (26). In contrast, there is disagreement with the assumption that fish farms lead to conflicts with other users and activities of the coastal zone (10). Similarly, they do not believe in a direct price-competition with the extraction fishery, since the two sectors produce two distinct products (12).

Perception 1 acknowledges, that in the past the fish farming sector strongly depended on subsidies, however, the present installations are considered economically viable (33). Nevertheless, it is believed that several factors work against the industry's successful development, such as the stringent environmental regulations (1) and the undervaluation by the regional administration (24). In addition, deficient marketing is considered to hinder the successful promotion of the quality of aquaculture products and the activity itself (28). Furthermore, respondents recognize the importance of focusing on producing both quantity and quality (31).

Perception 2

This perception is distinguished from the others by its concern for the environmental costs of fish farm operations, such as eutrophication on the benthos (3), negative effects through the use of chemical products (27) and the transmission of pathogens (20). There is a strong belief that economic activities, such as fish farming, do not legitimate every type of environmental impact (16). In addition to direct local effects, the use of fish meal and fish oil for aquafeeds is considered to generate overexploitation of fishery resources in other regions (11). Consequently, respondents of perception 2 support the idea of replacing fish meal by another food source, such as vegetable proteins (35), and suggest focusing more on cultivating fish species of lower trophic levels. In addition, it is believed that the implementation of integrated multi-trophic aquaculture (IMTA) systems could improve the environmental sustainability of fish farming in Catalonia (32). Overall, the cultivation of marine fish species is not considered more environmentally sustainable than the production of terrestrial animal protein (17). Further, this perception strongly disagrees with statement 1, which states that the fish farming sector is environmentally more stringent regulated than other coastal activities.

From a socio-economic viewpoint, fish farms are considered to generate competition and conflicts with other users of the coastal zone (10) and respondents emphasize the lack of a map that identifies appropriate zones for economic activities (5), in order to avoid such conflicts. Even though the low prices of aquaculture products are considered to make fish more accessible (26), there is concern that the low prices of farmed fish could negatively impact the price of wild-caught species (12). Further, it is not considered that farmed products diversify the offer in the market (39), since all cultivated fish species are also exploited by the extractive fishery.

Perception 3

Perception 3 particularly highlights the social and economic importance of the fish farming sector for creating new opportunities for economic activities (4), and representing a job alternative for fishermen (21) that provides better working conditions (29). It strongly disagrees with statement 33, which states that the fish farming sector is economically not viable being highly dependent on subsidies. However, it acknowledges that the sector suffers from distrust concerning the quality and condition of its products (18), partially because the information provided to consumers is deficient (30). Respondents agree that fish farm products promote a diversification in the market (39). However, there is concern that the low costs of farmed fish could negatively impact the price of wild-caught fish (12) and at the same time penalize the fish farming sector, if low prices are associated with low quality (26).

Perception 3 recognizes the importance of environmental aspects, but does not perceive high environmental risks associated with marine fish farming in Catalonia (3, 11, 20, and 27). Respondents argue that every economic activity has an environmental impact (16); the challenge is to reach a balance between economic growth and environmental protection. Similar to perception 2, respondents deny that the fish farming sector has to comply with more stringent environmental regulations compared with other coastal activities (1). They believe that fish farm installations have the potential to generate new biotopes (23), similar to small protection areas. An additional positive aspect of marine fish aquaculture is its potential contribution to the repopulation of overexploited species (13).

Perception 4

Perception 4 is distinguished from the other three perceptions by giving highest importance to economic aspects. Unlike all the other perceptions, it regards the present fish farming industry in Catalonia as economically not viable (33), mainly due to the competition with other countries that produce at lower costs (22). It believes, however, that there is a high potential for improving the sector's economic situation (2), e.g. by focusing more on producing high quality rather than quantity (31). In addition, it emphasizes the capacity of marine fish aquaculture to generate parallel economic activities (i.e. tourism, gastronomy) (4). Nevertheless, it does not consider the aquaculture sector as a job alternative for fishermen (21), arguing that the two sectors are too different. In addition, there is strong disagreement with the assumption that the fish farming sector is undervalued by the regional administration compared to other consolidated activities (24). Fish farms in Catalonia are not considered very important to meet the demand for animal protein (7), nor to make fish more accessible (26), since many wild-caught fish species are sold cheaper. Analogous to perception 2 and 3, there is a belief that the cheaper fish farm products directly compete with wild-caught fish of the same species (12). Environmental aspects were not a central theme in this discourse (3, 20, 27, and 11), it is considered that a certain impact has to be accepted from any economic activity (16). Yet, as in perception 3 there is a view that fish farms could help repopulate exploited fish species (13) and create new biotopes (23).

Table 3 provides a synopsis of the most important benefits and costs/issues (statements that were sorted at ±3 or ±4) and measures for improvement identified by each perception.

Areas of consensus

All four perceptions recognize the importance of introducing certifications of quality (34) in order to reduce consumers' distrust of the quality of farmed fish (18) and to better compete with countries producing at lower costs (22). In addition, all perceptions agree that fish farms provide opportunities for new economic activities, but are not considered to create a relevant amount of employment at the local level (8). The stakeholder groups agree on the need to implement a map that identifies appropriate zones for economic activities, to reduce impacts and user conflicts (5). With the exception of perception 3, there is a clear view that the visual impact of farms is not important (36). Furthermore, there is general disagreement with the idea that there is no difference in quality or taste between wild-caught and farmed fish (6). Finally, all perceptions disagree with statement 25, which states that fish farms reduce the exploitation of local fish stocks by the local fishery.

Stakeholders that share the same perception

Table 1 reveals that not all of the respondents who belong to the same stakeholder group share the same perception. Exceptions were participants from environmental NGOs and actors from the fish farming sector who both exclusively shared perception 1 and 2, respectively. Respondents from the aquaculture and fisheries administration shared mostly perception 1 and only one member the view of perception 2. Scientists were represented in all four perceptions. Those dealing with aquaculture shared perception 1, the fisheries economist perception 2, the marine ecologist perception 3 and the expert on aquaculture-environment interactions shared the view of perception 4. Most of the fishermen shared perception 4, and two perception 3. The two confounders belong to the regional fisheries and aquaculture administration. Both participants shared perception 1, but at the same time one respondent also shared perception 4, while the other participant significantly disagreed with perception 3.

Table 3 Synopsis of results
Overview of the most important benefits, costs/issues and measures for improvement of fish farming in Catalonia (Spain) identified by each perception (IMTA: Integrated multi-trophic aquaculture system).

	Perception1	Perception2	Perception3	Perception4
Benefits	• Environmental impact is marginal and lower compared with other coastal activities • Fish farming is more sustainable than meat production • Provision of animal protein • The low prices facilitate the access to fish	• The low prices facilitate the access to fish	• Fish farms generate new biotopes • Serve to restock overexploited species • Diversification of fish products in the market • Job alternative for fishermen • New opportunities for parallel economic activities	• New opportunities for parallel economic activities
Costs/Issues	• Stringent environmental regulations • The fish farming sector is undervalued by the regional administration	• Risk of environmental impacts • Fish farm feed generates overexploitation of fishery resources • Conflicts with other users of the coastal zone • Low prices lead to competition with capture fishery	• Distrust concerning quality and condition of cultivated fish • The information provided to consumers is deficient • The low price of farmed fish may be associated with low quality	• Activity is economically not viable • Cannot compete with other countries that produce at lower costs • Does not facilitate the access to fish, since many wild caught fish species are sold cheaper
Measures for improvement	• Introduction of certifications of quality and reinforcement of the designation of origin • Equivalent regulations for all aquaculture fish marketed in EU • Optimize administrative procedures • Develop aquafeeds that depend less on wild fish	• Cultivation of species of a lower trophic level • Reduction of environmental impacts • Integrated aquaculture systems (with agriculture or IMTA) • Implementation of a map to identify appropriate coastal zones for economic activities	• Provision of easy access to credible information for consumers • Introduction of certifications of quality	• Concentrate more on producing quality than quantity • Implementation of a map to identify appropriate coastal zones for economic activities

4.4 DISCUSSION

The structure of the discourse - the emergence of four distinct perceptions - indicated that marine fish farming is seen from diverse perspectives. Interestingly, all four perceptions were represented by various groups of stakeholders and not all respondents of a sector shared the same perception. Although the identified perceptions were well distinguished, several areas of agreement were identified, which can serve as a common ground for discussion. Finally, the findings revealed the main economic, social and environmental challenges faced by the fish farming industry in Catalonia.

Respondents of perception 1 strongly advocated marine fish farming, highlighting its aptitude to produce critically needed marine fish supplies of good quality to an affordable price. They considered the apprehension about potential environmental risks and damage caused by marine fish farming as disproportionate; given the fundamental dependence of farms on good environmental quality and hence, a common interest in its maintenance. However, they acknowledged that there are many external and internal factors that prevent the industry from developing its full economic potential. This perception was shared by all participants from the aquaculture industry, but also by all scientists specialized in aquaculture research, as well as three participants of the fishing and aquaculture administration. The support given by the members of the aquaculture industry is comprehensible, reflecting the objective to sustain and develop fish farming in the region. Furthermore, it seems logical that aquaculture scientists are in favour of the aquaculture industry, since they investigate and develop the cultivation of marine fish species. Respondents from the regional administration are directly involved in management, and may to a certain extent feel responsible for the sector and share an interest in its successful development.

Perception 1 and 2 contained the most opposing views, mainly due to their contradictory perceptions of environmental impacts caused by marine fish farming. Perception 2 did not regard the cultivation of marine fish as the solution to overfishing; believing that the decline of fish populations can only be solved through a responsible capture fishery. Moreover, the fish farming sector in Catalonia was not considered to provide considerable social or economic benefits. Perception 2 is consistent with previous findings which showed that the acceptance of aquaculture decreases where local concerns about environmental damage from aquaculture are high and perceived socio-economic benefits are low (Hugues-Dit-Ciles 2000; Katranidis et al. 2003). As expected, this perception was shared by all members of environmental NGOs. More surprisingly, this view was also supported by a fisheries economist and one respondent from the regional fisheries and aquaculture administration.

Perception 3 represented a more balanced view, valuing the socio-economic benefits of marine fish aquaculture and expressing moderate concern about environmental impacts. There is a clear view, that fish farming is a complementary activity to the extractive fishery and it is considered a potential job alternative for fishermen. This perception was shared by two fishermen and one marine ecologist. Interestingly, both fishermen are based at ports where aquaculture installations are operative, suggesting that the presence of fish farms positively influences their perception of aquaculture. Perception 4 was mainly shared by fishermen without aquaculture installations near their home port, and one scientist specialized in interactions of aquaculture with wild fish populations. In contrast to perception 3, in perception 4 fish farms were not considered to represent a job alternative for fishermen, regarding the two activities as too different. Proponents expressed the strongest concern about economic aspects, suggesting that fishermen are especially aware of economic issues of marine fish farming, since they may encounter similar problems. Most fishermen that shared perception 3 and 4 did not consider the fishery and fish farms to be in conflict over access to coastal areas, but they believed that the low price of aquaculture products could negatively impact the price of wild caught fish.

The fact that two respondents of the fisheries and aquaculture administration shared the perception of two viewpoints seems to reflect their professional background. The participant that shared perception 1 and 4 approached the topic from an aquaculture and fishery’s perspective. Similarly, the other member of the administration also shared the perception of the aquaculture industry; yet, the strong disagreement with the relatively balanced perception 3 remains puzzling to us. In total, five participants from the administration (including the two confounders) shared perception 1, indicating that they are willing to support a further development of marine fish aquaculture in the future.

Limitations, challenges and measures for improvement

During the interviews and the interpretation of the different perceptions a number of key themes were identified, suggesting that these are important issues of the marine fish farming debate in Catalonia. In the following section, the rationale behind the distinct perceptions will be discussed further by looking at the comments made during the sorting with respect to these challenges and limiting factors.

Commonly, the perception of aquaculture is linked to how its environmental impact is perceived (Katranidis et al. 2003; Rudell & Miller 2012; Whitmarsh & Wattage 2006). Similarly, in the present study, environmental aspects were important in terms of differentiating perceptions on fish farming. One of the most controversial topics was the capture of wild fish as raw material for fish feed. Most respondents of perception 1 believed that there is no other use for these fish species since they are normally not used for direct human consumption. However, all four perceptions recognized that an increase in marine fish farms will rise important sustainability issues as to the availability of sufficient fish feed supply. Yet, there was no common agreement on how to solve this issue. Respondents from the aquaculture sector highlighted that over the past decades, the level of fish meal and fish oil in fish feed has already been substantially reduced through the use of plant protein. In contrast, most fishermen did not like the idea of feeding carnivorous fish species with terrestrial plant proteins, arguing that the feed should be of marine origin. Respondents of perception 2 considered the development of novel aquafeeds, based on alternatives to fish meal and fish oil, as not sufficient and suggested a reconversion of the fish farming sector into the cultivation of species of a lower trophic level.

Direct environmental impacts at fish farm production sites were only considered as a high risk by participants that shared perception 2, whereas respondents of the other three perceptions believed that these effects can be minimized through responsible management and effective siting of farms. Moreover, members of the regional administration highlighted that the results of regular environmental impact assessments at farms are freely accessible. Yet, this information is usually not requested by other stakeholder groups, suggesting that the aquaculture industry and the government will need to find alternative ways to transmit this information more effectively in order to reduce confusion over perceived and real impacts. The apparent lack of knowledge about current regulations could explain the different perceptions about the legislation strictness (statement 1). Respondents of perception 1 considered the present fish farming sector overregulated, arguing that the current legislation represents an important constraint. In particular, the excessive difficulty and time (approx. 2 yrs) needed to obtain permissions and concessions are believed to discourage new business investments. Given that several respondents of perception 1 belong to the regional administration underlines the significance of this issue. This has also been recognized by the EU Commission, which identified the optimization of administrative procedures as one of the main objectives in the most recent strategic aquaculture plan (EU Commission 2013).

From an economic viewpoint, respondents believed that the price competition with other producer countries represents one of the main challenges for the fish farming sector in Catalonia. Respondents from the aquaculture sector criticized that the disparity in administrative and legal requirements to practice aquaculture within and outside the EU, is clearly threatening the EU aquaculture sector. Consequently, it was argued that producers in Europe have to be better protected by the implementation of equivalent regulations for all aquaculture fish marketed in the EU.

All participants shared the view that the labelling of fish products needs to be stricter controlled by the government. In particular, respondents of perception 1 were concerned that the lack of distinction impedes the identification of Spanish aquaculture products by consumers, favouring cheaper imported seafood. Consequently, the importance of reinforcing the concept of the designation of origin was emphasized, which has been shown to positively influence the image of farmed fish in the EU (Altintzoglou et al. 2010). In addition, there was common agreement that the lack of knowledge about production processes and the quality of farmed products causes distrust among consumers. These results suggest that the aquaculture sector, the government, NGOs and scientists should work together to provide easy access to credible information, which has been identified as a key component to build public trust in aquaculture (Mazur & Curtis 2008). In Spain, many aquaculture producers comply with the quality and environmental certifications ISO 9000 and ISO 14000, however, these have very little external recognition impact (Young et al. 1999). Consequently, respondents of all four perceptions emphasized the importance of introducing certifications of quality that ensure good production practices which can easily be recognized and understood by consumers.

Conclusions

By analyzing different stakeholder perceptions of marine fish farming in Catalonia, we have gained insight into how this activity is perceived. Most participants were in favour of a future aquaculture development, however, proponents of each perception recognized distinct environmental, social and economic challenges that need to be overcome to achieve a more sustainable fish farming sector.

General environmental impacts were not perceived as a high risk by the majority of the participants, yet, the reduction in the use of fish meal and fish oil in fish farming was considered a relevant aspect. In addition, the transmission of credible information about the quality of fish farm products and their correct labelling are regarded as critical. Moreover, it is believed that the sector's economic competitiveness could be resolved through regulatory EU reforms and by optimizing the application process for new fish farm installations.

The results of this case study cannot be extrapolated to a larger population or to other aquaculture discourses, however, the fish farming sector in other regions of the EU might face similar challenges. Understanding perceptions of different stakeholder groups can help clear misunderstandings, as well as identify which issues are crucial to be resolved to unleash the full potential of the aquaculture sector, while still achieving social, economic and environmental sustainability.

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General discussion and conclusions

GENERAL DISCUSSION

This multidisciplinary thesis provides new information about the complex dynamics of fish aggregation patterns at farms and investigates the effects and interactions of different sources of variability. We provide the first monitoring of commercial and recreational fishing effort at a marine fish farm and report on hidden fishing practices inside the farm. Moreover, this dissertation contributes to the scarce social science research on marine aquaculture, revealing limitations, challenges, and opportunities of this industry. This general discussion connects the different chapters by highlighting complementary and overlapping results and briefly addresses some new avenues of investigation which are left open in this work.

D.1 Farm location: habitat influences wild fish assemblages

The location of a fish farm influences the aggregated fish assemblage through habitat type, distance from the shore and coastal topography, in particular the steepness of the shelf slope.

In the littoral zone, greater structural complexity and heterogeneity of habitat have been found to support richer communities and higher abundances (Jenkins & Wheatley 1998; García-Charton & Pérez-Ruzafa 2001). In *chapter 2* we show the internal variability within a farm where fish abundance and biomass at the bottom were significantly higher at stations over rocky-sandy substrates than at sandy bottoms. In addition, substantially more species were observed at rocky–sandy stations (30) compared to sandy stations (10). Moreover, the effect of the rocky-sandy bottom substrate was not restricted to the bottom fish community, it also affected the abundance of wild fish in the water column. The high abundance and species diversity at the bottom suggests that the investigated

Gilthead seabream (SB) farm does not exert a negative effect on the fish community, but rather that the benthic community is also attracted to the constant food availability underneath farms. Most fish farms that have been investigated to date are located over sandy bottom characterized by a lower number of species (e.g. Dempster et al. 2005). The presence of both, pelagic and demersal species could increase the uptake of unconsumed food and faeces, thereby mitigating the impact of sea-cages, a clear example of bioremediation. Katz el al. (2002) demonstrated that mullets (*Mugil cephalus*) kept in experimental enclosures resuspended detritus, increased the oxygen supply to the benthos and oxygenated buried organic matter, which dramatically improved the status of the sediment. Therefore, it has been suggested that farms should be sited over artificial reefs in order to reduce the environmental impact of marine fish farming (Angel et al. 2002).

The distance from the shore is another factor that influences the species composition at sea-cage fish farms. Dempster et al. (2002) compared 9 Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*) farms along the Spanish coastline in the south-western Mediterranean and found that abundance, biomass and number of species were greater at farms close to shore, which was attributed to their relative proximity to rocky habitat and *Posidonia oceanica* meadows. In addition to the distance, the topography of the coast strongly influences the presence of different species. At two Croatian tuna farms, the close distance to the shore (100-200 m) in combination with a steep slope (bottom depth 60 m) favoured the presence of both, littoral reef-associated and pelagic species (Šegvić Bubić et al. 2011). On the other hand, fish aggregations at farms that are located at a larger distance (4.5 km offshore, 45-50 m bottom depth), such as the Atlantic bluefin tuna (ABT) farm in *chapter 1*, are less influenced by reef-associated species and mainly characterized by pelagic and bentho-pelagic species.

The farm location characteristics are not the only factors accounting for the species composition and abundance of associated wild fish. It has been found that, the size of a farm is an approximate index for the amount of lost feed, consequently farms with a greater number of cages have been found to have higher abundance, biomass and species diversity (Dempster et al. 2002). In addition, the type of food has also been suggested as an important factor, as pellets and their fine particulates may attract a more diverse fish community and can be more easily consumed than baitfish (Šegvić Bubić et al. 2011). Furthermore, whole baitfish differ substantially in their nutrient composition, food size and settling velocity from food pellets (Vassallo et al. 2006). The observed differences between the ABT farm and the SB farm in *chapter 1* may be attributed to the different farm feed, yet it is uncertain which factor is more important, location or food type.

The vertical distribution of fish species is associated with differences in their feeding ecology. Consequently, the depth of different water layers is an important source of variability within farms. The results of *chapter 1* and *2* revealed that depth interacts with all other factors that have been found to influence fish aggregation patterns. These factors and their interactions are schematized in the diagram illustrated in figure 1.

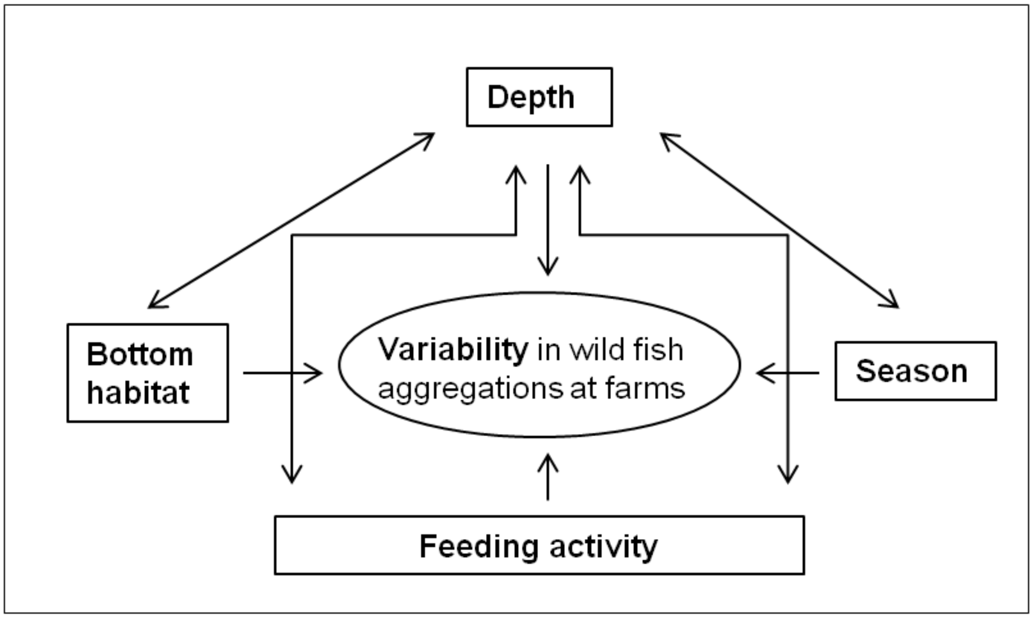

Figure 1 Factors influencing the variability of wild fish aggregations at fish farms

D.2 Seasonal variation is species-specific

The seasonal variability of wild fish aggregations (*chapter 1*) is not farm-dependent, but depends on species-specific seasonal behaviour. The fish community at the bottom of the SB farm was characterized by territorial Mediterranean reef fish species and was stable throughout the year (*chapter 1*) and on a daily basis, not being influenced by the farm feeding activity (*chapter 2*). On the contrary, in the water column species varied among seasons and were sensitive to the farm feeding activity. Of particular interest was *Diplodus sargus* which was hardly recorded at the SB farm in *chapter 1*, but was identified as the most abundant species during the free-diving survey (*chapter 2*). The permanent presence of this species was corroborated by the monthly catch data obtained from the farm employees (*chapter 3*), which revealed a year-round presence of *D. sargus* during two consecutive years (2011, 2012). Interestingly, *D. sargus* has rarely been observed at other Spanish fish farms (e.g. Dempster et al. 2002; Dempster et al.

