Aquaculture 282 (2008) 61–67

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

Interactions between bluefish *Pomatomus saltatrix* (L.) and coastal sea-cage farms in the Mediterranean Sea

P. Sanchez-Jerez [a,*], D. Fernandez-Jover [a], J. Bayle-Sempere [a], C. Valle [a], T. Dempster [b], F. Tuya [c], F. Juanes [d]

[a] *Department of Marine Science and Applied Biology, University of Alicante, P.O. Box 99, 03080 Alicante, Spain*
[b] *SINTEF Fisheries and Aquaculture, NO-7465 Trondheim, Norway*
[c] *Centre for Marine Ecosystems Research, Edith Cowan University, Joondalup Drive, Joondalup, WA 6027, Australia*
[d] *Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA 01003, USA*

ARTICLE INFO

Article history:
Received 14 March 2008
Received in revised form 17 June 2008
Accepted 18 June 2008

Keywords:
Pomatomus saltatrix
Predator
Escape
Seabream
Seabass
Fish farm
Aquaculture
Impact

ABSTRACT

Coastal sea-cage farms aggregate large concentrations of pelagic and demersal fish. The large numbers of cultured fish and aggregated wild fish often attract a range of marine mammal predators which may break into cages and attack the cultured fish. To date, predation by a finfish species within sea-cages has not been documented. In the Mediterranean Sea, the bluefish *Pomatomus saltatrix* (L.) aggregates around sea-cage farms and enters into cages to predate on the cultured fish. We obtained information about the effects of bluefish predation on aquaculture production through a questionnaire that was completed by fish farmers in Spain, Italy, Malta, Turkey, Greece and Cyprus. In addition, we identified the abundance, size and stomach contents of bluefish aggregated around three fish farms on the coast of Spain through visual counts, and from captured bluefish both inside and outside of the sea-cages. Bluefish occurred around fish farms in Spain, Italy, Malta and Turkey. Farmers in SE Spain reported its presence only inside seabream (*Sparus aurata*) cages, while in Turkey bluefish were reported from inside seabass (*Dicentrarchus labrax*) and seabream cages. Greatest aggregated biomass of bluefish reached 1049 and 3191 kg at the Altea and Guardamar farms, respectively, with abundance peaking at 4500 individuals at both farms. Size structures differed markedly between farms, with smaller individuals aggregating at Altea. Stomach content analysis revealed that bluefish on the outside of sea-cages consumed pelagic species such as *Sardinella aurita* and *Trachurus mediterraneus*, while they predated on seabream once they incurred into cages, often consuming only the tails of many fish. The interaction of bluefish with sea-cage aquaculture is, at present, a problem of local concern restricted to some areas of the Mediterranean Sea, but its widespread distribution suggests this piscivore may be a problematic predator in other regions.

1. Introduction

Marine finfish culture, through the development of innovative culture techniques such as floating cages, is growing rapidly (FAO, 2007). The increasing number of fish farms in coastal areas influences the surrounding wildlife, with ecological consequences. It is already well known that sea-cages cause large aggregations of pelagic and demersal fish (Dempster et al., 2002; Tuya et al., 2005). Due to the presence of the cultivated fish and the wild fishes aggregated around the cages, predators are also attracted to fish farms, with, in some circumstances, economic consequences for farmers (Nash et al., 2000).

Numerous types of predators interact with coastal aquaculture; marine mammals have proved particularly problematic for sea-cage farmers. On the Pacific coast of the USA and Canada, the Californian sea lion *Zalophus californianus*, the harbour seal *Phoca vitulina* and Steller and the sea lion *Eumatopias jubatus* interact with coastal fish farms by predating upon salmonids inside the cages while damaging netting in the process. On the Atlantic coast, harbour seals and grey seals *Halichoerus grypus* cause similar problems (Nash et al., 2000). In Chile, negative interactions of sea lions (*Otavia flavescens*) with salmon farms have been described (Sepulveda and Oliva, 2005). Sea-otters have also caused conflicts with production in specific regions (e.g. Freitas et al., 2007).

Along the Mediterranean coast, marine mammals and birds occur in relatively low numbers around fish farms since natural and human-induced disturbances have greatly reduced their populations. However, in spite of this reduced abundance compared with other geographical areas, predatory interactions with aquaculture occur; e.g. bottlenose dolphins *Tursiops truncatus* aggregate around farms along the coast of Italy (Díaz-López and Bernal-Shirai, 2007), with some deaths as a consequence of accidental net entanglements. Monk seals *Monachus monachus* have attacked fish at several marine fish farms in the Turkish Aegean Sea resulting in damage to both the net cages and fish, which escaped as a result of the attacks (Güçlüsoy and Savas, 2003).

* Corresponding author. Tel.: +34 965 909840; fax: +34 965 909897.
E-mail address: psanchez@ua.es (P. Sanchez-Jerez).

0044-8486/$ – see front matter
doi:10.1016/j.aquaculture.2008.06.025

To date, predatory interactions by finfish species with sea-cage aquaculture have not been documented, regardless of the large aggregations of wild fish around fish farms. A cosmopolitan piscivore, the bluefish *Pomatomus saltatrix* (L.), aggregates around sea-cages and affects fish farming in the western Mediterranean. Bluefish is a migratory species, living in warm and temperate latitudes, except for the eastern and northwest Pacific (www.fishbase.org; Tortonese, 1986). It is found in oceanic and coastal waters, migrating to warmer waters during winter and to cooler water in summer, and feeds on fish, crustaceans and cephalopods (Juanes et al., 1996).

The abundance of bluefish seems to be increasing in the western Mediterranean (Sabatés and Martin, 1993), and its prevalence around sea-cage installations has been recorded by several authors (Dempster et al., 2002; Valle et al., 2007). Numerous fish farmers in the region have reported that bluefish break into sea-cages and predate upon cultured fish. The aim of this work is to describe the ecological interaction of *P. saltatrix* with coastal Mediterranean seabass (*Dicentrarchus labrax*) and seabream (*Sparus aurata*) farms. Specifically, we sought to: i) identify whether a negative interaction with sea-cage production exists in the Mediterranean Sea; ii) estimate the magnitude of bluefish aggregations, and iii) quantify the population structure around fish farms along the SE coast of Spain.

2. Materials and methods

2.1. Estimation of the interaction of bluefish and fish farms

To identify the presence of bluefish aggregations around Mediterranean fish farms, and assess the effects of predation on aquaculture production, we interviewed fish farmers and aquaculture technicians from Spain, Italy, Malta, Turkey, Greece and Cyprus (Fig. 1) for the following information: 1) general information on the installations including year of commencement, production per year, distance from shore and depth; 2) observation of bluefish around the farms (including seasonality); 3) size structure of farm-associated bluefish; 4) potential ways of access of bluefish into the cages, and 5) potential consequences for the production.

2.2. Aggregation and population structure of bluefish around fish farms in SE Spain

Based on the results of the survey, we investigated the aggregation of bluefish around three fish farms off the coast of Spain (South-western Mediterranean Sea, Fig. 1). The three farms cultured both seabream and seabass. The farm at Guardamar was located 3.7 km from shore at a depth of 22.6 m, with 42 cages of 19 m diameter and 15 m deep producing 1200 t yr^{-1}. The farm at Altea was 2.8 km from shore at an average depth of 34 m, with 12 cages of 25 m diameter and 16 m deep producing 500 t y^{-1}. The farm located 3 km in 28.6 m of water off Campello was smaller, producing 300 t y^{-1} in 14 cages of 15.5 m diameter and 17 m deep.

We conducted rapid visual counts (Kingsford and Battershill, 1998) using SCUBA, to estimate the total abundance and size of bluefish. We followed the specific technique adopted by Dempster et al. (2002). At each farm, fish were counted at three random times over a period of two months for every season during two years, from winter 2004 until autumn 2005 (January and February for winter, April and May for spring, August and September for summer and October and November for autumn). Six 5-min rapid visual counts were conducted each time within the farm complex. Each count covered a volume of approximately 11,250 m^3 (15 m wide × 15 m deep × 50 m long). For analysis, data were standardized to 10,000 m^3. During counts, the average total length (TL) of each group was noted. Estimated fish lengths were grouped into three size classes: size 1, < 40 cm; size 2, 40–60 cm and size 3, > 60 cm (Salerno et al., 2001). In addition, we conducted visual counts inside the cages at the Altea and Guardamar farms when farmers noticed incursions of bluefish into cages. Counts were made on 25 separate occasions to determine the number and size of bluefish entrants, as well as to find out the point of entry into the cage (e.g. holes in the net). Data were managed via the ecoCEN package (Bayle-Sempere et al., 2001).