2005; Valle et al. 2007), whether this is due to the fact that these farms were located over sandy structureless seafloor or because *D. sargus*' abundance was underestimated due to its avoidance of scuba divers is not known. *Oblada melanura* was the only species that was observed all year-round at both, the SB and the ABT farm (*chapter 1*). This species appears to be a permanent species at fish farms in the Mediterranean (Valle et al. 2007; Fernandez-Jover et al. 2008; Šegvić Bubić et al. 2011), showing clear differences in size frequency distribution among seasons. At the ABT farm, only small individuals (4-11 cm, juveniles and advanced juveniles) were recorded. At the SB farm, we observed a similar pattern as described by Fernandez-Jover et al. (2009), small *O. melanura* individuals were present during summer and disappeared in winter and spring. The recruitment peak of *O. melanura* in summer occurred just after the period of reproduction (Bauchot & Hureau 1986), yet to date it is not known whether aggregated fish use fish farms as potential spawning sites. An indication for such spawning events was the collection of eggs inside the ABT cage at the beginning of July 2011 (as part of another project: Gordoa et al. 2009) that could be genetically determined as *Trachurus mediterraneus*. At the ABT farm, adult *Trachurus spp.* were mainly recorded in summer, whereas small individuals (3-8 cm) were present throughout the year, indicating several spawning events during the year, as has been shown for *T. trachurus* (Karlou-Riga & Economidis 1997). Hence, farm-associated fish may benefit from being aggregated in great numbers and use marine fish farms as potential spawning grounds.

The presence of *T. thynnus* during late-spring/summer and its absence in autumn/winter (*chapter 1*) can be explained by its spawning season and migratory pattern (Rooker et al. 2007). However, according to farm managers (pers. com. of the Balfegó Group, L'Ametlla de Mar), its presence continued until December 2011. Wild *T. thynnus* aggregations have also been observed at Croatian ABT farms (Šegvić Bubić et al. 2011), and at seabream and seabass farms in Turkey (Akyol & Ertosluk 2010) and Spain (Dempster et al. 2002; Fernandez-Jover et al. 2008). Atlantic bluefin tuna that are present at Mediterranean fish farms after the spawning season most likely belong to the meta-population resident in the Mediterranean, as discussed by Viñas et al. (2011) and supported by the results of an electronic tagging study (De Metrio et al. 2005). Future electronic tagging programs could further help to determine this species' spatio-temporal patterns in order to better understand the effect of fish farms.

Information on the seasonal pattern of different species is valuable as it provides knowledge of periods when wild fish are aggregated at farm farms, which could make them more vulnerable to fishing. During the field survey for *chapter 1*, we observed large numbers of recreational fishing vessels gathering at the border of the ABT farm, presumably to target aggregated *T. thynnus* and other pelagic species. The highest fishing effort has been observed in summer months (*chapter 3*), coinciding with the aggregation peak at the investigated farms. The Spanish recreational fishery is not obliged to record its catch, except captures of species under special regulatory measures (e. g. *T. Thynnus*), hence, there is a need of studies that take into account the catch of recreational vessels around fish farms.

D.3 Feeding activity

In addition to seasonal changes in fish aggregations (*chapter 1*) we also observed aggregation patterns associated with the feeding activity at the SB farm (*chapter 2*). In the water column (surface to 12 m), the feeding vessel exerted a strong influence on the spatial distribution of aggregated species. *D. sargus*, Mugilidae, *Oblada melanura*, and *Sarpa salpa* were observed to actively follow the feeding vessel, indicating that these species learnt to associate the boat noise with food availability through classic conditioning. In the afternoon, after feeding, *O. melanura* and *S. salpa*, seemed to leave the farm on a daily basis, whereas *D. sargus* and Mugilidae, were found to be very abundant at the farm throughout the day. In contrast, *Pomatomus saltatrix* was almost absent during feeding periods and entered the farm in shoals of hundreds of individuals in the afternoon. One possible explanation may be that this species avoids vessels or human activities, yet *P. saltatrix* has been recorded at other fish farms during feeding periods (e.g. Dempster et al. 2002; Sanchez-Jerez et al. 2008) and is known as an voracious species not avoiding fishing and being a popular game fish. The difference in daily aggregation patterns of these species may be a result of their different feeding ecologies. *P. saltatrix* does not feed on waste food, but predates on aggregated fish (Sanchez-Jerez et al. 2008). As a bentho-pelagic species, *O. melanura* may benefit from the waste food while it is suspended in the surface layer, but leaves the farm after the food is dispersed in favour of a more suitable habitat in search of its natural diet, consisting of benthic microorganisms. *S. salpa* is a generalist herbivore that usually forages on seagrass and benthic algae (Antolic et al. 1994). Our data suggest that this bentho-pelagic species opportunistically changes its feeding habits to benefit from the constant food supply at coastal fish farms. *S. salpa* is a species of high mobility with large home ranges (Pagès et al. 2013) that exhibits distinct diurnal activity patterns, actively grazing during the day and remaining inactive by night in resting areas, usually at the limit of *Posidonia* meadows and sandy patches (Jadot et al. 2006). The demersal species Mugilidae and *D. sargus* exhibited a wide vertical distribution, being opportunistic farm feeders often observed feeding on food pellets at the bottom or and also grazing at nets along the cages. *D. sargus* is a territorial species with a reduced home range (Di Lorenzo et al. 2014) that may leave its territory during the spawning period from March to June (Bauchot & Hureau 1986). Similarly to *D. sargus*, our data suggest that Mugilidae species also spend longer residence times at the farm. In contrast, a tagging study investigating movements of the same Mugilidae species at Spanish fish farms (Arechavala-Lopez et al. 2010) revealed frequent movements among farms and to adjacent fishing areas. Interestingly, the authors did not find any correlation between the presence of tagged Mugilidae and the farm feeding activity, which could explain the results obtained in chapter 2 (no significant differences between feeding and non-feeding periods). Such movements away from the farm may substantially increase vulnerability to fishing (Dempster et al. 2002). Even though *chapter 1 and 2* revealed a tight spatial aggregation pattern of the fish species in the water column, the results of *chapter 3* indicate that there must be some displacement of *Trachurus* spp., *D. sargus* and Mugilidae, because some vessels of the small-scale fleet reported catches of these species in farm proximity. *Trachurus* spp., *D. sargus* and Mugilidae are also the main species targeted by the farm employees inside the farm (*chapter 3*). Therefore, caught individuals may be replaced by new fishes from nearby habitats, since no decrease in annual catches was observed, creating movements towards the farm. Nevertheless, the findings of *chapter 3* suggest that these displacements may not occur in large densities or synchronized enough in order to have a strong effect on fishing catchability of the small-scale fleet.

D.4 Spatial extent of the aggregation effect

In *chapter 1*, we show that at both investigated farms (SB and ABT) the aggregation effect was limited to the cage, revealing an abrupt decline in aggregated fish rather than a gradient. However, the results of *chapter 2* opened a new perspective, revealing the displacement of some species of the water column during non-feeding hours, thereby extending the spatial aggregation extent of the farm. The spatial extent of fish aggregations might have direct implications for the local small-scale fishery, since it determines whether farm-associated fish are accessible to fishermen (*chapter 3*). It has been argued that fish that associate closely with the cage structures for long periods will receive greatest protection from fishing (Dempster et al. 2002). In our study, farm-aggregated fish are targeted by small-scale fishermen outside the farm and by farm employees inside the farm. Yet, due to the tight aggregation of farm-associated fish commercial fishermen do not benefit from this attraction effect (*chapter 3*). At the SB farm, the most vulnerable fish are the ones that aggregate during feeding hours, when they may get caught by farm employees. The species *D. sargus* and *Trachurus spp.* are most vulnerable to fishing activities inside the farm. In contrast, *S. salpa* and *Oblada melanura* are of low commercial interest and not heavily targeted by farm workers.

As shown in *chapter 1*, wild fish assemblages can substantially differ among farms, depending on the farm characteristics and season. Consequently, the effect of fish farms on the local fishery and local wild fish populations may equally vary. However, farms that attract similar type of species can be expected to exhibit similar aggregation patterns, since species are not likely to change their behaviour from one farm to another. Nevertheless, there is a need for more quantitative studies on the effects of coastal aquaculture on local fisheries. The scarcity of such studies is most likely due to the lack of detailed data on the behaviour of local fishing fleets around fish farms (e.g. whether vessels are fishing close to the farm, which gear type they use etc.). In addition, the high diversity of fishing tactics and the concurrent use of different fishing gears per day, as practiced by numerous Mediterranean small-scale fishermen (Forcada et al. 2010), adds a lot of variation and makes the study of this fishery practically unfeasible. Moreover, a high rate of underreporting (ca. 30%), as recorded in *chapter 3* further complicates investigation.

D.5 Social perception of marine fish farming

A relevant output of *chapter 4* is the number of viewpoints underlying the structure of aquaculture perception. This diverse space of perceptions indicates that this topic is not anchored in a bipolar opinion-frame, but in a more diverse one, which may facilitate a deeper understanding of the studied topic. Intermediate perspectives have less weight in the underlying structure, as they are represented by minority groups, but they could be pointing to working paths for a better mutual understanding and possible compromises.

Perception may be based on acquired knowledge or on different particular interests and subjectivities. Each person has its own perspective of the world influenced by knowledge and previous experiences. Chu et al. (2010) showed that stakeholders’ perceptions and expectations of marine aquaculture directly affect people's decision making and subsequent actions. Moreover, the regional settings and conditions can also affect perceptions of aquaculture, including the size and structure of the aquaculture industry, the regional economic diversity, population density and the potential for aquaculture-related conflicts (Mazur & Curtis 2008). At the time of interpreting perceptions it is therefore helpful to try to understand why different stakeholders hold a certain perception.

The positive perception of fish farming by the aquaculture industry is comprehensible and reflects the wish to maintain and develop this activity in the region. The support given by the majority of the administration staff could either indicate that they truly support marine aquaculture or that this perception represents their professional position. The public workers could be fully aware that aquaculture is under their responsibility and they believe they have to express their support, independent of their personal opinion. The third group that strongly supported marine fish farming are those scientists specialized in aquaculture production. The opinion of scientists may be expected to be less subjective and more based on knowledge, however, it seems logical that scientists specialized in aquaculture are in favour of its development, since their work depends on the success of this industry. Respondents of environmental NGOs were the only group that did not support a future marine aquaculture development in Catalonia, since their concerns about direct and indirect environmental damage are high and perceived socio-economic benefits are low.

The perception of fishermen can be expected to be directly influenced by the effect that fish farming exerts on the local fishery, yet the results of *chapter 3* showed no increase or decrease in catches in the proximity of the farm. Consequently, most fishermen did not consider the fishery and fish farms to be in conflict over coastal resources, but they believed that the low price of aquaculture products could negatively impact the price of wild caught fish. At the same time perception 3 and 4 recognized environmental benefits of fish farming (e.g. creating new biotopes/ potential of repopulation) and can be seen as intermediate and less strong-positioned than the first two perceptions. Overall, the fishermen of perception 3 shared a more positive attitude of the fish farming sector, suggesting that the presence of fish farming installations nearby positively influenced their perception of this industry. Hence, the perception that the relationship between wild fisheries and aquaculture is in conflict, may often be based on bias and misconception (Anderson 2002). The future of the aquaculture industry will also depend on the opinion of consumers and the wider public. A key issue for future studies is to analyse which perceptions are shared by the public and which stakeholder group exerts most influence on the public opinion.

D.6 Future studies

The work of this dissertation answered some questions, but opened up many new ones, including the following:

- Could marine fish farms act as spawning grounds for aggregated wild fish?

In the present study we collected eggs of *Trachurus mediterraneus* at the surface within one of the sea-cages of the Atlantic bluefin tuna farm, suggesting that this species has spawned there. Yet, the possibility of farms to act as spawning sites for wild fish has never been investigated. Farm-aggregated species may spawn at fish farm installations to take advantage of the high abundance of conspecifics, minimizing the energetic costs associated with the search for mates. In addition, the high fish aggregations at farms may enhance the probability of egg fertilization. Although coastal fish farms have been shown to act as settlement sites for juvenile fish (Fernandez-Jover et al. 2009), the consequences of such aggregations during the first life stages of fishes is unknown. The farm may act as a refuge, but could also increase predatory pressure due to the presence of carnivorous species (Sanchez-Jerez et al. 2008). Another uncertainty is the effect of farm-feed on the reproductive success of farm-associated species. The high lipid energy recorded in farm-aggregated species at Norwegian farms may positively affect egg production (Dempster et al. 2011), however, it has been argued that changes in biochemical compositions, as observed in Atlantic cod (*Gadus morhua*) could negatively affect egg quality (e.g. Lanes et al. 2012). Therefore, comparisons of the gonadosomatic index as well as egg and larvae quality of farm-aggregated and non-aggregated fish will improve our understanding of the overall effects of farms on wild fish populations.

- How do fish farms affect the local fishery in other areas?

The results of this study cannot be extrapolated to other areas, because the effect depends on the characteristics of each farm and the local fishing practices. It is therefore necessary to approach this topic in other regions to get a deeper understanding of the effect of farms on local fisheries. The effect of farms on the catches of local fisheries cannot be investigated through experimental fishing surveys, since the real fishing practice needs be analyzed. It therefore requires either a strong involvement of local fishermen or the participation of volunteers, as was the case in the present study.

- *Which are the factors shaping the perception of aquaculture in Europe?*

The fish farming sector in other regions of the EU might face similar challenges and limitations as described in this study. Hence, future studies should focus on how the perception of aquaculture differs among EU countries and regions and which are the key factors shaping these attitudes. Perceptions can be expected to vary according to the social, economic and environmental features of each area. Moreover, Whitmarsh & Palmieri (2009) discovered marked differences in attitudes towards aquaculture between stakeholders of different sectors and the wider public in Scotland. Hence, it is important to understand which factors shape people’s attitude about this industry and what information they rely on. The identification of examples of successful integration of aquaculture in the local community and the exchange of experiences and know-how can help to improve the situation in another area.

D.7 CONCLUSIONS

Chapter 1: "Spatial and temporal extension of wild fish aggregations at *Sparus aurata* and *Thunnus thynnus* farms in the north-western Mediterranean"

1. At both farms the attraction effect was limited to the cage, revealing an abrupt decline in aggregated fish at a short distance rather than a gradient, concluding that wild fish are not accessible to local small-scale fishermen while aggregated at farms.
2. At both farms species-specific seasonal aggregation patterns were observed, therefore, the potential of farms to protect wild fish depends on the behaviour of each particular species.
3. The SB farm attracted large aggregations of wild fish throughout the year, whereas at the ABT farm the attraction effect was limited to spring and summer. Consequently, the mitigating effect through waste feed consumption by wild fish takes place all year-round only at the SB farm.
4. At the SB farm, two depth-specific fish assemblages were recorded (bottom and midwater/surface), yet the farm attraction effect was restricted to a small number of species in the water column.
5. All investigated factors: depth, season and distance from cages significantly interacted, emphasizing the importance of applying an integrated approach to study wild fish aggregations at farms.

Chapter 2: "Feeding activity strongly affects the variability of wild fish aggregations within fish farms: a sea bream farm as a case study"

6. Biomass and species composition significantly differed between feeding and non-feeding periods; consequently the farm attraction effect cannot be extrapolated to non-feeding periods and may have been overestimated in previous studies.
7. The feeding vessel strongly influenced the distribution of wild fish aggregations in the water column, suggesting that species learnt to associate the boat noise with food availability through classic conditioning.
8. Rocky-sandy bottoms attracted larger and more diverse fish aggregations compared to sandy stations and even influenced fish abundance in the water column and should therefore be accounted for in future study designs.
9. The free-diving approach was found to be the best method to conduct an intensive sampling scheme and to prevent the underestimation of species, such as *Diplodus sargus* and *Dentex dentex* that avoid disturbance caused by open-circuit scuba gear.

Chapter 3: “Does marine fish farming affect local small-scale fishery catches? A case study in the NW Mediterranean Sea“

10. No farm-effect on the local small-scale fishery in terms of catch, income or species composition was detected. Thus, we conclude first, that the size of the leasehold area represents an effective protection for farm-aggregated fish and second, that displacements of wild fish away from the farm may not occur in large densities or synchronized enough to have an effect on fishing catchability.
11. Farm-aggregated fish are heavily targeted inside the farm, however, we did not detect a decrease in the catch rate from one year to another; suggesting that the removed biomass is continuously replaced.

12. The information of a relevant amount of commercial fishing days in farm vicinity were not recorded in the database of the Fishermen's Association, suggesting a relevant amount of underreporting (30 %) of the local small-scale fishery.

Chapter 4: "Stakeholders' perceptions of marine fish farming in Catalonia (Spain): A Q-methodology approach"

13. The emergence of four perceptions indicates that marine fish farming is seen from diverse perspectives in Catalonia. Consequently, perceptions are not highly polarized and the risk of local conflicts seems relatively low.
14. All four perceptions were represented by the various groups of stakeholders and not all respondents of an interest group shared the same perception, indicating diverse opinions even within sectors.
15. Environmental impacts were not perceived as a high risk by the majority of the participants. The major weaknesses were attributed to economic (e.g. price competition with other producer countries) and social issues (e.g. lack of credible information about farmed products).
16. The Q-methodology is a valuable technique for exploring and explaining patterns in subjectivities of marine fish farming, identifying consensus and contrasts between perceptions and might prove highly valuable in other areas of coastal and ocean management.

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Appendices

Appendix 1 All species recorded at different stations, depths and seasons at an SB farm and an ABT farm in Spain, summer 2010 to spring 2011. C: cage, B: border, L: limit; D. deep water, M: midwater, S: surface; SU: summer, AU: autumn, WI: winter, SP: spring. **+, Δ**, ●: presence of a species

		SB farm										ABT farm									
Family	Species	Station			Depth			Season				Station			Depth			Season			
		C	B	L	D	M	S	SU	AU	WI	SP	C	B	L	D	M	S	SU	AU	WI	SP
Apogonidae	*Apogon imberbis*	+	+	+	Δ			●	●		●										
Balistidae	*Balistes capriscus*												+	+		Δ	Δ		●		
Belonidae	*Belone belone*											+					Δ		●		
Blenniidae	*Parablennius rouxi*	+	+	+	Δ			●	●	●	●										
	Parablennius pilicornis	+	+		Δ			●	●	●	●										
Carangidae	*Seriola dumerili*											+	+	+	Δ	Δ	Δ	●			
	Trachurus spp.	+			Δ	Δ	Δ	●				+	+	+	Δ	Δ	Δ	●	●	●	●
	Trachinotus ovatus	+	+			Δ	Δ	●				+					Δ	●			
Carcharhinidae	*Prionace glauca*											+					Δ				●
Centracanthidae	*Spicara maena*	+	+	+	Δ	Δ			●	●											
Centrolophidae	*Hyperoglyphe perciformis*											+	+	+	Δ	Δ	Δ		●	●	●
Clupeidae	*Sardinella aurita*											+					Δ				●
	Sardina pilchardus			+			Δ		●		●	+			Δ	Δ					●
Congridae	*Conger conger*	+	+	+	Δ			●	●	●	●										
Dasyatidae	*Dasyatis pastinaca*			+	Δ			●													
Gobiidae	*Gobius xanthocephalus*	+	+	+	Δ			●	●	●	●										
	Gobius geniporus	+	+	+	Δ			●	●	●	●										
	Gobius cruentatus	+	+	+	Δ			●	●	●	●										
Labridae	*Coris julis*	+	+	+	Δ			●	●	●	●										
	Ctenolabrus rupestris		+	+	Δ			●			●										
	Labrus merula	+	+	+	Δ			●	●	●	●										
	Labrus bimaculatus			+	Δ			●													
	Symphodus melanocercus	+	+	+	Δ			●	●	●	●										
	Symphodus mediterraneus	+	+	+	Δ			●	●	●	●										
	Symphodus tinca	+	+		Δ				●												

Appendix 1 continued

Family	Species	SB farm										ABT farm									
		Station			Depth			Season				Station			Depth			Season			
		C	B	L	D	M	S	SU	AU	WI	SP	C	B	L	D	M	S	SU	AU	WI	SP
Mugilidae		+			Δ	Δ	Δ	●		●	●	+					Δ	●	●		
Mullidae	*Mullus surmuletus*	+	+	+	Δ			●	●	●	●										
Muraenidae	*Muraena helena*	+	+		Δ			●			●										
Myliobatidae	*Myliobatis aquila*	+	+		Δ		Δ	●													
	Pteromylaeus bovinus	+			Δ	Δ		●			●										
Pomacentridae	*Chromis chromis*	+	+	+	Δ	Δ		●	●	●	●										
Pomatomidae	*Pomatomus saltatrix*	+			Δ			●													
Scombridae	*Sarda sarda*			+		Δ					●	+	+	+	Δ	Δ		●			
	Scomber japonicus											+			Δ	Δ	Δ	●			●
	Thunnus thynnus											+			Δ	Δ		●			●
Scorpaenidae	*Scorpaena scrofa*		+		Δ			●		●											
	Scorpaena notata	+	+		Δ			●	●	●	●										
Serranidae	*Serranus cabrilla*	+	+	+	Δ			●	●	●	●										
	Serranus scriba	+	+	+	Δ			●	●	●	●										
Sparidae	*Boops boops*	+		+	Δ	Δ	Δ		●	●											
	Diplodus vulgaris	+	+	+	Δ	Δ		●	●	●	●	+			Δ					●	●
	Diplodus sargus	+	+	+	Δ			●	●	●											
	Diplodus cervinus	+			Δ			●													
	Diplodus puntazzo	+		+	Δ					●		+				Δ			●		
	Oblada melanura	+	+	+	Δ	Δ	Δ	●	●	●	●	+			Δ	Δ	Δ	●	●	●	●
	Pagellus acarne			+	Δ					●											
	Sarpa salpa	+					Δ	●			●	+			Δ	Δ	Δ			●	●

Appendix 2 All species recorded at the different bottom substrates, depths and feeding and non-feeding periods. F: feeding periods, NF: non-feeding periods R: rocky-sandy, S: sandy; B: bottom, M: midwater, S: surface. ●, Δ, **+**: species presence.