In order to compare the total biomass and abundance of bluefish around the fish farms, we calculated the total volume of water that wild fish occupied around the studied farms by multiplying the area of the farm by the depth, and withdrawing the volume of the cages following Dempster et al. (2004). We added 15 m of area around the farms, which was the volume of water covered by the visual censuses. The total biomass and abundance per 10,000 m^3 was scaled up to the total farm volume: Guardamar farm occupied 892,856 m^3 and Altea farm occupied 664,190 m^3.

Farm-associated bluefish were fished on several random days throughout the sampling period. Fish were measured and weighed. To determine the dietary composition, stomach contents were dissected, identified, and weighed. Results were expressed as a percentage of biomass (P.B. = 100 × (biomass of a particular prey in all guts/sum of the biomass of all prey items).

2.3. Statistical treatment

We tested for differences in abundances and biomasses of farm-associated bluefish among farms through the set of temporal scales considered with ANOVA; the design incorporated four factors: Location (Guardamar and Altea), Year (2004 and 2005), Season (spring, summer, autumn, winter) and Time (three random days per season). Location, Year and Season were considered as fixed and orthogonal factors, and Time was considered random and nested

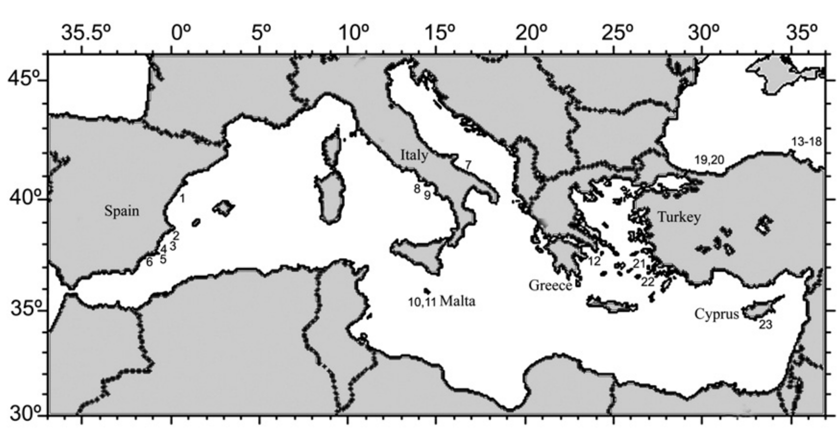

Fig. 1. Geographical locations of the fish farms across the Mediterranean Sea included in the survey. Numbers refer to Table 1.

within Location, Year and Season. Prior to ANOVA, heterogeneity of variance was tested with Cochran's C-test, and data were $\ln(x+1)$ transformed if necessary (Underwood, 1997). Post-hoc Student–Neuman–Kuels (SNK) tests were used to resolve differences among levels of fixed factors.

3. Results

3.1. Estimation of interaction of bluefish across Mediterranean Sea

Replies to our questionnaire were obtained from a total of 23 farms. Bluefish were reported to occur around fish farms in Spain, Italy, Malta and Turkey. Farmers from Greece, and Cyprus did not report aggregations (Table 1). Aggregations were more frequent during spring and summer for Spanish, Turkish and Maltese farms, and during summer and autumn for Italian farms. Of the 16 farms from which bluefish aggregations were detected, four reported problems for production, three from SE Spain and one from Turkey (Table 1). Entrances of bluefish were always observed within seabream cages irrespective of the size of the culture fish, except one occasion at a Turkish fish farm, where bluefish were in a seabass cage. The size of the fish farm, the distance from the coast and depth did not affect either the presence of bluefish aggregations or the entrance into cages. The frequency of bluefish incursions into cages varied from 2 to 15 times per year. Farm managers reported a negative impact of these events on production, ranking it from medium to severe; however, they found the economic impact very difficult to estimate. Economic costs associated with incursions were due to the reduction of seabream production (stopped or reduced feeding, increased swimming activity of the seabream and stress) and the time and cost of diving operations to eliminate bluefish from sea cages by spearfishing or seine fishing, estimated to be around €1000–5000 per cage per incident.