Family	Species	Sampling time		Substrate		Depth		
		F	NF	RS	S	B	M	S
Ammodytidae	*Gymnammodytes cicerelus*	+	+		●	Δ		
Apogonidae	*Apogon imberbis*	+	+	●		Δ		
Belonidae	*Belone belone*	+		●				Δ
Blenniidae	*Parablennius rouxi*	+	+	●		Δ		
	Parablennius pilicornis	+	+	●		Δ		
	Parablennius zvonimiri	+	+	●		Δ		
Carangidae	*Trachurus* spp.	+			●	Δ		
Congridae	*Conger conger*	+	+	●		Δ		
Gobiidae	*Gobius xanthocephalus*	+	+	●		Δ		
	Gobius geniporus	+	+	●		Δ		
	Gobius cruentatus	+	+	●		Δ		
	Gobius niger	+	+	●		Δ		
Labridae	*Coris julis*	+	+	●		Δ		
	Labrus merula	+	+	●		Δ		
	Symphodus mediterraneus	+	+	●		Δ		
	Symphodus tinca	+	+	●		Δ		
Mugilidae		+	+	●	●	Δ	Δ	Δ
Mullidae	*Mullus surmuletus*	+	+		●	Δ		
Muraenidae	*Muraena helena*	+	+	●		Δ		
Myliobatidae	*Myliobatis aquila*		+	●		Δ		
	Pteromylaeus bovinu	+	+	●	●	Δ	Δ	Δ
Pomacentridae	*Chromis chromis*	+	+	●		Δ	Δ	
Pomatomidae	*Pomatomus saltatrix*	+	+	●	●	Δ	Δ	Δ
Scorpaenidae	*Scorpaena notata*	+	+	●		Δ		
Serranidae	*Serranus cabrilla*	+	+	●		Δ		
	Serranus scriba	+	+	●		Δ		
Sparidae	*Diplodus vulgaris*	+	+	●	●	Δ		
	Diplodus sargus (LS)	+	+	●	●	Δ	Δ	Δ
	Diplodus sargus (SS)	+	+	●				Δ
	Diplodus cervinus	+	+	●		Δ		
	Diplodus puntazzo	+		●		Δ	Δ	
	Dentex dentex	+	+	●	●	Δ		
	Oblada melanura (LS)	+	+	●	●	Δ	Δ	Δ
	Oblada melanura (SS)	+	+	●	●	Δ		Δ
	Sarpa salpa	+	+	●			Δ	Δ

Appendix 3: Publication chapter 1

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Spatial and temporal extension of wild fish aggregations at *Sparus aurata* and *Thunnus thynnus* farms in the north-western Mediterranean

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ABSTRACT: Fish farms cause wild fish to aggregate nearby and thus act to modify their distribution, but the spatial and temporal extent of the attraction effect around farms is still poorly understood. We examined attraction using an integrated approach combining 3 factors: spatial extent, depth and season. We analysed an Atlantic bluefin tuna *Thunnus thynnus* (ABT) and a gilthead seabream *Sparus aurata* (SB) farm off the north-eastern coast of Spain which represent different fish farming models in the Mediterranean. Underwater visual counts were conducted from summer 2010 to spring 2011. We recorded 39 species at the SB farm and 17 species at the ABT farm. The analysis of fish abundance and biomass at 3 stations located along a distance gradient from the farm (SB: 0, 30, 200 m; ABT: 0, 100, 200 m) showed significantly higher values next to the cages than at more distant stations, revealing that the spatial extent of the attraction effect was mainly restricted to the cage rather than following a gradient. The intensity of the cage effect varied according to farm, season and depth, reflecting species-specific behaviours. At the SB farm, the cage effect persisted year round, varying with depth, whereas at the ABT farm, the effect was only detected in summer and spring. These distinct spatial and temporal aggregation patterns suggest that implementation of fishery regulatory measures to protect wild fish should be farm-specific. This study emphasizes the importance of using an integrated approach to study wild fish aggregations at farms.

KEY WORDS: Sea-cage · Aquaculture · Wild fish · Attraction effect · *Sparus aurata* · *Thunnus thynnus* · Mediterranean

INTRODUCTION

The impact of human activities on marine ecosystems extends around the world. A recent global study revealed that no area is unaffected by human influences and that a considerable proportion (41%) is heavily affected by multiple drivers (Halpern et al. 2008). Coastal areas in particular are being impacted by a wide variety of human activities as a consequence of the pressures of population growth (Burbridge 1999). Aquaculture is an activity that has been expanding rapidly in recent years due to the worldwide demand for seafood. This anthropogenic activity generates new feeding grounds for wild fish populations in the littoral zone. Several studies have shown that fish farms attract wild fish in their near vicinity, thereby altering natural distribution patterns (e.g. Carss 1990, Dempster et al. 2002, Boyra et al. 2004). Apart from high food availability, the presence of an artificial structure and the chemical attraction to farmed fish have been put forward as influences contributing to this aggregation effect (Tuya et al. 2006). The physiological consequences of this new food source on local fish populations are still unclear

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(Fernandez-Jover et al. 2011). A recent study has shown that farms do not seem to negatively affect wild fish species like saithe *Pollachius virens* and Atlantic cod *Gadus morhua* but rather act to enhance the body condition of farm-associated fish (Dempster et al. 2011). In parallel, consumption of lost food by wild fish may buffer the environmental impact on the benthos underneath farms (e.g. Lupatsch et al. 2003, Vita et al. 2004). Therefore, it has been argued that fish harvesting should be avoided in the vicinity of farms (Dempster et al. 2006), in order to fully benefit from the recycling function of wild fish. However, the spatial extent of fish aggregations around farms has been poorly studied to date. Previous work has examined differences between farms and distant control locations (e.g. Dempster et al. 2002, Boyra et al. 2004) and only recently has the distance factor been examined in the vicinity of Norwegian salmon farms (Dempster et al. 2010).

The natural distribution of fish populations in the littoral zone is influenced by different factors, such as depth (Bell 1983, García-Charton & Pérez-Ruzafa 1998) and habitat structure (Letourneur et al. 2003, Lombarte et al. 2012), which influence the type and distribution of food and shelter (García-Charton & Pérez-Ruzafa 2001). Depth has also been identified as an important factor determining spatial patterns of fish aggregations at fish farms (Dempster et al. 2005, Sudirman et al. 2009). In addition, previous studies have shown that the species composition of fish aggregations at farms changes with the season (Valle et al. 2007, Fernandez-Jover et al. 2008), indicating species-specific residence times at farms. Although the spatial and temporal variability of farms has been studied previously, no systematic approach to assess the spatial and temporal extent of the attraction effect has yet been undertaken. An understanding of whether this attraction persists across seasons, how it changes with time, and what spatial distances and depths are reached is essential. Despite the growing number of publications on the variability of wild fish aggregations at fish farms which have taken different factors into account (Table 1), an integrated analysis is currently lacking. This study is intended to begin filling this gap by putting forward a comprehensive approach that analyses and combines the main factors known to influence wild fish aggregations, namely spatial extent, depth and season. Determining these factors has implications for future regulatory measures to be implemented for fish farms. The specific objectives of this study were to examine the horizontal spatial attraction range along a distance gradient away from the farm for each depth, and to investigate temporal variability.

Sampling was carried out at 2 fish farms that represent different fish farming models in the Mediterranean Sea: an Atlantic bluefin tuna *Thunnus thynnus* (ABT) farm and a gilthead seabream *Sparus aurata* (SB) farm. Gilthead seabream has been cultured extensively for many years throughout the Mediterranean (FAO 2008), and ABT capture-based aquaculture, known as fattening farms, have developed rapidly and today are present in the waters of 9 Mediterranean countries (see www.ICCAT.int).

Table 1. Summary of studies that have investigated different factors influencing variation in fish aggregations at marine fish farms. Farm types: GR/RA = mixed groupers (*Epinephelus fuscoguttatus* and *Cromileptes altivelis*) and rabbitfish *Siganus* spp., SB/ESB = mixed gilthead seabream *Sparus aurata* and European seabass *Dicentrarchus labrax*, WSB = white seabass *Atractoscion nobilis*, ABT = Atlantic bluefin tuna *Thunnus thynnus*, AS = Atlantic salmon *Salmo salar*. Depths: S = surface, M1 = intermediate cage depth, M2 = between the cage and the sea bottom, AB = above bottom, B = bottom

Study location	No. farms	Factors	Farm type	Sampling sites	Sampling depths	Sampling period	Source
Spain	9	Distance between farms	SB/ESB	Cage, 200 m	Integrated (5–10 m)	Sep/Oct	Dempster et al. (2002)
Spain	5	Depth	SB/ESB	Cage	S, M1, M2, B	Oct/Nov	Dempster et al. (2005)
Norway	9	Depth	AS	Cage, 1–2 km	S, M1, M2, AB, B	Summer	Dempster et al. (2009)
Indonesia	1	Depth, time of day	GR/RA	Cage	1–3, 3–6, 6–9, >9 m	Dec–Apr	Sudirman et al. (2009)
USA	1	Depth, season	WSB	Cage, 200 m	S, M1, B	1 yr	Oakes & Pondella (2009)
Spain	1	Season	SB/ESB	Cage, 200 m	Integrated (5–10 m)	1 yr	Valle et al. (2007)
Spain	3	Season	SB/ESB	Cage	Integrated (5–10 m)	2 yr	Fernandez-Jover et al. (2008)
Canary Isl.	2	Season	SB/ESB	Cage, 500 m – 1 km	Integrated	1 yr	Boyra et al. (2004)
Croatia	2	Season	ABT	Cage, 200 m	Integrated (0–15 m)	1 yr	Šegvić Bubić et al. (2011)
Norway	9	Spatial extent	AS	Cage, 25, 50, 200 m	Integrated (5 m–B)	Jul/Oct	Dempster et al. (2010)
Spain	1	Extent, depth, season	ABT	Cage, 100, 200 m	S, M1, M2	1 yr	Present study
Spain	1	Extent, depth, season	SB	Cage, 30, 200 m	S, M1, B	1 yr	Present study

MATERIALS AND METHODS

Study site and farm characteristics

The selected farms are located in the littoral area influenced by the Ebro River in the north-western Mediterranean Sea (Fig. 1) off their common home port of L'Ametlla de Mar (40° 53′ 10″ N, 0° 48′ 13″ E). The SB farm is located about 1 km from the coast over a rocky-sandy bottom with a bottom depth of 20 m. The farm started operating in 1993, consists of 30 circular cages (each 19 m in diameter) with a net depth of 10 m, and covers a leased area of 400 000 m^2. On average, the farm contains 850 t of stocked fish biomass and produces 800 t of *Sparus aurata* annually. Farmed fish are fed 2500 t yr^{-1} of dry food pellets based on fish meal and vegetable oil. The ABT farm is located farther offshore (4.5 km) over a mixed gravel-mud-sand bottom with a bottom depth of 45 m. The farm started operating in 2004, and the total leased area is 300 000 m^2. During the study, 2 oval cages (each 120 × 60 m) and 4 round cages (each 50 m in diameter) with a net depth of 30 m were in use. On average, the farm stocks 700 t of wild adult *Thunnus thynnus* caught in the western Mediterranean spawning grounds and reaches an annual production of about 990 t. The tunas are exclusively fed with frozen fish (5700 t yr^{-1}) such as Atlantic mackerel *Scomber scombrus*, round sardinella *Sardinella aurita*, European pilchard *Sardina pilchardus* and Atlantic herring *Clupea harengus*.

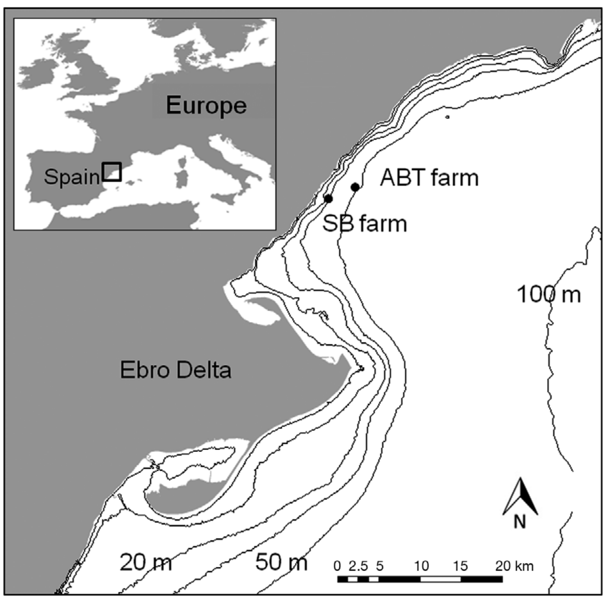

Fig. 1. Study stations adjacent to the Ebro River Delta off the north-eastern coast of Spain. SB: gilthead seabream, ABT: Atlantic bluefin tuna

Water temperature and visibility

Temperature and underwater visibility displayed high variability during the study period. Water temperature at the 2 farms ranged from a minimum of 12.3°C in winter to a maximum of 25.5°C in summer. Underwater visibility varied greatly from one day to another, and values were often low, which was expected due to the influence of the Ebro River runoff (Cruzado et al. 2002, Gordoa et al. 2008). The minimum and maximum visibility over the year ranged from 5 to 20 m, with lowest visibilities near the bottom during cold months and highest visibilities at the surface and midwater in summer and spring. Sampling was only conducted on days with at least 5 m of visibility.

Sampling design

Wild fish at both fish farms were counted by means of an underwater visual census (UVC). The spatial horizontal design at each farm comprised 3 fixed sampling stations located along a distance gradient from the farm within each farming concession area. The 3 sampling stations were chosen according to the different spatial dimensions of the cages (Fig. 2). Stations were: (1) cage: right next to one of the cages (distance 0 m), (2) border: off the edge of the cages (distance: SB farm 30 m, ABT farm 100 m) and (3)

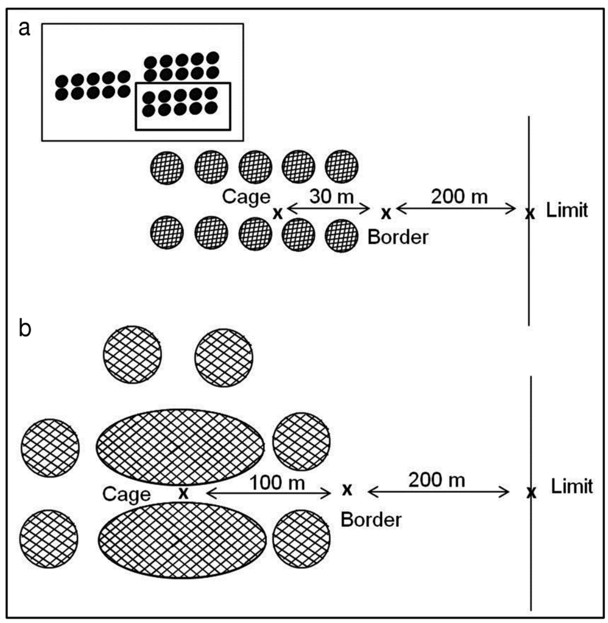

Fig. 2. Layout of the (a) gilthead seabream farm and (b) the Atlantic bluefin tuna (ABT) farm with corresponding sampling stations. Xs indicate the positions of the 3 types of sampling stations (cage, border, limit)

limit: at the boundary of the leasehold area (distance: 200 m). The 3 stations at each farm had the same ecological features: depth, bottom type and distance to the shore. Visual surveys at each station were performed in 3 distinct depth strata: surface (0–3 m), midwater (8–12 m) and deep/bottom (18–20 m). Bottom depths varied greatly between the 2 farms, hence the deep depth stratum was representative of the bottom at the SB farm but not at the ABT farm. Due to logistical constraints associated with no-decompression diving limits, we chose 20 m, i.e. the bottom depth at the SB farm, as the depth limit for the UVC.

Sampling was carried out from summer 2010 to spring 2011 on 3 randomly selected days per season. At each station, we performed 1 count d^{-1} $depth^{-1}$, resulting in a total of 108 fish counts at each farm. All surveys were performed during morning hours (8:30 to 12:00 h). The UVC counts were carried out using a method developed by Dempster et al. (2005) which is robust for comparisons of counts at different depth levels and at different visibilities. The method depends on stationary timed counts during which the diver rotates through 360°. To standardize the counts, fish are only counted from 1 m above to 1 m below eye level out to a radius of 5 m. Bottom counts at the SB farm were conducted kneeling on the seafloor and spanned the zone from the substrate to 2 m above. Counts lasted 7 min at each depth. All UVCs were performed by 2 divers. While the first diver concentrated on estimating the abundance of the dominant species, the second diver looked for more cryptic species. During the 7 min, the maximum number of individual fish of each species observed at any one time was recorded. This made it more unlikely to count the same fish twice. For schools of up to 20 fish, individual fish were counted; for larger shoals, estimates were obtained by subdividing the shoals into imaginary subgroups of equal size, counting the individuals in one of the subgroups and multiplying that count by the number of subgroups. The total length of individuals was recorded, and the biomass was calculated based on published length–weight relationships for each species (Morey et al. 2003, www.fishbase.org). Mugilidae species could not be identified visually to species level and were therefore recorded at the family level. Similarly, *Trachurus mediterraneus* and *T. trachurus* were recorded as *Trachurus* spp.

Statistical analysis

The assumptions of normality and homogeneity of variance can often be difficult to fulfil with biological data. A good alternative is the analysis of variance based on permutations (PERMANOVA), as it allows multivariate data to be analysed in the context of complex experimental designs and provides a robust approach to deal with skewed data and many zero counts (Anderson 2001). Therefore, all univariate and multivariate statistical analyses were carried out using the PRIMER V6.1.13 computer program (Clarke & Gorley 2006) with the PERMANOVA+ V1.0.3 add-on package (Anderson et al. 2008).

Univariate analysis

A univariate PERMANOVA with 3 factors (station, depth, season, all fixed) was performed to test differences in total fish abundance and biomass for each site. The similarity matrix was computed using the Euclidean distance on square root-transformed data, and post hoc pairwise comparisons were used to investigate significant results. In addition, the number of species per station, depth and season was estimated. For direct comparison between the SB and ABT farms, the deep stratum at the SB farm, which represents the bottom community unreachable at the ABT farm, was excluded.

Multivariate analysis

Permutational multivariate analysis of variance was used to test the differences in wild fish aggregations at the different stations, depth strata and seasons (PERMANOVA, Anderson 2001, Anderson et al. 2008). Prior to analysis, the data were fourth-root transformed in order to downweight the influence of more abundant species, whilst preserving information on relative abundance (Clarke & Green 1988). Since the Bray-Curtis similarity measure is undefined for 2 empty samples, we used the zero-adjusted Bray-Curtis for which a 'dummy species' is added to the original abundance matrix in order to generate meaningful non-metric multidimensional scaling (nMDS) displays (Clarke et al. 2006). nMDS ordinations averaged by season were produced to depict the multivariate patterns of fish aggregations. Statistical significance was tested using 9999 permutations of residuals under a reduced model (Freedman & Lane 1983) and Type III (partial) sums of squares (SS; Anderson et al. 2008). Significant terms were further examined by applying appropriate post hoc pairwise comparisons. We applied the similarity percentage analysis (SIMPER) routine to examine species contributions to within-group similarity for the most important factor at each farm.

RESULTS

Composition of wild fish species

In total, 14 475 individual fish were counted at the SB farm and 5627 at the ABT farm, belonging to 47 species and 23 families (Appendix 1). The vast majority of the species were Osteichthyes, only 4 being Chondrichthyes, including 3 species of rays and 1 blue shark *Prionace glauca*. In all, 39 species (17 families) were recorded at the SB farm and peripheral stations, the most common families being Sparidae (8 species) and Labridae (7 species). At the ABT farm and peripheral stations, 17 species belonging to 9 different families were observed, the most common being Sparidae (4 species) followed by Clupeidae (3 species) and Carangidae (3 species). The censuses included 2 unusual sightings in the Mediterranean, the barrelfish/driftfish *Hyperoglyphe perciformis* and the blue shark. Forty of the observed species are targeted by local fishermen. The number of species was higher at the cage than at the border and limit stations at both farms (Appendix 1).

SB farm

Fish were significantly more abundant at the cage compared to the border and the limit stations (mean ± SE abundance; cage: 240 ± 30, border: 73 ± 20, limit: 97 ± 28; Table 2, Fig. 3a). Similarly, biomass values were substantially higher at the cage compared to the border and the limit (mean ± SE biomass in kg; cage: 73.4 ± 16.6, border: 2.7 ± 1.2, limit: 1.3 ± 0.4; Table 2, Fig. 3b). However, the fish distribution was not homogeneous across depths. Significant differences in abundance and biomass at the cage compared to the border and the limit were only observed in the midwater and surface strata. At the bottom, abundance and biomass did not vary between the cage and the border but were significantly higher than at the limit (Fig. 3a,b). Overall, fish were more abundant at the bottom compared to the midwater (3 times; $p < 0.001$) and surface strata (2.4 times; $p < 0.001$; Table 2), although total fish biomass did not differ among depths (Fig. 3a,b). Fish abundance and biomass at the cage did not vary by season except in autumn, when small species were most abundant, resulting in significantly lower biomass values at that time of year. The higher abundance and biomass observed at the cage was constant all year round, except in autumn, when fish abundance at the cage was not significantly higher than at the limit (Fig. 3c,d, Table 2, triple interaction). Fish abundance at the limit revealed a different seasonal pattern compared to the other stations, attaining the highest values in summer and autumn and the lowest values in winter and spring (Fig. 3c).

At the cage, the species composition differed significantly from those at the border and the limit (Table 2). However, variability in the fish community was heavily depth-dependent, with a clear separation between the bottom and the water column (midwater and surface strata) all year round (nMDS ordination; Fig. 4). Midwater and surface aggregations differed from each other only in summer (Table 2). SIMPER analysis showed that assemblages at the bottom were stable over time at all stations and were largely (>50%) represented by 3 species (*Chromis chromis*, *Coris julis* and *Serranus cabrilla*; Table 3). In contrast, cage-aggregations in the water column differed significantly from those at the border and the limit, mirroring the spatial and seasonal aggregation patterns found for abundance and biomass (Table 2).

Table 2. Gilthead seabream (SB) farm: summary of results of permutational univariate and multivariate analysis of variance comparing abundance, biomass and species community for the factors station (ST), depth (DE) and season (SE) and post hoc tests for significant factors and interactions. C: cage, B: border, L: limit; D: deep water, M: midwater, S: surface; SU: summer, AU: autumn, WI: winter, SP: spring. Significant at *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Source	df	Total abundance MS	*F*	Total biomass MS	*F*	Species community MS	*F*
ST	2	703	21.95***	337130	29.34***	7963	9.23***
DE	2	887	27.70***	10073	0.88	56209	65.15***
SE	3	12	0.36	16191	1.41	2533	2.94***
ST × DE	4	72	2.24	45226	3.94**	4002	4.64***
ST × SE	6	65	2.02	16692	1.45	2055	2.38***
DE × SE	6	26	0.80	11495	1.00	1664	1.90***
ST × DE × SE	12	79	2.46*	12323	1.07	1143	1.32*
Residuals	69	32		11490		863	

Post hoc comparisons	Abundance/biomass		Species community
ST	C ≠ B = L	ST × DE	S: C ≠ B = L
DE	D ≠ M = S		M: C ≠ B ≠ L
	Biomass		D: C = B ≠ L
ST × DE	S: C ≠ B = L	ST × SE	SU/WI/SP: C ≠ B = L
	M: C ≠ L ≠ B		AU: C = B; C = L; B ≠ L
	D: C = B ≠ L	DE × SE	AU/WI/SP: D ≠ M = S
			SU: D ≠ M ≠ S

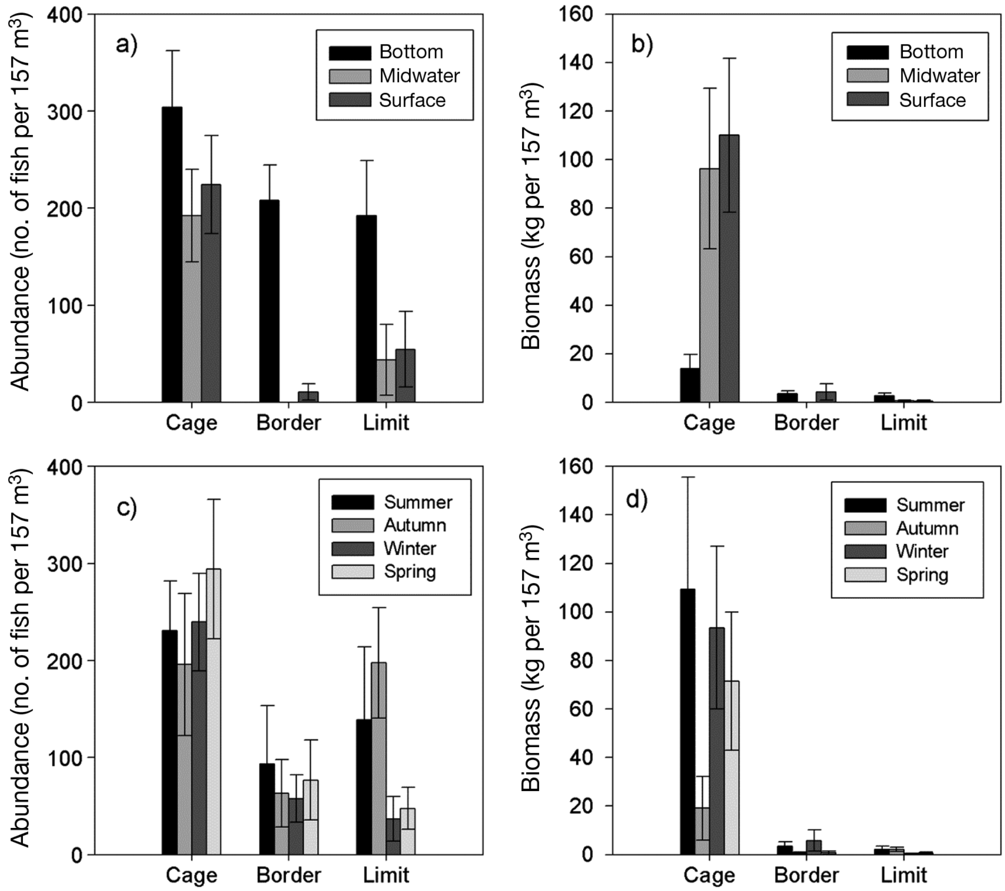

Fig. 3. Total abundance and biomass (kg) of wild fish at the gilthead seabream (SB) farm (a,b) by sampling station and depth and (c,d) by sampling station and season. Bars are mean ± SE of 12 underwater visual counts in a volume of 157 m^3

This aggregation pattern was stable over time, except in autumn, when fish assemblages at the cage did not differ from those at the border and the limit (Table 2). Cage-aggregations in the water column were dominated by 6 species which accounted for 94 % of total abundance (Fig. 5). Abundance values for these species varied by season, each season being characterised by a different combination of species (summer: *Oblada melanura*, Mugilidae, *Trachinotus ovatus*, *C. chromis* and *Sarpa salpa*; autumn: *Boops boops*; winter: *O. melanura*, *B. boops*; spring: *C. chromis*, *O. melanura*, Mugilidae; Fig. 5).

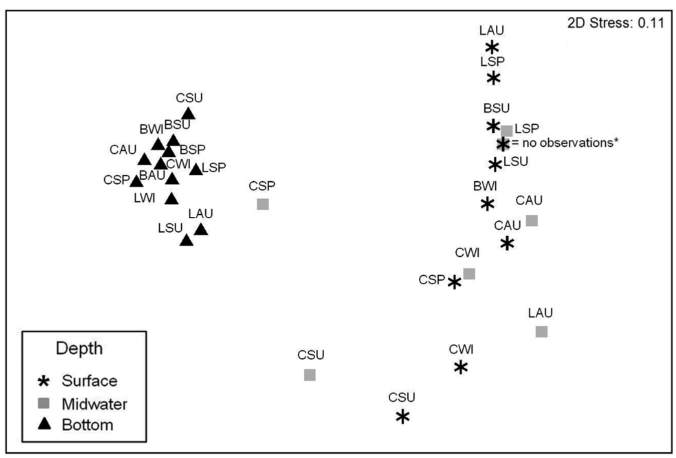

Fig. 4. Non-metric multidimensional scaling ordination plot of wild fish assemblages at the gilthead seabream (SB) farm based on a Bray-Curtis similarity matrix of fourth-root transformed abundance data, averaged per season (C = cage, B = border, L = limit; SU = summer, AU = autumn, WI = winter, SP = spring). Samples without fish observations ('no observations') were placed together; surface: BSP, LWI, BSU; midwater: BSU, LSU, BSP, BAU, BWI, LWI. Stress = 0.11

ABT farm

The majority of fish were observed at the cage, where abundance values were higher than at the border and the limit (mean ± SE abundance; cage: 113 ± 28, border: 12 ± 4, limit: 31 ± 10; Table 4). Likewise, fish biomass was substantially higher at

Table 3. Gilthead seabream (SB) farm. Results of the similarity percentage analysis showing the species contribution to within-group similarity (%) by sampling station and depth stratum. Full species names are listed in Appendix 1

	Cage	%	Border	%	Limit	%
Surface	*O. melanura*	83.0	All similarities are zero		*S. pilchardus*	100.0
	B. boops	10.1				
Midwater	*C. chromis*	39.3	No species observed		*B. boops*	100.0
	Mugilidae	27.5				
	O. melanura	23.8				
Bottom	*C. chromis*	32.0	*C. chromis*	33.1	*C. chromis*	34.0
	S. cabrilla	17.1	*C. julis*	19.4	*C. julis*	23.7
	C. julis	16.9	*S. cabrilla*	14.0	*D. vulgaris*	16.1
	G. xanthocephalus	7.4	*S. scriba*	12.8	*S. cabrilla*	12.9
	P. pilicornis	7.1	*D. vulgaris*	8.0	*O. melanura*	3.9
	S. scriba	5.0	*G. xanthocephalus*	4.3		
	P. rouxi	4.1				
	D. vulgaris	4.1				

the cage compared to the border and the limit (mean ± SE biomass in kg; cage: 424.8 ± 158.4, border: 4.2 ± 2.3, limit: 5.1 ± 4.3, $p < 0.001$; Table 4, Fig. 6a,b). Abundance and biomass at the cage varied significantly with season (Table 4), with higher values in summer and spring compared to autumn and winter (Fig. 6c,d). Indeed, fish biomass was strongly affected by seasonality, and as a consequence higher biomass values at the cage compared to the border and the limit were only detectable in summer and spring (Fig. 6d) and were restricted to the deep and midwater strata (significant interactions, Table 4, Fig. 6b). Overall, the highest fish biomass was recorded for the deep and midwater strata. However, these high values only occurred in summer, due to the presence of wild *Thunnus thynnus* which contributed 94.3% to the total fish biomass recorded in this season. During the rest of the year, no differences were recorded among depths (Table 4).

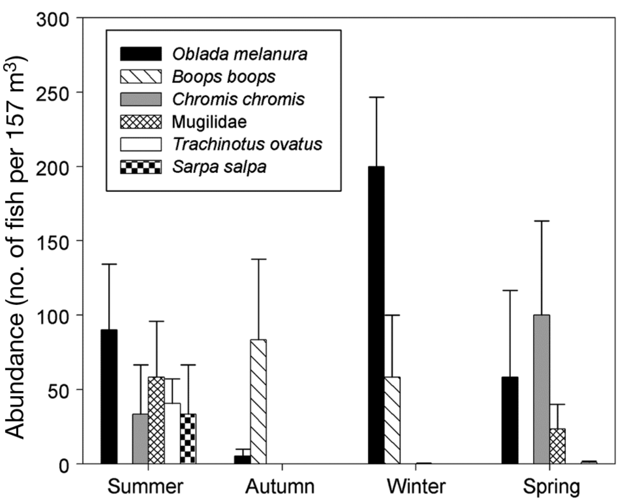

Fig. 5. Total abundance (mean ± SE) of the 6 most abundant species at the gilthead seabream (SB) farm in the midwater and surface strata at the cage by season

Wild fish communities at the cage differed significantly from those at the border and the limit in all 3 depth strata (Table 4). SIMPER analysis revealed that cage assemblages consisted mainly of 4 species (*Thunnus thynnus*, *Oblada melanura*, *Sarpa salpa* and *Sardina pilchardus*), which accounted for 91% of the group similarity. By contrast, fish aggregations at the border and the limit were dominated by *Trachurus* spp. (59%), *Hyperoglyphe perciformis* (22%) and *Seriola dumerili* (10%). The separation of the cage aggregations from the border and limit aggregations was confirmed by the nMDS ordination, but there was no clear interpretation for samples by depth and season (Fig. 7). Differences in fish aggregation patterns were only observed during summer and spring, while in autumn and winter, fish assemblages were station-independent (Table 4). Assemblages at the cage in summer and spring were clearly dominated by *T. thynnus*. Conversely, *T. thynnus* was never recorded at either the border or limit stations (Table 5). In autumn and winter, fish assemblages at the 3 stations were mainly composed of different species (Table 5). Assemblages at different depths did not differ by season except in summer, when there was a different predominant species at each depth (surface: *S. dumerili*, midwater: *T. thynnus*, deep: *Sarda sarda*). At the cage, each season exhibited a different species prevalence (summer: *O. melanura*, *Scomber japonicus*, *T. thynnus*; autumn: *O. melanura*; winter: *O. melanura*, *S. salpa*; spring: *O. melanura*, *S. pilchardus*, *S. japonicus*, *S. salpa*, *Sardinella aurita*, *T. thynnus*), which together accounted for 91% of total fish abundance (Fig. 8).

Inter-farm differences

The greater species diversity and fish abundance recorded at the SB farm was ascribable to the bottom

Table 4. Atlantic bluefin tuna (ABT) farm. Summary of results of permutational univariate and multivariate analysis of variance comparing abundance, biomass and species community for the factors station (ST), depth (DE) and season (SE) and post hoc tests for significant factors and interactions. C: cage, B: border, L: limit; D: deep water, M: midwater, S: surface; SU: summer, AU: autumn, WI: winter, SP: spring. Significant at *p < 0.05, **p < 0.01, ***p < 0.001, ns = non-significant

Source	df	Total abundance MS	Total abundance *F*	Total biomass MS	Total biomass *F*	Species community MS	Species community *F*
ST	2	293.99	10.20***	1195600	30.83***	6757	7.08***
DE	2	47.45	1.65	434790	11.21***	5507	5.77***
SE	3	97.10	3.37*	602830	15.54***	5411	5.67***
ST × DE	4	71.03	2.47	301250	7.77***	3484	3.65***
ST × SE	6	31.65	1.10	379900	9.79***	1934	2.03**
DE × SE	6	12.10	0.42	169150	4.36***	2217	2.32***
ST × DE × SE	12	14.80	0.51	116090	2.99**	1241	1.30
Residuals	72	28.81		38785		954	

Post hoc comparisons			Biomass	Species community
	Abundance/ Biomass	ST × DE	S: C = B = L	S: C ≠ B = L
ST	C ≠ B = L		M: C ≠ B = L	M: C ≠ B = L
DE	ns D ≠ M = S		D: C ≠ B = L	D: C ≠ B ≠ L
SE	SU = SP ≠ WI = AU	ST × SE	SU/SP: C ≠ B = L	SU/SP: C ≠ B = L
			AU/WI: C = B = L	AU/WI: C = B = L
		DE × SE	SU: D = M ≠ S	SU: D ≠ M ≠ S
			AU/WI/SP: D = M = S	AU/WI/SP: D = M = S

community (26 species, see Appendix 1), which was excluded from the comparative analysis performed here (see 'Materials and methods'). The results of previous statistical analyses carried out in the present study showed that attraction at both farms was restricted to the cage station, though with significant differences by season. Taking into account only the cage sampling station at both farms, we recorded a total of 5001 individual fish (10 species) at the SB farm and 4053 fish (16 species) at the ABT farm. The total sampled fish biomass at the cage during the study period was 6 times higher at the ABT farm (15.3 t yr^{-1}) compared to the SB farm (2.5 t yr^{-1}). Species diversity at both farms was highest in spring and summer. The seasonal variations in abundance at both farms

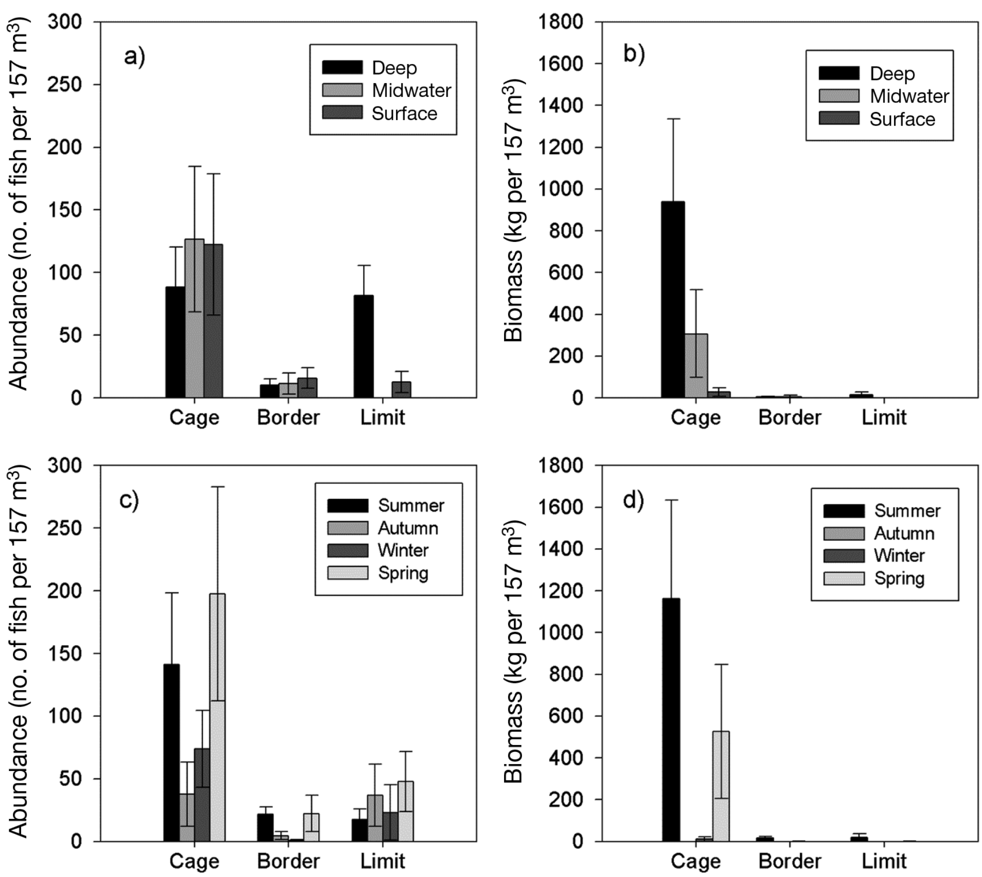

Fig. 6. Total abundance and biomass (kg) of wild fish at the Atlantic bluefin tuna (ABT) farm (a,b) by sampling station and depth and (c,d) by sampling station and season. Bars are mean ± SE of 12 underwater visual counts in a volume of 157 m^3

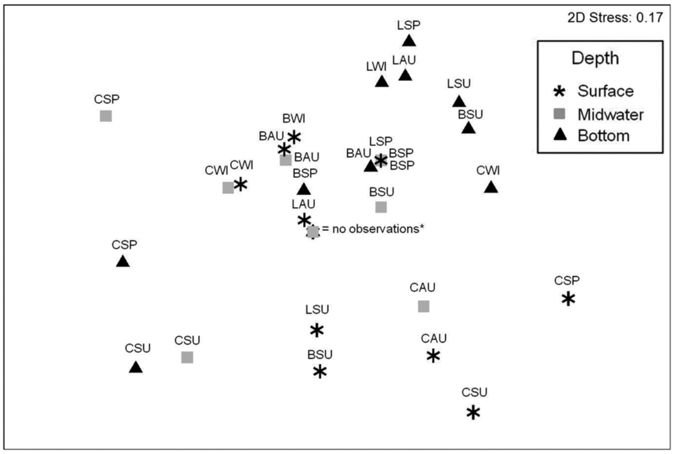

Fig. 7. Non-metric multidimensional scaling ordination plot of wild fish assemblages at the Atlantic bluefin tuna (ABT) farm based on a Bray-Curtis similarity matrix of fourth-root transformed abundance data, averaged per season (C = cage, B = border, L = limit; SU = summer, AU = autumn, WI = winter, Sp = spring). Samples without fish observations ('no observations') were placed together; surface: BSP, LWI, LSP; midwater: BWI, BSP, LSU, LAU, LWI, LSP; deep: CAU, BWI. Stress = 0.17

notwithstanding, differences between the farms were recorded all year long except in spring (Fig. 9).

DISCUSSION

Our study revealed a strong attraction effect for wild fish at both investigated fish farm facilities. Cage aggregations differed from those at the border and limit stations in abundance, biomass and fish community, revealing an abrupt decline in aggregated fish at a short distance from the cage rather than a gradient. However, the spatial and temporal extent of the cage attraction effect was different at each farm type. Different species exhibited species-specific spatial and seasonal aggregation patterns, depending on their ecology.

The SB farm attracted large aggregations of wild fish throughout the year, and no seasonal variability in abundance was recorded, indicating that this aquaculture facility provides a permanent habitat for local fish populations. There were 2 depth-specific fish assemblages: a bottom community characterised by high diversity (35 species) and a water-column community composed mainly of 6 species. The total number of species recorded was more than twice the maximum previously reported at SB farms in the Mediterranean (Dempster et al. 2002). We attribute this difference to the absence of any analysis of the bottom community in most previous studies, with the exception of Dempster et al. (2005), in which the sandy bottom type may have been responsible for the lower diversity (14 species), fish abundance and biomass being higher in the water column than on the bottom. Contrary to the abundance pattern, our biomass results corroborated the findings of Dempster et al. (2005) because of species size differences at the different depths.

SB community composition on the bottom was represented by the typical Mediterranean reef fish species (e.g. Dufour et al. 1995, García-Charton & Pérez-Ruzafa 2001, Gordoa 2009) at all 3 sampling stations and was very stable over time. Differences in abundance were observed only at the limit of the leasehold area, probably caused by lower abundance of just a few benthic species, such as blennids and gobiids. This difference suggests that bottom fish species are also attracted to the high food availability around the cages. Moreover, this shows that the SB farm did not exert a negative effect on the fish community on the rocky bottom underneath the farm. At farms that aggregate both pelagic and demersal species, unconsumed food and faeces from farmed fish will be consumed in the water column and at the bottom. It thus follows that the mitigating influence of wild fish on farm effluent dispersal should be consid-

Table 5. Atlantic bluefin tuna (ABT) farm. Results of the similarity percentage analysis showing the species contribution to within-group similarity (%) by season at the 3 sampling stations. Full species names are listed in Appendix 1

	Summer	%	Autumn	%	Winter	%	Spring	%
Cage	*T. thynnus*	81.1	*O. melanura*	100.0	*S. salpa*	100.0	*T. thynnus*	58.5
	S. dumerili	9.6					*S. pilchardus*	35.0
Border	*S. dumerili*	52.6	*B. capriscus*	58.6	*H. perciformis*	100.0	*Trachurus* spp.	100.0
	S. sarda	30.8	*H. perciformis*	41.4				
	Trachurus spp.	16.7						
Limit	*S. sarda*	41.5	*Trachurus* spp.	100.0	*H. perciformis*	100.0	*Trachurus* spp.	94.9
	S. dumerili	35.9						
	Trachurus spp.	22.6						

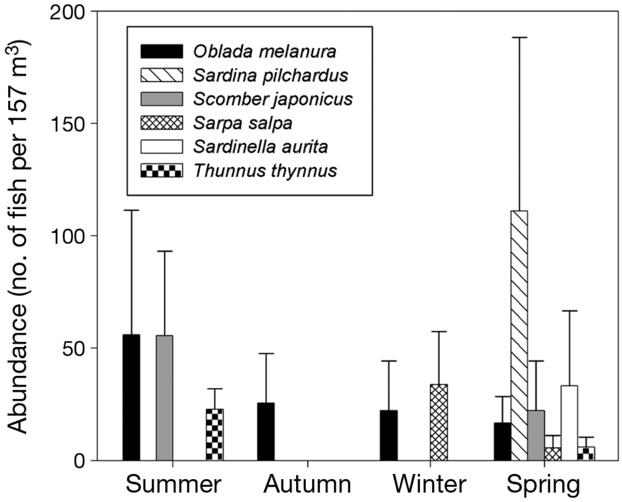

Fig. 8. Total abundance (mean ± SE) of the 6 most abundant species at the Atlantic bluefin tuna (ABT) farm at the cage by season

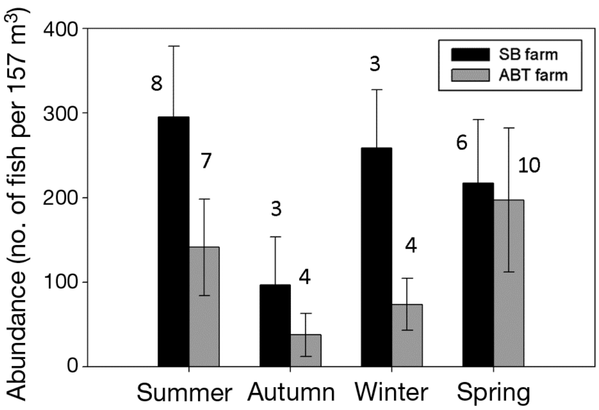

Fig. 9. Total abundance (means ± SE) and number of fish species (on top of bars) at the cage by season at the gilthead seabream (SB) and Atlantic bluefin tuna (ABT) farms. Values for the SB farm include counts from the midwater and surface strata only (see 'Materials and methods')

ered, and it has been suggested that farms may be better sited over artificial reefs (Angel et al. 2002) that could increase consumption of waste particles. Similarly, mixed rocky-sandy bottoms, which sustain a more numerous and diverse fish community than sandy bottoms, may have the potential to increase waste particle consumption. Still, the impact on other rocky bottom organisms needs to be taken into account.