3.2. Aggregation and population structure of bluefish around SE Spain fish farms

Bluefish aggregated around the three studied farms during the study period. However, the abundance, biomass and size structure of aggregations differed greatly among farms and times. Around farms at Altea and Guardamar, bluefish were recorded in every season, but the farm at Campello showed very insignificant aggregations. Maximum total abundances were similar between Altea and Guardamar farms, with a peak of 54 individuals 10,000 m^{-3} at Guardamar farm and 70 individuals 10,000 m^{-3} at Altea, but with significant differences among times (Table 2), exhibiting a similar temporal pattern as biomass (Fig. 2). In contrast, bluefish were observed at only one occasion (4 individuals) during the 2-year sampling period at Campello farm (spring 2004, data not shown). Total biomass differed significantly between farms, peaking at 36 and 31 kg 10,000 m^{-3} at Guardamar, during winter and spring 2005, respectively, and reaching around 15 kg 10,000 m^{-3} at Altea during summer and autumn 2004 (Table 2; Fig. 2).

With respect to the size structure, size 2 peaked during winter and size 3 during spring 2005 at Guardamar farm (54 and 25 individuals 10,000 m^{-3}, respectively). Size 1 fish aggregated only during spring

Table 1
Results of interviews with Mediterranean fish farmers about bluefish interactions

Country		Farm location	Production (t)	Cages	Farm start	Offshore (km)	Depth (m)	Season	TL (cm) outside	No. bluefish entrants	Entrant TL (cm)	Problem for production (L/M/S)	Incursions per year	Species affected	Effects	Cost
Spain	1	Villanova	Br, Ba	15	1998	4.8	33	Spr	80	–	–	–	–	–	–	–
	2	Altea	500 Br, 500 Ba		2001	2.8	35	Spr-Sum	40–60	10s	50–60	L	8	Br	stress, less growth, mortality	40 h per cage for removal
	3	Villajoiosa	1500 Br, 1000 Ba	24	1998	2.8	36	Sum	40–70	10–100s	40–70	M	2	Br	stress, less growth, mortality	1000 € per cage
	4	Campello	400 Br, Ba	9	200	3	28	Spr-Sum	20–40	–	–	–	–	–	–	–
	5	Guardamar	900 Br, 100 Ba	39	2000	4.0	21	Sum	40–80	1–400	50–80	M–S	10	Br	stress, less growth, mortality	1000–5000 € per cage
	6	Aguilas	Br, Ba	24	1999	1.6	40	–		–	–	–	–	–	–	–
Italy	7	Bisceglie	300 Br, 400 Ba	18	1995	2.5	25	Sum-Aut	20–40	–	–	–	–	–	–	–
	8	Gaeta	Br, Ba	15	?	1.0	12	Sum-Aut	20–40	–	–	–	–	–	–	–
	9	Salerno	Br, Ba	15	1997	3.0	30	Sum-Aut	20–40	–	–	–	–	–	–	–
Malta	10	Marsascala	250 Br	4	1992	1.0	50	–	–	–	–	–	–	–	–	–
	11	Marsaxlokk	200 Br	10	1994	0.5	12	Sum	50–70	–	–	–	–	–	–	
Greece	12	Petalioi	? Br, Bs	?	1987	0.5	60	–	–	–	–	–	–	–	–	–
Turkey	13	Torba	1000 Br, Ba	30	1996	0.1	45	Spr	30–40	–	–	–	–	–	–	–
	14	Torba	1000 Br, Ba	20	1996	0.1	35	Spr	20–70	–	–	–	–	–	–	–
	15	Torba	200 Br, 800 Ba	44	1996	2.5	36	Spr	60–65	–	–	–	–	–	–	–
	16	Torba	1000 Br, Ba	14	1998	6.5	55	–		–	–	–	–	–	–	–
	17	Torba	1000 Br, Ba	30	2001	8.0	40	–		–	–	–	–	–	–	–
	18	Torba	1000 Br, Ba	30	2002	2.5	55	Spr	55–60	–	–	–	–	–	–	–
	19	Güvercinlik	1000 Br, Ba	18	1998	2.5	38	Spr	30–40	–	–	–	–	–	–	–
	20	Güvercinlik	1000 Br, Ba	20	2002	2.5	38	Spr	20–60	–	–	–	–	–	–	–
	21	Kazikli	1000 Br, Ba	14	2004	8.0	57	Spr		–	–	–	–	–	–	–
	22	Bodrum	800 Br, 200 Ba	30	2002	0.35	47	All year	30–70	10–100 s	30–70	M–S	3	Br–Bs	Stress, mortality of 30,000 ind.	2 divers, 6 workers per day and cage
Cyprus	23	Limassol	? Br,Ba	22	2004	0.5	20	–	–	–	–	–	–	–	–	–

L: low, M: moderate, S: severe, ?: no data). Br: seabream, Ba: seabass.