The fish community in the water column at the cage was dominated by a relatively small number of species (*Oblada melanura*, *Boops boops*, *Chromis chromis*, Mugilidae, *Trachinotus ovatus* and *Sarpa salpa*) which, except for *C. chromis*, have been reported to dominate fish aggregations in previous SB farm studies (e.g. Dempster et al. 2002, Fernandez-Jover et al. 2008). Due to the rocky-sandy bottom, we observed high abundances of *C. chromis* year round, which indicates that bottom type also exerts an influence on the water column community. Larger individuals of *C. chromis* frequently moved from the bottom to a depth of 10 m and fed actively on uneaten food pellets. The seasonal aggregation patterns of the most abundant species *O. melanura* (all year long) and *B. boops* (higher abundance in autumn and winter) were consistent with the results of previous studies (Valle et al. 2007, Fernandez-Jover et al. 2008). Some species such as *Diplodus sargus* and *Pomatomus saltatrix* were observed when we entered the water before starting the survey but were seldom recorded during counting. Thus, we presume that these species avoid divers and are underestimated with the scuba diving methodology. These limitations of underwater visual counts have been described in previous studies (e.g. Thresher & Gunn 1986).

The ABT farm attracted large aggregations of wild fish, although this effect exhibited strong seasonal variability. Our censuses recorded 17 species compared to the 20 species recorded at 2 Croatian ABT farms (Šegvić Bubić et al. 2011). Substantial differences in the species composition between the Croatian farms and the Spanish farm would appear to be caused by the presence of littoral reef-associated species at the Croatian farms as a result of ecological differences between the farm locations. In both studies, the farms were situated over similar bottoms and depths. The most relevant difference between the locations was the distance from shore, i.e. 200 m for the Croatian farms and 4500 m for the Spanish farm, with the associated difference in slope steepness and the proximity of the continental shelf. These bathymetrical features at the Croatian farms were conducive to the presence of both littoral reef-associated and oceanodromous species. At the Spanish ABT farm, the seasonality of pelagic species such as *Sardina pilchardus*, *Scomber japonicus*, *Sardinella aurita*, *Sarda sarda*, *Seriola dumerili* and *Thunnus thynnus* strongly influenced the seasonality of the cage effect, limiting it to summer and spring. Although the Croatian farms were also subject to the seasonality effects of oceanodromous species, the permanent high abundances of *Boops boops* and *Belone belone* resulted in a year-long attraction effect at the Croatian farms (Šegvić Bubić et al. 2011). The seasonal variability of the cage effect in the present study was mainly attributable to the seasonal occurrence of *T. thynnus*. The presence of this species during summer-spring and its absence in autumn-winter can be explained by its spawning season and migratory pattern (Rooker et al. 2007). Nevertheless, the presence of *T. thynnus* around the ABT farm continued at least until December in 2011 (pers. com. of the Balfegó Group, L'Ametlla de Mar, Spain, outside the study period). The attraction of wild *T. thynnus* to ABT farms is beginning to elicit a new scientific topic, namely, whether farms could alter *T. thynnus* migration patterns. At the ABT farm investigated in the present study, no escapement ever occurred, and the closest ABT farm facilities are at a distance of ~550 km (Cartagena, Spain), hence; the possibility that the observed individuals of *T. thynnus* were feral animals that escaped from a farm was considered very small. The present study also yielded some additional information from the ABT farm which has not been expressly analysed but which we believe is worth mentioning. Specifically, only small individuals of the species *Oblada melanura,* Mugilidae, *Sarpa salpa*, *Seriola dumerili*, *Trachinotus ovatus* and *Sardina pilchardus* were recorded; in total, 65% of cage aggregated fish were <11 cm. Individuals of that size are not likely to feed on whole baitfish and may feed on very small particles of baitfish and/or living organisms that cover the cage ropes. It is therefore reasonable to assume that these small individuals are attracted not only to the available food but also to the farm structures in search of shelter, as has been suggested by other authors (Fernandez-Jover et al. 2009, Šegvić Bubić et al. 2011). In addition, at the beginning of July 2011 during monitoring of *T. thynnus* spawning in captivity that our group has been carrying out since 2008 (Gordoa et al. 2009), we collected 2 types of eggs inside the ABT cage that could be genetically determined as *T. thynnus* and *Trachurus mediterraneus*. Thus, ABT farms may act as new spawning grounds with unknown viability for larvae, but they at least have the potential to provide eggs as food for aggregated species.

Further, we observed the unexpected presence of the barrelfish/driftfish at the ABT farm all year round, except in summer. This species, which typically has an Atlantic distribution, has only been observed once in the Mediterranean (Karrer 1986). In addition, we made the first sighting of a blue shark, circling the farm near the surface in spring.

Our results revealed differences and similarities between the 2 fish farm models considered here. At both farms, the attraction effect was mostly constrained to the cage station. The seasonal occurrence of pelagic species restricted the attraction effect to summer and spring at the ABT farm, whereas the SB farm attracted fish all year long. Nevertheless, the cage attraction effect, compared to border and limit stations, was considerably stronger at the ABT farm. Differences in fish abundance and species composition recorded at the SB and ABT farms may be related to the type of food used and/or the type of habitat at each farm. Whole baitfish differ substantially in their nutrient composition, food size and settling velocity from the food pellets used at SB farms (Vassallo et al. 2006). Šegvić Bubić et al. (2011) suggested that the pellets and their fine particulates may attract a more diverse fish community and can be more easily consumed than baitfish. In addition, the ABT farm is located 4 times as far from shore over deeper, muddy bottoms, compared to the shallower mixed rocky-sandy seafloor of the SB farm. The exposed situation of the ABT farm compared to the SB farm attracts more mobile pelagic species, from small plankton feeders (e.g. *Sardina pilchardus* and *Sardinella aurita*) to big species such as *Thunnus thynnus* whose diet is mostly based on small pelagics.

Fishing near fish farms is a common practice that has been reported in Spain (Fernandez-Jover et al. 2008, Arechavala-Lopez et al. 2011), Croatia (Šegvić Bubić et al. 2011), Greece (Machias et al. 2006) and Norway (Maurstad et al. 2007), and even within farms in Turkey (Akyol & Ertosluk 2010). The farms studied here are located in waters within the jurisdiction of the local government, which has not implemented any fishing restrictions in their vicinity. Nonetheless, the cages are located in the centre of the leasehold farm area, and their distance from the perimeter acts as a protective zone for wild fish. The potential for farms to protect wild fish highly depends on the behaviour of each particular species. The results of the current study show that the majority of aggregated fish concentrated in close proximity to the cage and suggest that they are to some extent protected. The territorial species recorded at the SB farm all year long reap the greatest protection. In contrast, pelagic and semipelagic species that conduct seasonal movements away from the farm (e.g. *Thunnus thynnus*, *Scomber japonicus*, *Sarda sarda*, *Sardina pilchardus*) are only partly protected by the farm area. In addition, daily movements could substantially increase fish vulnerability. A study by Arechavala-Lopez et al. (2010) recorded rapid and repeated movements of grey mullets *Chelon labrosus* and *Liza aurata* to other farms and to nearby fishing areas. To date, no data on the efficiency of fishing near farm boundaries exist. The presence of a species of such high commercial value as *T. thynnus* at such a short distance from the coast could trigger illegal fishing activities from fleets that do not have any quota allocation (Spanish Mediterranean artisanal fleet) or only a very limited allocation with a short fishing period (recreational fleet). During the study, large numbers of recreational fishing vessels were observed gathering at the concession boundary to presumably target this species. Further, the potential of farms to attract rare species, such as the blue shark and the barrelfish/driftfish, requires the implementation of conservation actions.

Our work emphasizes the importance of applying an integrated approach to study wild fish aggregations at farms. The spatial extent of fish attraction is a key item of information for determining the effective size of an appropriate protection zone around farms. Data on the seasonal aggregation pattern provides knowledge of periods when exploited species are especially vulnerable at farms. As demonstrated here, different farm types exhibit distinct fish aggregation patterns which may require different regulatory measures. Without such measures, the proliferation of fish farming facilities along the coast might result in the decline of a number of highly targeted fish species.

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Appendix 1. All species recorded at different stations, depths and seasons at an SB farm and an ABT farm in Spain, summer 2010 to spring 2011. C: cage, B: border, L: limit; D: deep water, M: midwater, S: surface; SU: summer, AU: autumn, WI: winter, SP: spring. +, Δ, ●: presence of a species

Family	Species	Gilthead seabream (SB) farm										Atlantic bluefin tuna (ABT) farm									
		Station			Depth			Season				Station			Depth			Season			
		C	B	L	D	M	S	SU	AU	WI	SP	C	B	L	D	M	S	SU	AU	WI	SP
Apogonidae	*Apogon imberbis*	+	+	+	Δ			●	●		●										
Balistidae	*Balistes capriscus*												+	+		Δ	Δ		●		
Belonidae	*Belone belone*											+					Δ		●		
Blenniidae	*Parablennius rouxi*	+	+	+	Δ			●	●	●	●										
	Parablennius pilicornis	+	+		Δ			●	●	●	●										
Carangidae	*Seriola dumerili*											+	+	+	Δ	Δ	Δ	●			
	Trachurus spp.	+			Δ	Δ	Δ	●				+	+	+	Δ	Δ	Δ	●	●	●	●
	Trachinotus ovatus	+	+			Δ	Δ	●				+					Δ	●			
Carcharhinidae	*Prionace glauca*											+					Δ				●
Centracanthidae	*Spicara maena*	+	+	+	Δ	Δ			●	●											
Centrolophidae	*Hyperoglyphe perciformis*											+	+	+	Δ	Δ	Δ		●	●	●
Clupeidae	*Sardinella aurita*											+					Δ				●
	Sardina pilchardus			+			Δ		●		●	+			Δ	Δ					●
Congridae	*Conger conger*	+	+	+	Δ			●	●	●	●										
Dasyatidae	*Dasyatis pastinaca*			+	Δ			●													
Gobiidae	*Gobius xanthocephalus*	+	+	+	Δ			●	●	●	●										
	Gobius geniporus	+	+	+	Δ			●	●	●	●										
	Gobius cruentatus	+	+	+	Δ			●	●	●	●										
Labridae	*Coris julis*	+	+	+	Δ			●	●	●	●										
	Ctenolabrus rupestris		+	+	Δ			●			●										
	Labrus merula	+	+	+	Δ			●	●	●	●										
	Labrus bimaculatus			+	Δ			●													
	Symphodus melanocercus	+	+	+	Δ			●	●	●	●										
	Symphodus mediterraneus	+	+	+	Δ			●	●	●	●										
	Symphodus tinca	+	+		Δ				●												
Mugilidae		+			Δ	Δ	Δ	●		●	●	+					Δ	●	●		
Mullidae	*Mullus surmuletus*	+	+	+	Δ			●	●	●	●										
Muraenidae	*Muraena helena*	+	+		Δ			●			●										
Myliobatidae	*Myliobatis aquila*	+	+		Δ		Δ	●													
	Pteromylaeus bovinus	+			Δ	Δ		●			●										
Pomacentridae	*Chromis chromis*	+	+	+	Δ	Δ		●	●	●	●										
Pomatomidae	*Pomatomus saltatrix*	+			Δ			●													
Scombridae	*Sarda sarda*			+		Δ					●	+	+	+	Δ	Δ		●			
	Scomber japonicus											+			Δ	Δ	Δ	●			●
	Thunnus thynnus											+			Δ	Δ		●			●
Scorpaenidae	*Scorpaena scrofa*		+		Δ			●		●											
	Scorpaena notata	+	+		Δ			●	●	●	●										
Serranidae	*Serranus cabrilla*	+	+	+	Δ			●	●	●	●										
	Serranus scriba	+	+	+	Δ			●	●	●	●										
Sparidae	*Boops boops*	+		+	Δ	Δ	Δ		●	●											
	Diplodus vulgaris	+	+	+	Δ	Δ		●	●	●	●	+			Δ					●	●
	Diplodus sargus	+	+	+	Δ			●	●	●											
	Diplodus cervinus	+			Δ			●													
	Diplodus puntazzo	+		+	Δ					●		+				Δ			●		
	Oblada melanura	+	+	+	Δ	Δ	Δ	●	●	●	●	+			Δ	Δ	Δ	●	●	●	●
	Pagellus acarne			+	Δ					●											
	Sarpa salpa	+					Δ	●			●	+			Δ	Δ	Δ			●	●

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Appendix 4: Publication chapter 2

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Feeding activity strongly affects the variability of wild fish aggregations within fish farms: a sea bream farm as a case study

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Abstract

Factors influencing within-farm variability of wild fish aggregations have not been systematically studied. We tested the hypothesis that fish abundance and species composition vary between feeding and non-feeding periods and different bottom substrates within a *Sparus aurata* (L.) farm. Sampling took place during feeding and non-feeding periods on six consecutive days in July 2011. Visual censuses were carried out at three different depths and at three sampling stations over rocky–sandy and sandy substrates respectively. In all, 33 species belonging to 17 families were observed. Total fish abundance, biomass and species community significantly differed between feeding and non-feeding periods. Each depth was represented by a distinct species community and was therefore affected differently by the feeding activity. At the surface, fish abundance was significantly higher during feeding compared with non-feeding periods. The distance from the feeding vessel significantly influenced fish aggregations in the water column, indicating that planktivorous species learnt to associate the boat noise with food availability through classic conditioning. At the bottom, substrate type was the dominant factor explaining aggregation variability. This study provides new information about the dynamics of fish aggregations within farms, emphasizing the importance of considering the different sources of variability in future study designs.

Keywords: fish farm, within-farm variability, feeding effect, substrate type, Mediterranean Sea

Introduction

Marine fish farming is expanding worldwide creating new artificial structures and feeding grounds in the littoral system. These new habitats attract a wide variety of fish species in high numbers from its surroundings (e.g. Carss 1990; Thetmeyer, Pavlidis & Cromey 2003; Boyra, Sanchez-Jerez, Tuya, Espino & Haroun 2004), thereby altering natural distribution patterns. The ecological and biological consequences of this aggregation effect at farms have received increasing interest in recent years and are being examined by a growing number of studies covering a wide range of topics. Fish farms influence local fish populations through effects on distribution (Uglem, Dempster, Bjorn, Sanchez-Jerez & Okland 2009; Arechavala-Lopez, Uglem, Sanchez-Jerez, Fernandez-Jover, Bayle-Sempere & Nilsen 2010), abundance and biomass (Dempster, Sanchez-Jerez, Bayle-Sempere, Gimenez-Casalduero & Valle 2002), species composition (Tuya, Sanchez-Jerez, Dempster, Boyra & Haroun 2006), transmission of disease and parasites (e.g. Saunders 1991; Johnsen & Jensen 1994; Fernandez-Jover, Faliex, Sanchez-Jerez, Sasal & Bayle-Sempere 2010), genetic contamination (Hindar, Ryman & Utter 1991), physiology (Dempster, Sanchez-Jerez, Fernandez-Jover, Bayle-Sempere, Nilsen, Bjørn & Uglem 2011) and feeding habits (Fernandez-Jover, Jimenez, Sanchez-Jerez, Bayle-Sempere, Casalduero, Lopez & Dempster 2007). The intensity of the farm attraction effect has been shown to be highly variable, changing with season (e.g. Valle, Bayle-Sempere, Dempster, Sanchez-Jerez & Giménez-Casalduero 2007; Fernandez-Jover, Sanchez-Jerez, Bayle-Sempere, Valle & Dempster 2008;

Šegvić Bubić, Grubišić, Tičina & Katavić 2011) and depth (Dempster, Fernandez-Jover, Sanchez-Jerez, Tuya, Bayle-Sempere, Boyra & Haroun 2005; Dempster, Uglem, Sanchez-Jerez, Fernandez-Jover, Bayle-Sempere, Nilsen & Bjørn 2009; Bacher, Gordoa & Sagué 2012), reflecting species-specific behaviour.

To determine the effect of marine fish farm installations on wild fish populations, it is essential to obtain representative estimations of abundance and species composition of fish aggregations. Even though the farm attraction effect on wild fish has been widely studied, the magnitude of this effect will depend on factors influencing within-farm variability. At present, there is an absence of studies analyzing patterns of variability in fish aggregations within farms. This lack of knowledge represents a critical gap, as this information would represent a crucial contribution to achieve a more complete image of the adaptive feeding response of wild fish and within-farm dynamics. Variability in fish aggregations within farms has been discussed in two previous studies (Boyra *et al.* 2004; Dempster *et al.* 2005), but no further approach was developed to search for patterns of variability and associated factors. As wild fish are mainly attracted by the farm waste food (Tuya *et al.* 2006), substantial variation within farms associated with the daily pattern of feeding activity can be expected. In addition, habitat heterogeneity within farms may have a marked effect on wild fish spatial distribution.

Sampling surveys in previous studies have always been performed under the effect of the feeding activity, when wild fish are more likely to be attracted by waste food falling from cages (e.g. Valle *et al.* 2007; Fernandez-Jover *et al.* 2008). This common criterion of sampling during feeding periods is valuable as it makes the results of different studies directly comparable, but leaves uncertainty about whether fish leave the farm during non-feeding periods. This approach is therefore biased towards feeding periods and may not capture the global picture of the farm attraction effect. An additional source of within-farm variability, also associated with feeding, might be caused by the distance of the feeding vessel from the sampling locations. This subject was already highlighted by Dempster *et al.* (2005), who suggested that the spatial distribution pattern of aggregated fish during the feeding period might be a direct response to where feeding is occurring within the farm. Hence, variability in the distance of the feeding vessel at different sampling events can add a great amount of uncertainty about the magnitude of the farm attraction effect. Furthermore, the response of wild fish to the feeding activity is likely to vary between distinct species and life history stages. Fish species vary at distinct depth strata within farms, reflecting species-specific distribution patterns (Dempster *et al.* 2005; Sudirman, Halide, Jompa, Zulfikar, Iswahyudin & McKinnon 2009; Bacher *et al.* 2012) associated with differences in feeding ecology. Consequently, the feeding activity may affect distinct depths differently.

In natural systems, the habitat type modulates fish communities, greater structural complexity supporting richer communities and higher abundances (e.g. Jenkins & Wheatley 1998; Guidetti 2000). Likewise, higher abundance of certain fish species was recorded at farms located over rocky bottoms compared with those on sandy bottoms (Dempster *et al.* 2009; Bacher *et al.* 2012). Thus, the presence of different types of bottom substrates within a farm may significantly influence the spatial variability in fish aggregations.

Analyzing the variability within fish farms will provide an in-depth view on the interaction between species-specific feeding ecologies and their adaptive response to farming activities. Moreover, the identification of significant factors will be highly valuable to weigh the potential bias of previous estimations and to optimize future sampling programmes aimed at estimating fish aggregations at farms.

The aim of this study was to investigate the within-farm variability in wild fish aggregations at a gilthead sea bream (*Sparus aurata*) farm. This farm was chosen as a case study, due to the profound knowledge of its dynamics acquired by the authors in a previous study (Bacher *et al.* 2012). The specific objectives were as follows: (1) to analyse whether fish aggregations differ between feeding and non-feeding periods; (2) to investigate if the distance of the feeding vessel influences the distribution pattern of aggregated fish; (3) to evaluate how different bottom substrate types affect fish aggregations within farms; and (4) to test whether the effect of the feeding activity changes with depth. In addition, all known factors influencing variability at farms and their effects are summarized in a conceptual diagram combining the results of this study and previous publications.

Materials and methods

Study site and farm characteristics

The investigated gilthead sea bream farm is located in L'Ametlla de Mar (40°53′10″N, 0°48′ 13″E) in the littoral zone influenced by the Ebro River in the north-western Mediterranean Sea (Fig. 1). The farm is located about 1 km from the coast over a mixed rocky–sandy and sandy bottom with a bottom depth of 18–20 m. The farm started operating in 1993, and consists of 30 circular cages (each 19 m in diameter) with a net depth of 10 m, and covers a leased area of 400 000 m^2. On average, the farm contains 850 t of stocked fish biomass, and fish are fed 2500 t yr^{-1} of dry food pellets based on fish meal and vegetable oil.

Underwater visual census

Previous counts of wild fish at fish farms in warm temperate ecosystems have been conducted using an open-circuit scuba system (e.g. Dempster *et al.* 2002; Boyra *et al.* 2004). In this study, it was decided to count fish by free-diving, for two reasons. First, sampling effort is not restricted to the non-decompression limits associated with scuba diving, facilitating an intense sampling scheme during a short temporal window as required in this study. Second, observations made during previous counts in 2011 (Bacher *et al.* 2012) at the same farm suggested that certain fish species, such as *Diplodus sargus* (L.) and *Dentex dentex* (L.) were hardly ever recorded during fish counts taken by scuba diving. Nevertheless, these species were regularly spotted on the dive down before starting the survey counts, but immediately disappeared thereafter. Certain fish species are known to have a tendency to avoid scuba divers (e.g. Stanley & Wilson 1995; Schmidt & Gassner 2006), behaviour thought to be triggered mainly by breathing and related noises produced by the demand valve (Chapman & Atkinson 1986). Our intention was therefore to employ a free-diving technique to minimize underestimation of species that avoid the disturbance caused by scuba gear.

Sampling design

To examine the variability associated with feeding and non-feeding periods, an intense sampling during a short temporal window was chosen to minimize other sources of variation, such as oceanographic conditions or the previously described seasonal variability in this specific farm (Bacher *et al.* 2012). Thus, sampling was carried out on six consecutive days in July 2011 in the morning (8:00–11:30 hours) and in the afternoon (4:30–8:00 hours). To analyse the influence of bottom substrate type, six stations were selected within the facility, namely, three stations over a rocky–sandy substrate and three stations over a sandy substrate (Fig. 1). At each station, underwater visual censuses (UVCs) were performed in three distinct depth strata: surface (0–2 m), midwater (9–11 m) and bottom (18–20 m). Hence, at each station, two counts per day and depth were performed over six consecutive days, yielding a total of 216 fish counts. Fish counts were conducted by two divers. The first diver, professionally qualified in free-diving, carried out the UVCs in the midwater and bottom strata, while the second

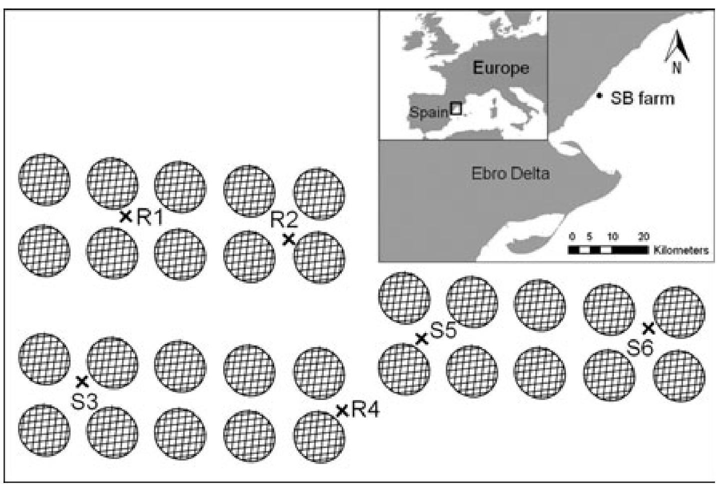

Figure 1 Map of the gilthead sea bream (SB) farm location in L'Ametlla de Mar (Spain) and the six sampling stations. R: rocky–sandy substrate, S: sandy substrate.

diver stayed at the surface, recording the fish observed by the first diver and surveying the surface. Fish counts lasted a total of 5 min at each depth. To complete the 5-min counts, the free-diver made three dives to the bottom and two dives to the midwater at each station.