Table 2
Analysis of variance testing the effect of locations, years, seasons, and times within locations, years and seasons on total abundance, total biomass and size structure of the bluefish *Pomatomus saltatrix*

		Biomass		Abundance		Size 1		Size 2		Size 3	
	DF	MS	P	MS	P	MS	P	MS	P	MS	P
Location	1	17.99	0.003**	40.93	0.001**	3.56	0.047*	35.66	0.000**	0.41	0.060
Year	1	2.29	0.250	3.74	0.260	0.00	0.959	1.63	0.405	0.52	0.035*
Season	3	2.81	0.189	4.73	0.194	0.39	0.703	4.63	0.131	0.38	0.025*
L×Y	1	2.01	0.280	2.84	0.378	0.62	0.392	0.12	0.817	0.41	0.060
L×S	3	4.44	0.065	2.27	0.087	0.35	0.742	10.40	0.009**	0.41	0.019*
Y×S	3	2.75	0.197	6.80	0.138	1.73	0.122	1.09	0.702	0.38	0.025*
L×Y×S	3	0.22	0.939	5.60	0.832	0.66	0.508	0.53	0.876	0.41	0.019*
Time(L×Y×S)	32	1.66	0.226	0.82	0.121	0.83	0.096	2.29	0.115	0.11	0.987
Residual	240	1.39		2.14		0.60		1.71		0.21	
SNK		Loc: 1<2		Loc: 1>2		Loc: 1>2		L×S: L1: W<Sp=Su=A		Y 2005 L2: Sp>Su=A=W	

Location (L), Year (Y), Season (S). *: significant $p<0.05$. **: significant $p<0.01$. All data were ln (x+1) transformed.

2005 with less than 4 individuals 10,000 m^{-3}. At Altea, the patterns of temporal variation in abundances were specific for each size class. Size 1 fish reached nearly 38 individuals 10,000 m^{-3} during summer 2004. In contrast, in 2005, highest numbers were recorded during spring with 11 individuals 10,000 m^{-3} (Fig. 3). Fish abundances of size 2 were high during spring, summer and autumn in both years, showing significant differences (Table 2), ranging from 10 to 30 individuals 10,000 m^{-3}. However, fish of size 3 occurred at very low levels throughout the sampling period, with 0.03 individuals 10,000 m^{-3} present in summer 2005.

The average biomass estimated for the total farm volume was higher at Guardamar (818 kg) than Altea (471 kg). However, the pattern of abundance was the opposite, with a maximum value of 1105 individuals at Guardamar and 1562 individuals at Altea.

3.3. Gut contents analysis

The stomach contents of 75 adult bluefish caught outside the cages were examined. Fish total lengths ranged from 31 cm (280 g) to 64 cm (2872 g), with a mean value of 46 cm (1056 g). Of the 75 sampled fish,