The UVC counts were carried out using the method developed by Dempster *et al.* (2005), which is robust for comparing counts at different depth levels and under differing conditions of visibility. The method consists of stationary timed counts during which the diver rotates through 360°. To standardize the counts, fish are counted only from 1 m above to 1 m below eye-level out to a radius of 5 m. Bottom counts spanned the zone from the substrate to 2 m above the bottom. The maximum number of individual fish of each species observed at any one time was recorded, to reduce the likelihood of counting the same fish twice. For schools of up to 20 fish, individual fish were counted; for larger shoals estimates were obtained by subdividing the shoals into imaginary subgroups of equal size, counting the individuals in one of the subgroups and multiplying that count by the number of subgroups. Individual length was recorded, and biomass was calculated based on published length–weight relationships for each species (www.fishbase.org). Mugilidae species could not be identified visually to species level and were therefore recorded as Mugilids. Similarly, *Trachurus mediterraneus* (Steindachner) and *Trachurus trachurus* (L.) were recorded as *Trachurus* spp. The species *Oblada melanura* (L.) and *D. sargus* were represented by two distinct size classes (*O. melanura*: 2–3 and 20–30 cm; *D. sargus*: 2–4 and 22–35 cm), and were therefore separated into small size class (SS) and large size class (LS) prior to analysis. This separation permits to distinguish between individuals of a few centimetres that are believed to use fish farm cages as a shelter (Fernandez-Jover, Sanchez-Jerez, Bayle-Sempere, Arechavala-Lopez, Martinez-Rubio, Jimenez & Lopez 2009) and larger individuals that are attracted due to the high food availability.

Influence of the feeding vessel

To determine whether fish systematically change their location in response to where feeding is occurring, the distance of the feeding vessel in relation to the sampling stations was recorded. It was not possible to integrate the influence of the feeding vessel as a predefined factor, because feeding at cages did not follow a clear schedule and/or order. Particularly for this specific study with six sampling locations, the timing of fish counts according to the vessel's distance to the cages was unfeasible. This factor was therefore subsequently included and analysed independently for the valuable information it may provide. Three distances were defined for the purposes of data analysis: nearby (at the cage where the census was being taken or at the cage adjacent to it); middle-distance (in the same group of cages where the census was being carried out); and distant (in another group of cages).

Statistical analysis

The assumptions of normality and homogeneity of variance can often be difficult to fulfil with biological data. A good alternative is the analysis of variance based on permutations (PERMANOVA), as it allows multivariate data to be analysed in the context of complex experimental designs and provides a robust approach to deal with skewed data and many zero counts (Anderson 2001). Therefore, all univariate and multivariate statistical analyses were carried out using the PRIMER V6.1.13 computer program (Clarke & Gorley 2006) with the PERMANOVA+ V1.0.3 add-on package (Anderson, Gorley & Clarke 2008). Statistical significance was tested using 9999 permutations of residuals under a reduced model (Freedman & Lane 1983) and Type III (partial) sums of squares (SS, Anderson *et al.* 2008).

Univariate analysis

The univariate analysis considered three fixed factors: feeding vs. non-feeding (FE), substrate type (SU), depth (DE) and day (DA) as a random factor to test for differences in total fish abundance and biomass. To test the feeding effect on the most abundant fish species in the water column, univariate permutational one-way analysis of variance was carried out for the factors: feeding vs. non-feeding (FE) and distance from the feeding vessel (DI). The species considered in the analysis were as follows: *D. sargus* (LS), Mugilids, *O. melanura* (LS), *S. salpa* and *Pomatomus saltatrix* (L.). The later species was not included in the analysis on the distance from the feeding vessel, as *P. saltatrix* was almost absent during feeding periods. The number of samplings at different distances from the feeding vessel was unbalanced (nearby: 9; middle-distant: 10; distant:

17), due to the reasons already explained. However, an unbalanced design in a one-way case can be overcome by applying the most conservative Type III (partial) sums of squares (Anderson *et al.* 2008). The similarity matrix was computed on square root-transformed data using the Euclidean distance, and post hoc pairwise comparisons were used to investigate significant results.

Multivariate analysis

Permutational multivariate analysis of variance was used to test the differences in wild fish aggregations for the same four factors as in the univariate analysis (PERMANOVA, Anderson 2001; Anderson *et al.* 2008). Prior to analysis, the data were fourth-root transformed to downweight the influence of more abundant species while preserving information on relative abundance (Clarke & Green 1988). Significant terms were further examined by applying appropriate post hoc pairwise comparisons. The Similarity Percentage Analysis (SIMPER) routine was employed to examine species contributions to within-group similarity for distinct depth strata at rocky–sandy and sandy stations.

Free-diving vs. scuba diving

The abundance and species composition data obtained by free-diving in this study was examined together with that recorded by scuba diving during a previous study (Bacher *et al.* 2012) with the purpose of identifying potential bias or differences between both sampling techniques. Consequently, only equivalent survey data were considered, fixing: season, number of sampling days, census duration, substrate type and feeding periods. As census duration at each depth differed between the studies (7 min vs. 5 min), the counts were standardized to the number of fish recorded per minute of sampling.

Results

Composition of wild fish species

Overall, 33 different species belonging to 17 different families were observed (Appendix 1). The most common families were Sparidae (7 species) followed by Labridae (4 species) and Gobiidae (4 species). Counts included the two ray species *Myliobatis aquila* (L.) and *Pteromylaeus bovinus* (Geoffroy Saint-Hilaire). The most abundant species were *D. sargus* (LS), followed by *Chromis chromis* (L.), Mugilids, *O. melanura*, *O. melanura* (SS) *and Sarpa salpa* (L.), which together made up 86.4 % of total abundance. For all stations combined, the highest species diversity, 30 species, was recorded at the bottom compared with 8 species in the mid-water and 7 species in the surface. Substantially, more species (30) were observed at rocky–sandy stations than at sandy stations (10), whereas differences between feeding (32 species) and non-feeding (30 species) periods were small.

Feeding vs. non-feeding periods

Total fish abundance, biomass and species community significantly differed between feeding and non-feeding periods (Table 1). Even though the feeding interaction with depth was not significant for total abundance and biomass, post hoc results revealed that fish abundance significantly differs at the surface between feeding and non-feeding periods (Fig. 2a; Table 1). The feeding effect at the surface was also observed at the species community level (Table 1). These differences in species composition and abundance at the surface were primarily caused by the presence of *Sarpa salpa* and *O. melanura* (LS) during feeding periods, whereas at non-feeding periods, aggregations were mainly composed of *O. melanura* (SS) and Mugilids (Table 2). Except for four infrequent species, all species were present at the farm during both feeding and non-feeding periods (Appendix 1). Nevertheless, some species showed a significant preference for certain periods of day. For instance, the frequency of *S. salpa* (Feeding: 96.1%, Non-feeding: 3.9%) and *O. melanura* (LS) (Feeding: 77.3%, Non-feeding: 22.7%) was clearly shifted to feeding periods. In contrast, *P. saltatrix* was much more abundant during non-feeding periods (Feeding: 5.5%, Non-feeding: 94.5%). The preferences of these three species were statistically confirmed; in contrast, the abundance of Mugilids and *D. sargus* (LS) did not significantly differ between feeding and non-feeding periods (Table 3).

The random factor (day) does not account for daily differences in the feeding effect. Daily variability was only observed for species community at certain depths and substrates.

Influence of the feeding vessel

The feeding vessel had a clear depth-dependent effect on wild fish aggregations. Fish abundance at the bottom was not influenced by the location of the feeding activity (Fig. 3). In contrast, fish abundance in the water column was significantly higher when the feeding vessel was nearby the cage where the census was being taken compared with when the feeding vessel was moderately distant or far off. Responsible for this effect were the most abundant species of the water column (*D. sargus* (LS), Mugilids, *O. melanura* (LS) and *S. salpa*) whose total abundance significantly decreased with increasing distance from the feeding vessel (Table 3). The same gradual pattern was observed for each species separately (Fig. 4), but was not statistically significant (Table 3). Yet, post hoc analyses for *D. sargus* (LS) ($P = 0.023$) and Mugilids ($P = 0.048$) revealed significant differences in abundance between nearby and far distances from the feeding vessel. In contrast, the small size classes of *O. melanura* and *D. sargus* were permanently in residence at the cages and insensitive to feeding vessel proximity (Fig. 4).

Bottom substrate and depth

Both fish abundance and biomass were significantly higher at stations over rocky–sandy substrates than at stations over sandy substrates (Table 1). Fish abundance was significantly higher at rocky–sandy substrate for each depth (Fig. 2b, Table 1), whereas biomass did not change with depth. At rocky–sandy substrates, fish abundance was significantly higher at the bottom than in the midwater and surface strata; in contrast, at sandy stations, abundance did not differ by depth (Fig. 2b). The species composition of the fish community significantly differed between different depths and substrate types (Table 1). Yet, the difference between substrate types was restricted to the bottom community. The rocky–sandy bot-

Table 1 Summary of results of permutational univariate and multivariate analysis of variance (PERMANOVA) comparing abundance, biomass and species community for the factors feeding vs. non-feeding (FE), substrate (SU), depth (DE) and day (DA) and post hoc tests for significant factors and interactions. R, rocky–sandy substrate; S, sandy substrate; B, bottom; M, midwater; S, surface; F, feeding period; NF, non-feeding period. All multiple interactions with the random factor (DA) were not significant and are not shown

		Total abundance		Total biomass		Species community	
Source	d.f.	MS	*F*	MS	*F*	MS	*F*
FE	1	119	12.71*	26800	6.66*	4329	4.74*
DE	2	182	3.66	101310	1.77	51718	12.81***
SU	1	2368	74.13**	610370	10.29*	46114	19.53**
DA	5	74	2.14	93311	2.62*	3492	2.73***
FE × DE	2	43	1.25	16345	0.46	4530	3.72*
FE × SU	1	3	0.14	8136	0.96	1542	2.82
FE × DA	5	9	0.27	4026	0.11	913	0.71
DE × SU	2	396	19.01***	13782	0.35	27583	21.20***
DE × DA	10	50	1.43	57189	1.61	4037	3.15***
SU × DA	5	32	0.92	59323	1.67	2361	1.85*
FE × DE × SU	2	4	0.14	31499	1.00	1212	0.87
Residuals	144	35		35609		1280	

Post hoc	Total abundance	Total biomass	Species community
FE	F ≠ NF	F ≠ NF	F ≠ NF
FE × DE	B: F = NF	n.s.	B: F = NF
	M: F = NF		M: F = NF
	S: F ≠ NF		S: F ≠ NF
DE	n.s.	n.s.	B ≠ M ≠ S
SU	RS ≠ S	RS ≠ S	RS ≠ S
DE × SU	B: RS ≠ S	n.s.	B: RS ≠ S
	M: RS ≠ S		M: RS = S
	S: RS ≠ S		S: RS = S

Significant at *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, n.s. = non-significant.

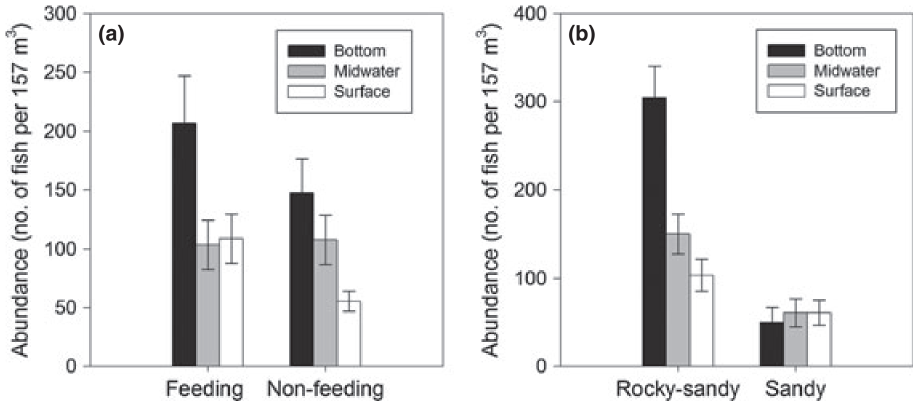

Figure 2 Total fish abundance at feeding and non-feeding periods (a) and at the two substrate types (b) by depth. Bars are mean ± SE of 36 underwater visual counts in a volume of 157 m^3.

Table 2 Accumulated species contributions (%) to total fish abundance at the surface over rocky–sandy and sandy substrates at feeding and non-feeding periods. Full species names are listed in Appendix 1

Feeding		Non-feeding	
Species	%	Species	%
S. salpa	31.6	*O. melanura* (SS)	42.4
O. melanura (LS)	53.3	Mugilids	74.0
O. melanura (SS)	74.3	*P. saltatrix*	84.6
D. sargus (LS)	88.4	*D. sargus* (SS)	93.0
D. sargus (SS)	97.8	*D. sargus* (LS)	100.0
B. belone	99.1		
Mugilids	100.0		

tom was characterized by a diverse rocky-reef fish community dominated by *C. chromis*, *Coris julis* (L.) and *Serranus cabrilla* (L.), whereas the sandy bottom was mainly populated by Mugilids, Myliobatidae, *D. sargus* (LS) and *P. saltatrix* (Table 4). In contrast, species compositions at the midwater and surface did not differ between substrates (Table 1). The midwater was characterized by *D. sargus* (LS) and Mugilids and the surface was represented by *O. melanura* (SS), *D. sargus* (SS), Mugilids and *D. sargus* (LS) (Table 4).

The results on mean abundances and species contributions obtained in this study were similar to the findings obtained by the scuba diving technique (Table 5). Yet, more species were observed using free-diving (scuba diving: 19 species; free-diving: 24 species) and a remarkably higher abundance of *D. dentex and D. sargus* (LS) was recorded. These two species were hardly ever seen during surveys taken by scuba diving (Bacher *et al.* 2012).

Discussion

This study revealed complex patterns of variability within the investigated farm. The feeding activity exerted a strong effect on the abundance and distribution of species in the water column. The substrate type clearly influenced the species diversity, abundance and biomass of aggregated wild fish at the bottom between different sites within the farm.

In this study, most species were recorded in similar numbers throughout the day, suggesting that they did not leave the farm after feeding, corroborating the findings of Sudirman *et al.* (2009). Two exceptions were *O. melanura* (LS) and *S. salpa*; these two species dominated the surface during feeding periods and seemed to leave the farm on a daily basis in the afternoon after feeding. Conversely, *D. sargus* (LS) and Mugilids, equally strongly affected by the proximity of the feeding vessel, were found to be very abundant at the farm throughout the day. The difference in daily aggregation patterns of these species is most likely a result of their different feeding ecologies. As a planktivorous species, *O. melanura* may benefit from the waste food while it is suspended in the surface layer, but may leave the farm after food is dispersed in favour of a more suitable habitat in search of other food sources. A recent tagging study of saithe (*Pollachius virens* L.), also a pelagic feeder, revealed a diurnal residence pattern around Norwegian salmon farms (Uglem *et al.* 2009). The response to feeding activity of an herbivorous species, such as *S. salpa* whose natural diet mainly consists of benthic algae and seagrass (Antolic, Skaramuca, Span, Musin & Sanko-Njire 1994), represents an adaptive and opportunistic feeding

Table 3 Summary of results of permutational univariate analysis of variance on the abundance of the most abundant fish species in the water column for the factors: feeding vs. non-feeding (FE) and distance from the feeding vessel (DI)

		P. saltatrix		*O. melanura*		*S. salpa*		*D. sargus*		Mugilids	
Source	d.f.	MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
Fe	1	19	5.17*	40	4.27*	53	6.44*	1	0.04	29	2.24
Residuals	142	4		9		8		27		13	
		Total abundance		*O. melanura*		*S. salpa*		*D. sargus*		Mugilids	
Source	d.f.	MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
DI	2	406	8.37**	49	0.20	56	2.11	114	3.07	54	3.17
Residuals	33	48		29		27		37		17	

Significant at $*P < 0.05$, $**P < 0.01$.

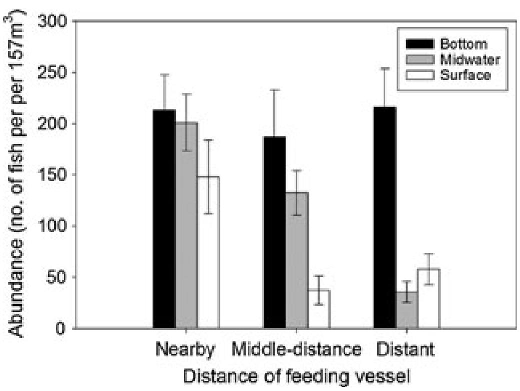

Figure 3 Total abundance (mean ± SE) of wild fish in relation to the distance of the feeding vessel from the sampling location. The data in this figure include fish counts from both substrate types. Number of samples for each distance: nearby: 9, middle-distance: 10, distant: 17.

change. Individuals of this species have repeatedly been observed feeding on waste food next to the cages and their estimated body length of 50 cm is among the largest ever recorded (www.fishbase.org). This increase in body condition due to the fat and protein content of farm food has been observed in other farm-aggregated species (Fernandez-Jover *et al.* 2007; Dempster *et al.* 2011). The precise physiological consequences of this shift in the diet remain unclear; however, there is evidence for some species at Norwegian farms that the food supply of farms overrides other potentially negative effects (Dempster *et al.* 2011).

The demersal species Mugilids and *D. sargus* (LS) exhibited a wider vertical distribution, being opportunistic farm feeders often observed feeding on lost food pellets or grazing at nets along the cages. Our data suggest that these species spend longer residence times at the farm. In contrast, a recent tagging study investigating movements of the same Mugilidae species at Spanish fish farms (Arechavala-Lopez *et al.* 2010) revealed frequent movements among farms and to adjacent fishing areas. As visual census is limited to daylight hours, movements at night cannot be discarded. Regular movements away from the farm, at night or earlier in the afternoon, as were observed in this study, may substantially increase vulnerability to fishing of aggregated wild fish (Dempster *et al.* 2002).

The location of the feeding vessel exerted a strong influence on the spatial distribution of fish in the water column, as fish were observed to actively follow the vessel around the farm. An experiment on learning behaviour in relation to feeding in fish (Fujiya, Sakaguchi & Fukuhara 1980) demonstrated that individuals of red sea bream (*Pagrus major*, Temminck and Schlegel) could be conditioned to a sound source within a minimum of 2 days to a maximum of 2 weeks. The results of this study indicate that the planktivorous species *D. sargus* (LS), Mugilids, *O. melanura* (LS) and *S. salpa* have learnt to associate the noise of the feeding vessel with food availability through classic conditioning. The year-round presence of *D. sargus* (LS), Mugilids and *O. melanura* (LS) at the farm (Bacher *et al.* 2012) suggests that this effect of the feeding activity may extend throughout the year. Moreover, it is very probable that other planktivorous species that have been shown to dominate wild fish aggregations at the farms in the Mediterranean (e.g. Dempster *et al.* 2002; Valle *et al.* 2007), Canary Islands (Boyra *et al.*

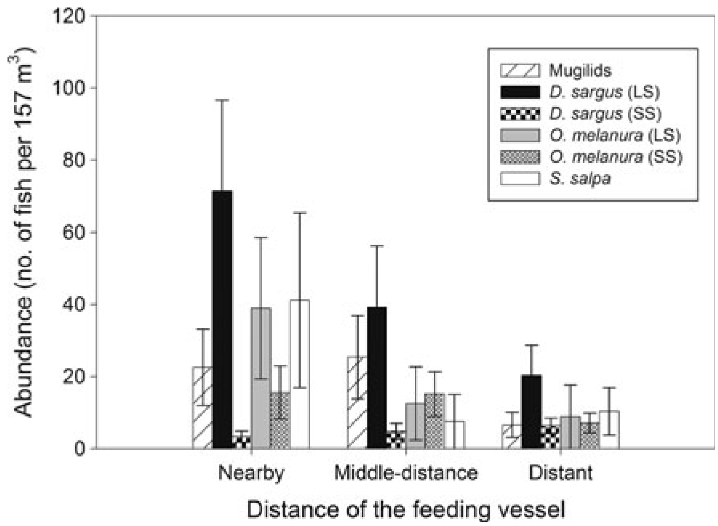

Figure 4 Abundance (mean ± SE) of the most frequent species in the water column in relation to feeding vessel distance. Full species names are listed in Appendix 1.

Table 4 Results of the SIMPER analysis showing the species contribution (%) to within-group similarity in different depth strata at rocky–sandy and sandy stations. Full species names are listed in Appendix 1

	Rocky–sandy	%	Sandy	%
Surface	*O. melanura* (SS)	53.4	*O. melanura* (SS)	40.2
	D. sargus (SS)	82.7	*D. sargus* (SS)	70.6
	Mugilids	90.6	Mugilids	87.5
	S. salpa	94.1	*D. sargus* (LS)	99.3
	D. sargus (LS)	97.2		
Midwater	*D. sargus* (LS)	45.9	*D. sargus* (LS)	60.6
	Mugilids	90.8	Mugilids	96.1
	P. saltatrix	97.1		
Bottom	*C. chromis*	25.9	Mugilids	59.5
	C. julis	44.0	Myliobatidae	75.6
	S. cabrilla	55.7	*D. sargus* (LS)	89.6
	P. pilicornis	67.1	*P. saltatrix*	95.8
	G. xanthocephalus	74.9		
	P. rouxi	78.6		
	D. sargus (LS)	82.0		
	Mugilids	85.4		
	C. conger	88.7		
	G. cruentatus	91.5		

2004; Tuya, Boyra, Sanchez-Jerez & Haroun 2005), Norway (Dempster *et al.* 2009) and Indonesia (Sudirman *et al.* 2009) have acquired a similar adaptive behaviour.

In contrast, the small size classes of *D. sargus* and *O. melanura* did not follow the feeding vessel, but were permanently observed right next to the cage structures at the surface or concentrated on the bottom. This result corroborates previous findings by Dempster *et al.* (2005) strengthening the hypothesis that close association with floating structures may be a natural behaviour of juveniles in search of shelter (Fernandez-Jover *et al.* 2009).