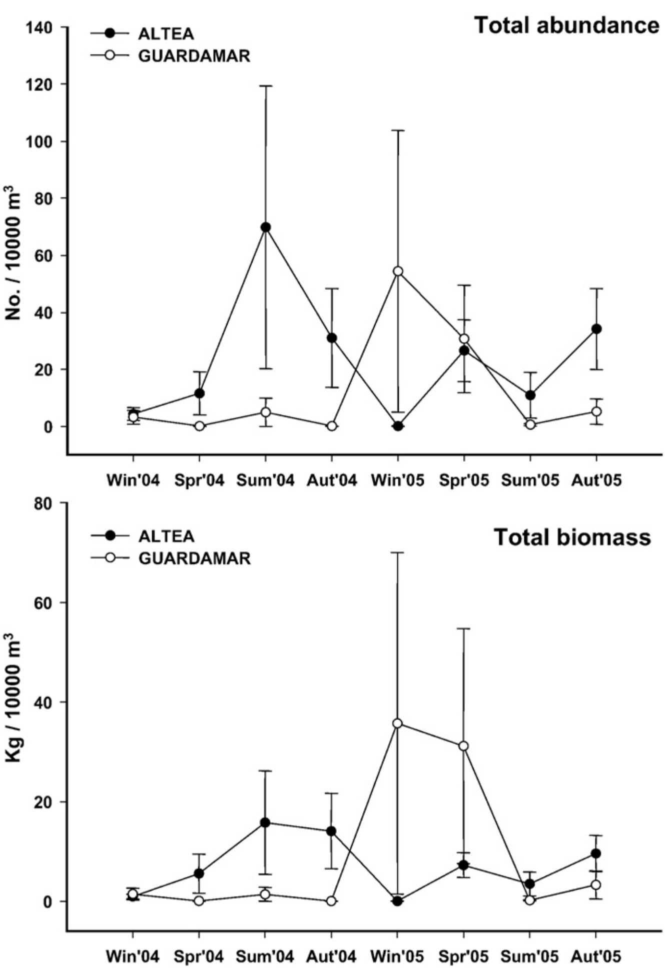

Fig. 2. Mean (±SE) bluefish total abundance and total biomass per season during 2004 and 2005 at the Altea and Guardamar fish farms (SW Mediterranean Sea).

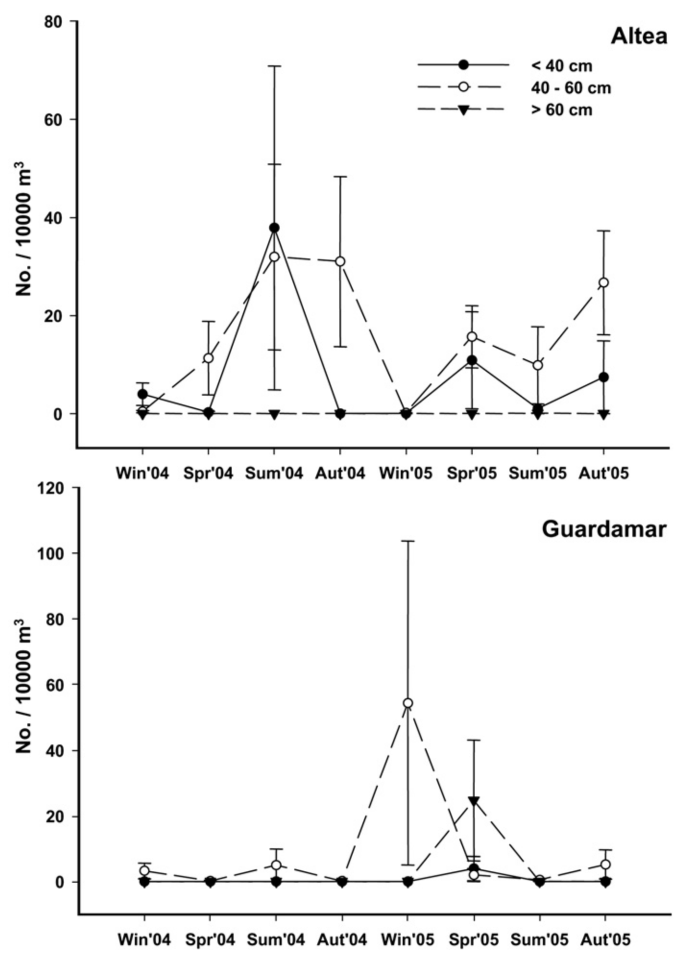

Fig. 3. Mean (±SE) bluefish abundance by size class per season during 2004 and 2005 at the Altea and Guardamar fish farms (SW Mediterranean Sea) (size 1: <40 cm, size 2: 40–60 cm., size 3: >60 cm).

46 had food within the stomach; these fish had an average stomach content of 47 g wet weight. The diet was dominated by teleost fish, predominantly consisting of two pelagic species, *Sardinella aurita* (63.7% biomass) and *Trachurus mediterraneus* (17.3%). Two demersal species, *Serranus cabrilla* (8.5%) and *Mullus surmuletus* (2.4%), were also important dietary components, as well as digested unidentified fish (8.0%).