Bluefish (*P. saltatrix*) exhibited an aggregation pattern distinct from those of all the other species, as this species' presence was clearly shifted to the afternoon/evening, with only isolated sightings during the feeding period in the morning. These results revealed that bluefish enter the farm in shoals of hundreds of individuals in the afternoon, possibly to avoid vessels or human activities during feeding periods in the morning. This predator species does not feed on waste food, but is rather attracted to wild fish aggregations and is known to break into sea cages in the Mediterranean to prey on cultured fish (Sanchez-Jerez, Fernandez-Jover, Bayle-Sempere, Valle, Dempster, Tuya & Juanes 2008).

The bottom substrate type significantly affected the spatial variability in species diversity, abundance and biomass at different sites within the farm. This effect is explained by the fact that the more complex habitat structure of rocky bottoms results in greater species diversity and abundance (García-Charton & Pérez-Ruzafa 1998). As expected, differences between rocky–sandy and sandy habitat were most pronounced at the bottom. In contrast, the species community in the water column was mainly composed of five species: *O. melanura*, *D. sargus*, Mugilids, *S. salpa* and *P. saltatrix* at every station and seemed to be independent of the bottom substrate type. Nevertheless, fish abundance at the water column was higher at rocky–sandy stations compared with sandy stations, indicating that substrate type also exerted an effect on the entire water column.

Table 5 Average abundance (mean ± SE) and species' contributions (%) to total abundance recorded by free-diving (current study) and scuba diving visual census techniques (Bacher *et al.* 2012). The data shown here were collected over a rocky–sandy substrate at three different depths (surface, midwater, bottom) during feeding periods (see Materials and methods). Full species names are listed in Appendix 1

Free-diving			Scuba diving		
Species	Abundance	%	Species	Abundance	%
C. chromis	21.1 ± 12.1	46.9	*C. chromis*	9.4 ± 4.9	28.4
Mugilids	6.3 ± 4.4	60.8	*O. melanura* (LS)	8.6 ± 4.6	54.4
D. sargus (LS)	5.9 ± 4.4	73.9	Mugilids	5.6 ± 3.7	71.3
O. melanura (LS)	4.4 ± 4.4	83.8	*T. ovatus*	3.9 ± 1.8	83.0
S. salpa	2.2 ± 2.2	88.7	*S. salpa*	3.2 ± 3.2	92.6

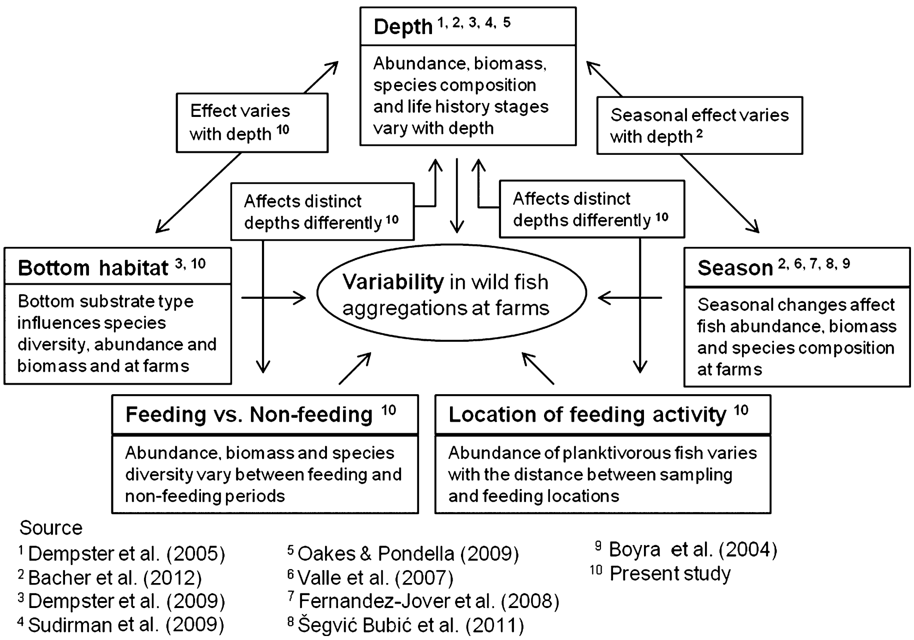

Figure 5 Conceptual diagram reviewing the factors influencing the variability in wild fish aggregations at marine fish farms.

According to the results of this study, most species at the investigated farm did not seem to avoid scuba divers and were recorded in similar numbers by both sampling methods. Two exceptions were *D. sargus* (LS) and *D. dentex*, which were underestimated by scuba diving, indicating that these species associated the noise produced by scuba divers with a potential danger. The present findings revealed that far from being an infrequent visitor (Bacher *et al.* 2012), *D. sargus* is actually the most abundant species at the farm. The noise of the open-circuit scuba system potentially influences fish behaviour over a much larger distance compared with the silent free-diving technique. Still, both underwater census techniques are subject to limitations. When using scuba diving, the number of dives and diving time are restricted by non-decompression diving limits. Although free-diving is more depth-restricted, this technique permits a higher sampling effort, more dives per day (e.g. more stations) and consequently more factors to be examined under the most similar environmental conditions, thereby reducing undesirable natural variability.

In conclusion, the feeding activity leads to three sources of variability which future studies should take into account. First, it may not be possible to extrapolate the farm attraction effect to non-feeding periods, as fish abundance, biomass and species composition significantly differed between feeding and non-feeding periods. Second, the feeding vessel strongly influences the distribution of wild fish aggregations in the water column during feeding periods and may mask other factors under analysis. Although it is not possible to entirely control for this factor, fish counts taken close and further away from feeding events should be balanced. Third, predator species such as *P. saltatrix* may avoid farming activity and will thus be absent or underestimated in fish counts during feeding periods. Moreover, habitat heterogeneity within farms directly affects fish estimations and should be accounted for in future study designs.

This study provides new information about the dynamics of fish aggregations, revealing a system of high complexity within farms that has previously not been addressed. The effects and interactions of different sources of variability influencing wild fish aggregations are summarized in a conceptual diagram (Fig. 5), combining the results of this study and previous publications. This synopsis clearly shows that several factors have received little or no attention to date. Although it is unfeasible to control for all the different factors, future studies should be aware of the different sources of variability. The conceptual diagram can be a useful tool for the design and interpretation of future work in this field of research.

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Appendix

All species recorded at the different bottom substrates, depths and feeding and non-feeding periods. F: feeding periods, NF: non-feeding periods R: rocky–sandy, S: sandy; B: bottom, M: midwater, S: surface. ●, Δ, +: species presence.

Family	Species	Sampling time		Substrate		Depth		
		F	NF	RS	S	B	M	S
Ammodytidae	*Gymnammodytes cicerelus* (Rafinesque)	+	+		●	Δ		
Apogonidae	*Apogon imberbis* (Linnaeus)	+	+	●		Δ		
Belonidae	*Belone belone* (Linnaeus)	+		●				Δ
Blenniidae	*Parablennius rouxi* (Cocco)	+	+	●		Δ		
	Parablennius pilicornis (Cuvier)	+	+	●		Δ		
	Parablennius zvonimiri (Kolombatovic)	+	+	●		Δ		
Carangidae	*Trachurus* spp.	+			●	Δ		
Congridae	*Conger conger* (Linnaeus)	+	+	●		Δ		
Gobiidae	*Gobius xanthocephalus* (Heymer & Zander)	+	+	●		Δ		
	Gobius geniporus (Valenciennes)	+	+	●		Δ		
	Gobius cruentatus (Gmelin)	+	+	●		Δ		
	Gobius niger (Linnaeus)	+	+	●		Δ		
Labridae	*Coris julis* (Linnaeus)	+	+	●		Δ		
	Labrus merula (Linnaeus)	+	+	●		Δ		
	Symphodus mediterraneus (Linnaeus)	+	+	●		Δ		
	Symphodus tinca (Linnaeus)	+	+	●		Δ		
Mugilidae	Mugilids (Risso)	+	+	●	●	Δ	Δ	Δ
Mullidae	*Mullus surmuletus* (Linnaeus)	+	+		●	Δ		
Muraenidae	*Muraena helena* (Linnaeus)	+	+	●		Δ		
Myliobatidae	*Myliobatis aquila* (Linnaeus)		+	●		Δ		
	Pteromylaeus bovinus (Saint-Hilaire)	+	+	●	●	Δ	Δ	Δ
Pomacentridae	*Chromis chromis* (Linnaeus)	+	+	●		Δ	Δ	
Pomatomidae	*Pomatomus saltatrix* (Linnaeus)	+	+	●	●	Δ	Δ	Δ
Scorpaenidae	*Scorpaena notata* (Rafinesque)	+	+	●		Δ		
Serranidae	*Serranus cabrilla* (Linnaeus)	+	+	●		Δ		
	Serranus scriba (Linnaeus)	+	+	●		Δ		
Sparidae	*Diplodus vulgaris* (Saint-Hilaire)	+	+	●	●	Δ		
	Diplodus sargus (LS) (Linnaeus)	+	+	●	●	Δ	Δ	Δ
	Diplodus sargus (SS)(Linnaeus)	+	+	●				Δ
	Diplodus cervinus (Lowe)	+	+	●		Δ		
	Diplodus puntazzo (Cetti)	+		●		Δ	Δ	
	Dentex dentex (Linnaeus)	+	+	●	●	Δ		
	Oblada melanura (LS) (Linnaeus)	+	+	●	●	Δ	Δ	Δ
	Oblada melanura (SS) (Linnaeus)	+	+	●	●	Δ		Δ
	Sarpa salpa (Linnaeus)	+	+	●			Δ	Δ

Appendix 5: Publication chapter 4

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Stakeholders' perceptions of marine fish farming in Catalonia (Spain): A Q-methodology approach

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ABSTRACT

Marine aquaculture production is becoming increasingly important to meet global seafood demands. Conversely, there are concerns about potential environmental impacts, especially associated with marine fish farming, and the access to and use of coastal resources. While only a small number of studies on social acceptability of fish farming exist, understanding the range of perceptions among social groups is a key challenge for successful management of aquaculture, and thus for sustainable development. The case study presented here uses the Q-methodology to explore the perceptions of five aquaculture-related key stakeholder groups (NGOs, local fishermen, fish farming industry, scientists and regional administration) towards marine fish aquaculture in Catalonia (NE Spain). The 30 participants were asked to sort 39 statements about environmental, social and economic aspects of marine fish farming, on a scale from strongly agree to strongly disagree. The factor analysis identified four distinct factors, each representing a different perception. While Perception 1 regards fish farming as an activity with important socio-economic benefits and low environmental costs, Perception 2 gives highest importance to environmental concerns. Perception 3 represents a more balanced view, valuing the socio-economic benefits and expressing moderate concern about environmental impacts, whereas Perception 4 focuses mainly on economic aspects. Interestingly, the four perceptions were represented by various groups of stakeholders and not all respondents from the same sector shared the same perception. This study contributes to the scarce scientific information on social research on aquaculture, revealing limitations, challenges, and opportunities of the industry.

1. Introduction

The worldwide decline of capture fisheries (e.g. Myers and Boris, 2003; Pontecorvo and Schrank, 2012) and a simultaneous increase in seafood demand has triggered a rapid growth of marine aquaculture (FAO, 2012). Responsible for this continuous growth are the developing countries, particularly in Asia, whereas annual growth rates in the European Union (EU) have been minimal since 2000, averaging only 0.4% (FAO, 2012). The EU increasingly relies on fish originating from other regions, importing 65% of its finfish products (AIPCE-CEP, 2012). The causes for the stagnation of the European aquaculture sector are believed to be numerous, e.g. limited access to space and licensing, price instability, pressure from imports, limited access to loans and stringent EU regulations (EU Commission, 2002, 2009). Moreover, the social acceptability of the industry and its products has been identified as a key factor for the successful achievement of the sector's growth potential (Fezzardi et al., 2013; Kaiser and Stead, 2002). The recognition of the range of perceptions that exist on marine aquaculture's economic, social and environmental benefits and costs is therefore a central aspect towards a sustainable development of this industry (Burbridge et al., 2001; Kaiser and Stead, 2002; Mazur and Curtis, 2008).

Marine aquaculture production is becoming increasingly important to meet global seafood demands, and is believed to improve the economic development of rural coastal communities (Burbridge et al., 2001; Katranidis et al., 2003; Varadi et al., 2001). Conversely, there are concerns about aquaculture's negative environmental effects, especially associated with marine sea-cage fish farming, due to its high dependence on fish meal and fish oil (Naylor et al., 2000, 2009). Potential impacts of fish farm production involve various effluents (e.g. waste feed, feces, pesticides and medications) (Primavera, 2006), negative interactions with wild fish populations (Diamant et al., 2000; Heggberget et al., 1993) and reduced amenity values (Read and Fernandes, 2003). The access to and use of coastal resources of fish farms can lead to conflicts with other users of the coastal zone (Halwart et al., 2007; Hoagland et al., 2003; Nimmo et al., 2011). In addition, there are consumer concerns about the quality of farmed fish products (Verbeke et al., 2007).

Therefore, the range of perceptions of different stakeholders, as an important part of marine aquaculture management and planning, should be taken into account (Chu et al., 2010; Mazur and Curtis, 2008; Robertson et al., 2002). Insufficient participation and consultation

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of relevant stakeholder groups could lead to mismanagement of resources and social conflict and/or decreased public support and trust (Buanes et al., 2004; Kaiser and Stead, 2002; Shindler et al., 2002). Hence, there is a need to develop effective stakeholder involvement that aids communication and understanding on the many complex issues related to aquaculture (Stead et al., 2002). It is now widely accepted that a more competitive and sustainable future aquaculture industry has to be based on an integrated approach (Fezzardi et al., 2013; GESAMP, 2001), representing an interdisciplinary framework that combines knowledge from natural resource management and social sciences (Stead et al., 2002).

There is a small but increasing number of social science studies on fish farming. However, most of them focus on consumer perceptions (Altintzoglou et al., 2010; Fernández-Polanco and Luna, 2010, 2012; Verbeke et al., 2007) or the opinions of the general public (Freeman et al., 2012; Katranidis et al., 2003; Shafer et al., 2010), rather than perceptions of aquaculture-related key stakeholder groups (Chu et al., 2010; Rudell and Miller, 2012; Whitmarsh and Palmieri, 2009). Developing an overview of the different stakeholder perspectives can increase stakeholders' awareness of other perceptions (Raadgever et al., 2008) and may result in better mutual understanding and consensus between distinct groups and sectors (Pahl-Wostl and Hare, 2004). Moreover, studies of the different perceptions inform about what stakeholder groups consider the most important issues (Mazur and Curtis, 2008) and their attitudes towards measures for improvement. This can help governments and the aquaculture industry to develop a socially acceptable and sustainable aquaculture sector.

The present case study investigates the different perceptions on marine fish farming held by a diverse group of aquaculture-related key stakeholders in Catalonia (Spain). Spain is the third largest marine fish producer in the EU after the United Kingdom and Greece (APROMAR, 2013) and the third largest importer of fish products worldwide (FAO, 2012), with a per capita seafood consumption of 26.8 kg in 2011 (MAGRAMA, 2011). Yet, in 2010 the production of marine fish aquaculture in Spain has decreased 9.4%. Despite a slight increase in 2012, the production volume still remains 8.8% below the level of 2009 (APROMAR, 2013). In the autonomous region of Catalonia (NE Spain) industrialized marine fish farm production started at the beginning of the 1990s and has mainly focused on producing Gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*). Most of the farm installations have been initiated in cooperation with fishermen's guilds. Catalonia used to be the second most important region for marine fish farm production in Spain and has been pioneering in the development of offshore farming systems (Jordana, 1999). However, partially due to increasing national and international competition, the financial crisis and the price instability of aquaculture products (Fernández-Polanco, 2012), 60% of the Catalan fish farming installations had to close over the past decade (APROMAR, 2013). As a consequence, the total farmed fish production has decreased 22.3% from 2005 to 2012 (APROMAR, 2013). Even though recent production numbers indicate a slight increase, the development of the aquaculture sector remains complex (APROMAR, 2013).

This study aims at understanding the causes for the decrease of the present fish farming sector in Catalonia and to investigate the limitations, challenges and opportunities in an environmental, social and economic context. For this purpose, Q-methodology was applied, consisting of collecting and selecting statements directly from stakeholders, getting stakeholders to sort the statements according to their agreement or disagreement, factor analysis of the sorts, and finally analysis and interpretation of the factors identified.

The specific research questions were: (1) what are the distinct perceptions regarding the ecological, social and economic costs and benefits of fish farming in Catalonia, (2) which are the major areas of agreement and disagreement between perceptions, (3) which stakeholder groups share the same perception and (4) which are the most important issues and proposed measurements for improvement?

2. Material and methods

Previous studies of social perception towards aquaculture (e.g. Freeman et al., 2012; Mazur and Curtis, 2008; Robertson et al., 2002; Whitmarsh and Palmieri, 2011) predominantly applied survey-based research methods. An alternative to such techniques is the Q-methodology. While the typical result of a survey-based study is a statistical analysis of pre-specified categories selected by the researcher, the outcome of a Q-study is a set of factors to explain the perceptions that exist among people (Addams and Proops, 2000), allowing participants to raise their own topics rather than these being imposed by the researcher (Dryzek and Berejikian, 1993). This method, developed by the British psychologist William Stephenson in the 1930s (Stephenson, 1953), combines the benefits of both qualitative and quantitative research (McKeown and Thomas, 1988; Stephenson, 1953). Q-methodology does not require large population samples to obtain statistically valid results (Brown, 1980), as it produces an in-depth view of different perspectives that exist in a given situation, but does not intend to generalize its results to a larger population (Steelman and Maguire, 1999). Q-methodology is increasingly being used to explore perspectives of people involved in environmental issues (e.g. Bischof, 2010; Frantzi et al., 2009; Mattson et al., 2006; Raadgever et al., 2008; Swedeen, 2006), including aquaculture (Rudell and Miller, 2012).

2.1. Collection and selection of statements

The first step of a Q-study is to generate a series of statements on the topic under investigation. In this study, semi-structured face-to-face interviews with 35 well-informed stakeholders were conducted during the period from April to June 2012. Participants were recruited on the basis of their relevance to the study aim and their knowledge of the aquaculture industry. The selected stakeholders included scientists, NGOs, fish farmers, fishermen and the regional fishing and aquaculture administration. The scientific sector included experts in aquaculture economics (University of Barcelona), marine ecology (CSIC — Spanish National Research Council), aquaculture research (CSIC and IRTA — Institute of Food and Agricultural Research in Catalonia) and aquaculture–environment interactions (University of Alicante). The fish farming sector consisted of respondents from different fish farms in Catalonia, the Catalan Association of Aquaculture (ACA), the Spanish Fish Farmers Association (APROMAR) and a consultancy specialized in marine fish farming. The administration was represented by the fisheries and aquaculture administration, the environment department and the coast directorate from the regional administration in Catalonia. Environmental NGOs were represented by national and regional organizations (WWF Spain, Greenpeace Spain, Ocean2012, Oceana Spain, Fundació Mar and Nereo). Actors from the fisheries sector consisted of the presidents of the fishermen's guilds ("cofradía") at different ports (with and without fish farm installations nearby) along the Catalan coast. Participants were encouraged to speak freely about positive and negative aspects of fish farming in an environmental, social and economic context, and on measures to improve the sector's sustainability. A total of 356 statements were initially extracted from the interviews. Statements on similar aspects of aquaculture were combined, which considerably reduced the number of statements. To ensure that the whole range of perceptions is represented, the statements were sorted into the three categories of interest: environment, social and economic. In each category, statements were chosen that were representative of all the sub-themes that arose during the interviews. This process reduced the number of statements to a final list of 39 (13 statements from each category).

2.2. Sorting of statements

Out of the 35 participants that have been interviewed, 30 respondents (six from each sector) were asked to sort the 39 statements.

Stakeholders were asked to sort the statements by how strongly they agreed or disagreed with them. The statements were provided to the participants on separate and numbered cards with the instruction to sort the statements using a 9 point chart ranging from −4, least agree to +4, most agree. In this way, a set of sorted data is collected for each participant, the pattern of the sort representing the individual perceptions. Respondents were encouraged to distribute their statements according to a quasi-normal distribution, yet, they were allowed to put more or less statements in a certain scoring category if it helped to better describe their perception. Respondents were asked to comment the scoring of the statements, which added valuable contextual information at the time of interpreting the results. The sorting was conducted face-to-face, however, to avoid long-distance traveling, five sorts were conducted by Skype.

2.3. Statistical analysis

The statistical analysis was conducted using the PQMethod software (Schmolck and Atkinson, 2002). First, the software calculated a correlation matrix of all 30 sorts representing the level of similarity of the perceptions of individual participants (Van Exel and de Graaf, 2005). The data were then factor analyzed using Principal Component Analysis (PCA). In this process, the sorts of participants that share similar perceptions grouped together and formed a factor. Factors were then varimax rotated in order to find the best solution maximizing the variance explained by the factors. The number of factors was determined by selecting factors with eigenvalues greater than two, meaning that each factor is defined by at least two significantly loading sorts (Brown, 1980). The factor loading expresses the extent to which each sort agrees with a factor's viewpoint (Brown, 2004). The sorts that loaded significantly (± 0.41 or above, with $p < 0.01$; for equation see Brown, 1980) on a given factor were merged to form one single sort, configured to represent the perception of that factor. In other words, for each factor an idealized sort was constructed which is a weighted average of all the individual sorts that loaded on this factor (Watts and Stenner, 2005). The resulting sort for each factor is then subject to interpretation.

2.4. Interpretation

The aim of a Q-study is to understand and explain the perceptions represented by each factor (Watts and Stenner, 2012). During interpretation, particular attention was given to statistically distinguishing statements for each factor ($p < 0.05$). Moreover, the explanations gathered from respondents during the interviews and the sorting process added valuable information. Statements were identified as consensus statements when all factors agreed or when three factors agreed and one factor had a neutral rating.

3. Results

In this study, four well defined factors were identified. The four factors explained 54% of the total variance between all 30 sorts. Table 1 shows which participants define and thus share a factor (perception). Factor sort values for each statement are listed in Table 2. The Results section first describes the four perceptions represented by each factor, followed by areas of agreement among perceptions. Two participants loaded significantly on two different factors ("confounders"), as standard practice in Q-studies their sorts were excluded from the construction of the factors' viewpoints (Brown, 1993). Possible explanations for their hybrid-views are discussed.

3.1. Perception 1

Central to this perception is the belief that fish farms cause low environmental impacts (statements 3, 20 and 27). Unlike all other viewpoints, this perception regards the fish farming industry as environmentally more sustainable than other economic activities in the coastal zone (38), or terrestrial meat production (17). However, integrated multi-trophic aquaculture systems (IMTA, see for explanation e.g. Ridler et al., 2007) are not considered appropriate for the cultivation of marine fish in Catalonia (32).

This perception emphasizes the social importance of marine fish aquaculture for the supply of fish protein (7) and the development and welfare of coastal communities (37). Moreover, the low prices and the permanent availability of farmed products are considered to facilitate the access to fish (26). In contrast, there is disagreement with the assumption that fish farms lead to conflicts with other users and activities of the coastal zone (10). Similarly, they do not believe in a direct price-competition with the extraction fishery, since the two sectors produce two distinct products (12).

Perception 1 acknowledges, that in the past the fish farming sector strongly depended on subsidies, however, the present installations are considered economically viable (33). Nevertheless, it is believed that several factors work against the industry's successful development, such as the stringent environmental regulations (1) and the undervaluation by the regional administration (24). In addition, deficient marketing is considered to hinder the successful promotion of the quality of aquaculture products and the activity itself (28). Furthermore, respondents recognize the importance of focusing on producing both quantity and quality (31).

Table 1
Factor loadings. Overview of the factor loadings for each sort ranging from 1 (complete agreement) to −1 (complete disagreement with the perception of that factor).

Q sorts	F1	F2	F3	F4
Factor 1				
Scientist (fish biology)	**0.73**	0.04	−0.43	−0.01
Scientist (aquaculture)	**0.68**	0.07	−0.04	0.32
Scientist (aquaculture)	**0.75**	−0.06	0.09	−0.04
Fish farming sector (producers association)	**0.73**	−0.23	0.22	0.18
Fish farming sector (consultancy)	**0.43**	0.07	0.17	0.07
Fish farming sector (producers association)	**0.74**	−0.21	−0.03	0.00
Fish farming sector	**0.84**	−0.29	−0.01	0.05
Fish farming sector	**0.48**	0.04	0.32	−0.18
Fish farming sector	**0.69**	−0.09	0.21	0.03
Administration (fisheries and aquaculture)	**0.68**	0.29	−0.01	0.13
Administration (environment)	**0.66**	0.06	−0.22	0.21
Administration (coastal services)	**0.44**	0.04	0.09	−0.03
Factor 2				
Environmental NGO	0.22	**0.57**	−0.37	0.00
Environmental NGO	−0.25	**0.69**	−0.09	0.48
Environmental NGO	−0.16	**0.74**	0.22	−0.07
Environmental NGO	−0.31	**0.63**	−0.03	−0.13
Environmental NGO	0.21	**0.59**	0.19	0.29
Environmental NGO	0.06	**0.61**	0.45	0.03
Scientist (aquaculture economics)	0.18	**0.41**	0.16	0.27
Administration (fisheries and aquaculture)	−0.12	**0.51**	0.03	0.24
Factor 3				
Scientist (marine ecology)	0.14	0.04	**0.74**	0.11
Fisherman (aquaculture installations nearby)	0.04	0.23	**0.81**	0.08
Fisherman (aquaculture installations nearby)	0.20	0.08	**0.65**	0.19
Factor 4				
Scientist (aquaculture–environment interactions)	0.14	0.25	−0.17	**0.44**
Fisherman	0.09	0.03	0.34	**0.73**
Fisherman	−0.08	−0.07	0.23	**0.76**
Fisherman (aquaculture installations nearby)	−0.03	0.02	0.01	**0.72**
Fisherman	0.19	0.25	−0.02	**0.61**
Confounded sorts				
Administration (fisheries and aquaculture)	0.44	0.19	0.07	0.51
Administration (fisheries and aquaculture)	0.46	0.39	−0.43	0.28
% explained variance	**21%**	**12%**	**10%**	**11%**
Total defining Q sorts	**12**	**8**	**3**	**5**
Total Q-sorts	**13**	**8**	**3**	**6**

Table 2
Factor sort values for each statement.

#	Statements	F1	F2	F3	F4
1	A more stringent environmental regulation applies to the fish farming sector compared to other coastal activities (e.g. ports, fishery, waste water discharge, etc.)	+3	−4	−3	+1
2	There is a high potential for improvement to reduce the economic risk associated with fish farming and to permit its economic viability	0	+1	−1	+2
3	The environmental impact of fish farms on the benthos is marginal and limited to the farm area	+3	−3	0	+2
4	Fish farms create new opportunities for economic activities (e.g. fishing, boating, gastronomy)	+1	0	+4	+3
5	There is a lack of a map that identifies appropriate zones for economic activities to reduce impacts and conflicts with other users	0	+4	+1	+3
6	There is no difference in quality or taste between wild caught and farmed fish	−1	−3	−4	−4
7	Fish farms are necessary to assure the provision of protein	+4	0	+1	−1
8	The fish farming sector creates a relevant amount of employment at a local level	−1	−1	0	0
9	The fish farming sector lacks a good business management	−1	+1	0	+1
10	Fish farms generate competition and conflicts with other users and activities of the coastal zone	−2	+3	−1	0
11	Fish farm feed generates overexploitation of fishery resources	−2	+4	+1	−3
12	The low prices of aquaculture products negatively impact the price of similar wild caught fish	−4	+3	+2	+1
13	Fish farming could contribute to the repopulation of overexploited species	0	0	+3	+2
14	Fish farming is an activity with low social appreciation	0	−1	+2	−2
15	The network for commercialization is deficient negatively affecting the final state and price of the product	−3	−2	−1	+2
16	Fish farming is an economic and not ecological activity therefore certain impact has to be accepted	+1	−3	−3	+3
17	The production of cultivated fish is environmentally more sustainable than the production of meat (e.g. poultry, beef)	+4	−4	−2	−2
18	There is a distrust concerning quality and condition of cultivated fish	+1	+1	+4	+1
19	Environmental NGOs promote a negative image of the fish farming industry	0	0	−2	−1
20	There is a high risk of biological contamination from fish farms (e.g. genetic contamination due to escapes and transmission of pathogens)	−2	+2	0	−1
21	The fish farming sector represents a potential job alternative for fishermen	−1	−2	+3	−3
22	The fish farming sector here cannot compete with other countries that produce at lower costs	+1	+1	0	+4
23	Fish farms generate new biotopes	0	0	+3	+1
24	The fish farming sector is undervalued by the regional administration compared to other consolidated activities	+2	−2	0	−3
25	Fish farms reduce the exploitation of local fish stocks by the local fishery	−4	−4	−3	−3
26	The low price of fish farm products is positive as it facilitates the access to fish	+3	+2	−3	−4
27	There is a high risk of negative impacts from the use of chemical products at fish farms	−4	+3	−2	−1
28	There is a great deficiency in the marketing of fish farming products	+2	0	−1	−1
29	Working conditions in the fish farming sector are better compared to the fishing sector	+2	+1	+2	0
30	The traceability of fish farm products is appropriate	+1	−1	−4	−2
31	The fish farming sector misleadingly concentrates on producing high fish quantity instead of quality	−2	+2	+1	+4
32	A sustainable development of the aquaculture activity requires integrated multi-trophic aquaculture systems (IMTA)	−3	+3	+2	0
33	The fish farming sector is economically not viable and depends excessively on subsidies	−3	0	−4	+3
34	The fish farming industry should introduce certifications of quality	+4	+2	+3	+4
35	The fish farming sector should substitute the fish meal with vegetable proteins	−1	+4	−2	−2
36	The visual impact of fish farms is important	−3	−3	+1	−4
37	Marine fish farms promote the development and welfare of coastal communities	+2	−1	−1	0
38	The environmental impact of marine fish aquaculture is of a lower magnitude compared with other coastal activities	+3	−1	0	0
39	The fish farming industry promotes a diversification of the fish products in the market	0	−2	+4	0

3.2. Perception 2

This perception is distinguished from the others by its concern for the environmental costs of fish farm operations, such as eutrophication on the benthos (3), negative effects through the use of chemical products (27) and the transmission of pathogens (20). There is a strong belief that economic activities, such as fish farming, do not legitimate every type of environmental impact (16). In addition to direct local effects, the use of fish meal and fish oil for aquafeeds is considered to generate overexploitation of fishery resources in other regions (11). Consequently, respondents of Perception 2 support the idea of replacing fish meal by another food source, such as vegetable proteins (35), and suggest focusing more on cultivating fish species of lower trophic levels. In addition, it is believed that the implementation of integrated multi-trophic aquaculture (IMTA) systems could improve the environmental sustainability of fish farming in Catalonia (32). Overall, the cultivation of marine fish species is not considered more environmentally sustainable than the production of terrestrial animal protein (17). Further, this perception strongly disagrees with statement 1, which states that the fish farming sector is environmentally more stringent regulated than other coastal activities.

From a socio-economic viewpoint, fish farms are considered to generate competition and conflicts with other users of the coastal zone (10) and respondents emphasize the lack of a map that identifies appropriate zones for economic activities (5), in order to avoid such conflicts. Even though the low prices of aquaculture products are considered to make fish more accessible (26), there is a concern that the low prices of farmed fish could negatively impact the price of wild-caught species (12). Further, it is not considered that farmed products diversify the offer in the market (39), since all cultivated fish species are also exploited by the extractive fishery.

3.3. Perception 3

Perception 3 particularly highlights the social and economic importance of the fish farming sector for creating new opportunities for economic activities (4), and representing a job alternative for fishermen (21) that provides better working conditions (29). It strongly disagrees with statement 33, which states that the fish farming sector is economically not viable being highly dependent on subsidies. However, it acknowledges that the sector suffers from distrust concerning the quality and condition of its products (18), partially because the information provided to consumers is deficient (30). Respondents agree that fish farm products promote a diversification in the market (39). However, there is concern that the low costs of farmed fish could negatively impact the price of wild-caught fish (12) and at the same time penalize the fish farming sector, if low prices are associated with low quality (26).

Perception 3 recognizes the importance of environmental aspects, but does not perceive high environmental risks associated with marine fish farming in Catalonia (3, 11, 20, and 27). Respondents argue that every economic activity has an environmental impact (16); the challenge is to reach a balance between economic growth and environmental protection. Similar to Perception 2, respondents deny that the fish farming sector has to comply with more stringent environmental regulations compared with other coastal activities (1). They believe that fish farm installations have the potential to generate new biotopes (23), similar to small protection areas. An additional positive aspect of marine fish aquaculture is its potential contribution to the repopulation of overexploited species (13).

3.4. Perception 4

Perception 4 is distinguished from the other three perceptions by giving highest importance to economic aspects. Unlike all the other perceptions, it regards the present fish farming industry in Catalonia as economically not viable (33), mainly due to the competition with other countries that produce at lower costs (22). It believes, however, that there is a high potential for improving the sector's economic situation (2), e.g. by focusing more on producing high quality rather than quantity (31). In addition, it emphasizes the capacity of marine fish aquaculture to generate parallel economic activities (i.e. tourism, gastronomy) (4). Nevertheless, it does not consider the aquaculture sector as a job alternative for fishermen (21), arguing that the two sectors are too different. In addition, there is strong disagreement with the assumption that the fish farming sector is undervalued by the regional administration compared to other consolidated activities (24). Fish farms in Catalonia are not considered very important to meet the demand for animal protein (7), nor to make fish more accessible (26), since many wild-caught fish species are sold cheaper. Analogous to Perception 2 and Perception 3, there is a belief that the cheaper fish farm products directly compete with wild-caught fish of the same species (12). Environmental aspects were not a central theme in this discourse (3, 20, 27, and 11), it is considered that a certain impact has to be accepted from any economic activity (16). Yet, as in Perception 3 there is a view that fish farms could help repopulate exploited fish species (13) and create new biotopes (23).

Table 3 provides a synopsis of the most important benefits and costs/issues (statements that were sorted at ± 3 or ± 4) and measures for improvement identified by each perception.

3.5. Areas of consensus

All four perceptions recognize the importance of introducing certifications of quality (34) in order to reduce consumers' distrust of the quality of farmed fish (18) and to better compete with countries producing at lower costs (22). In addition, all perceptions agree that fish farms provide opportunities for new economic activities, but are not considered to create a relevant amount of employment at the local level (8). The stakeholder groups agree on the need to implement a map that identifies appropriate zones for economic activities, to reduce impacts and user conflicts (5). With the exception of Perception 3, there is a clear view that the visual impact of farms is not important (36). Furthermore, there is general disagreement with the idea that there is no difference in quality or taste between wild-caught and farmed fish (6). Finally, all perceptions disagree with statement 25, which states that fish farms reduce the exploitation of local fish stocks by the local fishery.

3.6. Stakeholders that share the same perception

Table 1 reveals that not all of the respondents who belong to the same stakeholder group share the same perception. Exceptions were participants from environmental NGOs and actors from the fish farming sector who both exclusively shared Perception 1 and Perception 2, respectively. Respondents from the aquaculture and fisheries administration shared mostly Perception 1 and only one member the view of Perception 2. Scientists were represented in all four perceptions. Those dealing with aquaculture shared Perception 1, the aquaculture economist Perception 2, the marine ecologist Perception 3 and the expert on aquaculture–environment interactions shared the view of Perception 4. Most of the fishermen shared Perception 4, and two Perception 3. The two confounders belong to the regional fisheries and aquaculture administration. Both participants shared Perception 1, but at the same time one respondent also shared Perception 4, while the other participant significantly disagreed with Perception 3.

4. Discussion

The structure of the discourse — the emergence of four distinct perceptions — indicated that marine fish farming is seen from diverse perspectives. Interestingly, all four perceptions were represented by various groups of stakeholders and not all respondents of a sector shared the same perception. Although the identified perceptions were well distinguished, several areas of agreement were identified, which

Table 3
Synopsis of results. Overview of the most important benefits, costs/issues and measures for improvement of fish farming in Catalonia (Spain) identified by each perception (IMTA: integrated multi-trophic aquaculture system).

	Perception 1	Perception 2	Perception 3	Perception 4
Benefits	• Environmental impact is marginal and lower compared with other coastal activities • Fish farming is more sustainable than meat production • Provision of animal protein • The low prices facilitate the access to fish	• The low prices facilitate the access to fish	• Fish farms generate new biotopes • Serve to restock overexploited species • Diversification of fish products in the market • Job alternative for fishermen • New opportunities for parallel economic activities	• New opportunities for parallel economic activities
Costs/issues	• Stringent environmental regulations • The fish farming sector is undervalued by the regional administration	• Risk of environmental impacts • Fish farm feed generates overexploitation of fishery resources • Conflicts with other users of the coastal zone • Low prices lead to competition with capture fishery	• Distrust concerning quality and condition of cultivated fish • The information provided to consumers is deficient • The low price of farmed fish may be associated with low quality	• Activity is economically not viable • Cannot compete with other countries that produce at lower costs • Does not facilitate the access to fish, since many wild caught fish species are sold cheaper
Measures for improvement	• Introduction of certifications of quality and reinforcement of the designation of origin • Equivalent regulations for all aquaculture fish marketed in EU • Optimize administrative procedures • Develop aquafeeds that depend less on wild fish	• Cultivation of species of a lower trophic level • Reduction of environmental impacts • Integrated aquaculture systems (with agriculture or IMTA) • Implementation of a map to identify appropriate coastal zones for economic activities	• Provision of easy access to credible information for consumers • Introduction of certifications of quality	• Concentrate more on producing quality than quantity • Implementation of a map to identify appropriate coastal zones for economic activities

can serve as a common ground for discussion. Finally, the findings revealed the main economic, social and environmental challenges faced by the fish farming industry in Catalonia.

Respondents of Perception 1 strongly advocated marine fish farming, highlighting its aptitude to produce critically needed marine fish supplies of good quality to an affordable price. They considered the apprehension about potential environmental risks and damage caused by marine fish farming as disproportionate; given the fundamental dependence of farms on good environmental quality and hence, a common interest in its maintenance. However, they acknowledged that there are many external and internal factors that prevent the industry from developing its full economic potential. This perception was shared by all participants from the aquaculture industry, but also by all scientists specialized in aquaculture research, as well as three participants of the fishing and aquaculture administration. The support given by the members of the aquaculture industry is comprehensible, reflecting the objective to sustain and develop fish farming in the region. Furthermore, it seems logical that aquaculture scientists are in favor of the aquaculture industry, since they investigate and develop the cultivation of marine fish species. Respondents from the regional administration are directly involved in management, and may to a certain extent feel responsible for the sector and share an interest in its successful development.

Perception 1 and Perception 2 contained the most opposing views, mainly due to their contradictory perceptions of environmental impacts caused by marine fish farming. Perception 2 did not regard the cultivation of marine fish as the solution to overfishing; believing that the decline of fish populations can only be solved through a responsible capture fishery. Moreover, the fish farming sector in Catalonia was not considered to provide considerable social or economic benefits. Perception 2 is consistent with previous findings which showed that the acceptance of aquaculture decreases where local concerns about environmental damage from aquaculture are high and perceived socio-economic benefits are low (Hugues-Dit-Ciles, 2000; Katranidis et al., 2003). As expected, this perception was shared by all members of environmental NGOs. More surprisingly, this view was also supported by an aquaculture economist and one respondent from the regional fisheries and aquaculture administration.

Perception 3 represented a more balanced view, valuing the socio-economic benefits of marine fish aquaculture and expressing moderate concern about environmental impacts. There is a clear view, that fish farming is a complementary activity to the extractive fishery and it is considered a potential job alternative for fishermen. This perception was shared by two fishermen and one marine ecologist. Interestingly, both fishermen are based at ports where aquaculture installations are operative, suggesting that the presence of fish farms positively influences their perception of aquaculture. Perception 4 was mainly shared by fishermen without aquaculture installations near their home port, and one scientist specialized in interactions of aquaculture with wild fish populations. In contrast to Perception 3, in Perception 4 fish farms were not considered to represent a job alternative for fishermen, regarding the two activities as too different. Proponents expressed the strongest concern about economic aspects, suggesting that fishermen are especially aware of economic issues of marine fish farming, since they may encounter similar problems. Most fishermen that shared Perception 3 and Perception 4 did not consider the fishery and fish farms to be in conflict over access to coastal areas, but they believed that the low price of aquaculture products could negatively impact the price of wild caught fish.

The fact that two respondents of the fisheries and aquaculture administration shared the perception of two viewpoints seems to reflect their professional background. The participant that shared Perception 1 and Perception 4 approached the topic from an aquaculture and a fishery's perspective. Similarly, the other member of the administration also shared the perception of the aquaculture industry; yet, the strong disagreement with the relatively balanced Perception 3 remains puzzling to us. In total, five participants from the administration (including the two confounders) shared Perception 1, indicating that they are willing to support a further development of marine fish aquaculture in the future.

4.1. Limitations, challenges and measures for improvement

During the interviews and the interpretation of the different perceptions a number of key themes were identified, suggesting that these are important issues of the marine fish farming debate in Catalonia. In the following section, the rationale behind the distinct perceptions will be discussed further by looking at the comments made during the sorting with respect to these challenges and limiting factors.

Commonly, the perception of aquaculture is linked to how its environmental impact is perceived (Katranidis et al., 2003; Rudell and Miller, 2012; Whitmarsh and Wattage, 2006). Similarly, in the present study, environmental aspects were important in terms of differentiating perceptions on fish farming. One of the most controversial topics was the capture of wild fish as raw material for fish feed. Most respondents of Perception 1 believed that there is no other use for these fish species since they are normally not used for direct human consumption. However, all four perceptions recognized that an increase in marine fish farms will rise important sustainability issues as to the availability of sufficient fish feed supply. Yet, there was no common agreement on how to solve this issue. Respondents from the aquaculture sector highlighted that over the past decades, the level of fish meal and fish oil in fish feed has already been substantially reduced through the use of plant protein. In contrast, most fishermen did not like the idea of feeding carnivorous fish species with terrestrial plant proteins, arguing that the feed should be of marine origin. Respondents of Perception 2 considered the development of novel aquafeeds, based on alternatives to fish meal and fish oil, as not sufficient and suggested a reconversion of the fish farming sector into the cultivation of species of a lower trophic level.

Direct environmental impacts at fish farm production sites were only considered as a high risk by participants that shared Perception 2, whereas respondents of the other three perceptions believed that these effects can be minimized through responsible management and effective siting of farms. Moreover, members of the regional administration highlighted that the results of regular environmental impact assessments at farms are freely accessible. Yet, this information is usually not requested by other stakeholder groups, suggesting that the aquaculture industry and the government will need to find alternative ways to transmit this information more effectively in order to reduce confusion over perceived and real impacts. The apparent lack of knowledge about current regulations could explain the different perceptions about the legislation strictness (statement 1). Respondents of Perception 1 considered the present fish farming sector overregulated, arguing that the current legislation represents an important constraint. In particular, the excessive difficulty and time (approx. 2 years) needed to obtain permissions and concessions are believed to discourage new business investments. Given that several respondents of Perception 1 belong to the regional administration underlines the significance of this issue. This has also been recognized by the EU Commission, which identified the optimization of administrative procedures as one of the main objectives in the most recent strategic aquaculture plan (EU Commission, 2013).

From an economic viewpoint, respondents believed that the price competition with other producer countries represents one of the main challenges for the fish farming sector in Catalonia. Respondents from the aquaculture sector criticized that the disparity in administrative and legal requirements to practice aquaculture within and outside the EU, is clearly threatening the EU aquaculture sector. Consequently, it was argued that producers in Europe have to be better protected by the implementation of equivalent regulations for all aquaculture fish marketed in the EU.

All participants shared the view that the labeling of fish products needs to be strictly controlled by the government. In particular, respondents of Perception 1 were concerned that the lack of distinction impedes the identification of Spanish aquaculture products by consumers, favoring cheaper imported seafood. Consequently, the importance of reinforcing the concept of the designation of origin was emphasized, which has been shown to positively influence the image of farmed fish in the EU (Altintzoglou et al., 2010). In addition, there was common agreement that the lack of knowledge about production processes and the quality of farmed products causes distrust among consumers. These results suggest that the aquaculture sector, the government, NGOs and scientists should work together to provide easy access to credible information, which has been identified as a key component to build public trust in aquaculture (Mazur and Curtis, 2008). In Spain, many aquaculture producers comply with the quality and environmental certifications ISO 9000 and ISO 14000, however, these have very little external recognition impact (Young et al., 1999). Consequently, respondents of all four perceptions emphasized the importance of introducing certifications of quality that ensure good production practices which can easily be recognized and understood by consumers.

5. Conclusions

By analyzing different stakeholder perceptions of marine fish farming in Catalonia, we have gained insight into how this activity is perceived. Most participants were in favor of a future aquaculture development, however, proponents of each perception recognized distinct environmental, social and economic challenges that need to be overcome to achieve a more sustainable fish farming sector.

General environmental impacts were not perceived as a high risk by the majority of the participants, yet, the reduction in the use of fish meal and fish oil in fish farming was considered a relevant aspect. In addition, the transmission of credible information about the quality of fish farm products and their correct labeling are regarded as critical. Moreover, it is believed that the sector's economic competitiveness could be resolved through regulatory EU reforms and by optimizing the application process for new fish farm installations.

The results of this case study cannot be extrapolated to a larger population or to other aquaculture discourses, however, the fish farming sector in other regions of the EU might face similar challenges. Understanding perceptions of different stakeholder groups can help clear misunderstandings, as well as identify which issues are crucial to be resolved to unleash the full potential of the aquaculture sector, while still achieving social, economic and environmental sustainability.

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