3.4. Bluefish sampled from inside the cages

A limited sample of 10 fish was captured, as a result of difficulties with spearfishing within the cages and the problems that this activity places on the cultured seabream. Captured bluefish were relatively large, with a mean TL of 63.4 cm (2717 g). Abundances of bluefish inside cages ranged from 1 to 2 individuals to 400 individuals in a single cage, with an average of 23 individuals over the 25 sampling occasions. Stomach contents from the 10 sampled bluefish indicated that they exclusively consumed cultured seabream. In addition, injured seabream, missing the tail or the posterior part of the body, were frequently observed within the cages. Holes in the nylon sea-cage netting, ranging between 15 cm and 22 cm in diameter, were always detected when bluefish were inside.

4. Discussion

Our study has demonstrated that the bluefish, *P. saltatrix,* is extensively aggregated around Mediterranean fish farms. However, there are relevant differences in the magnitude of these aggregations, with patterns in seasonality of these aggregations depending on the geographical location of each farm. Occurrences around farms were more frequent during spring to autumn. Importantly, negative interactions with aquaculture were limited to farms in SE Spain and Turkey. In particular, mainly cages containing seabream were affected, with relatively important economic losses for the farmers.

The bluefish is distributed throughout the entire Mediterranean, but is more abundant in the southern and eastern Mediterranean because of the higher water temperatures (Tortonese, 1954). Sabatés and Martin (1993) remark that the expansion of the species to the north of the Catalan Sea (NW Mediterranean) is related to the gradual increase of temperature in the region. During the present study, bluefish were detected associated with fish farms from different geographical areas, but strong differences in the presence of aggregations existed at a regional scale (hundreds of km). Dempster et al. (2002) detected bluefish at four fish farms from the SW Mediterranean, but not at five other farms located just 50 to 200 km to the south. Despite records of bluefish aggregations at Sicilian, Maltese and Turkish farms, it has not been noticed at Greek farms (Machias et al., 2004). Furthermore, bluefish were not recorded at two fish farms at the Canary Islands in the Atlantic ocean (Boyra et al., 2004), despite its presence in adjacent natural habitats (Tuya, pers. obs.).

Standing aggregations of potential prey (tons to tens of tons) at fish farms compared to surrounding areas (Dempster et al., 2002) is a likely reason to explain why aggregations of bluefish around farms are so dense. Lack of prey across the continental shelf may force schools of bluefish to search for alternative feeding areas. Once bluefish arrive at a fish farm, they may remain resident in the vicinity for extended periods due to the continuous availability of wild fish in their surroundings. Dagorn et al. (2000) modelled processes involved in the aggregation and residence of pelagic fish predators with fish aggregation devices (FADs), and suggested that the availability of sufficient suitable prey within the area of a FAD is crucial for the continued residence of large predatory fish. In our study, bluefish predated mainly upon *S. aurita* and *T. mediterraneus*, which are two of the most abundant species aggregated around cages (Dempster et al., 2002). No food pellets were found in bluefish gut contents, indicating that they did not feed on lost food from the farms, as commonly observed for other farm-associated wild fish (Fernandez-Jover et al., 2007). Bluefish have a specific vertical distribution around farms; they are located from the surface to 25 m depth, where prey species are also located in highest abundances (Dempster et al., 2005). Bluefish attack using a cooperative behaviour, and appear to use nets to stop prey from escaping (per. obs.). Consequently, bluefish may predate more efficiently around cages than in natural habitats.

The reason behind why the bluefish only aggregated at particular fish farms is difficult to explain. Certain farms may be located in areas which attract passing schools of bluefish more often than other locations, e.g. within seasonal migration routes. The density and assemblage structure of wild fish prey could also affect their aggregation at farms and their period of residence. The use of farms as a 'new' habitat type for bluefish may be comparable to the shoaling effect found in conjunction with artificial reefs, presumably due to the benefits from the associated community and increased shelter (Costa-Pierce and Bridger, 2002). Bluefish likely combine the use of fish farms with other natural coastal habitats, as the population is not permanently aggregated at the cages, migrating away after a period of residence, as our results showed. Temporal fidelity to particular farms and movement patterns of bluefish along the Mediterranean continental shelf should be determined with telemetry-based techniques to better understand their habitat use in space and time.

Around the three fish farms studied in the SW coast of Spain, several size classes were found simultaneously. The concurrent presence of different cohorts could be explained by reproductive patterns. For the northwest Atlantic coast, the size structure of the bluefish stock is bimodal, with the spring-spawned cohort more abundant compared to the summer-spawned cohort (Chiarella and Conover, 1990). This could also be the case for the Mediterranean populations; however the prevalence of different sizes changed depending on the fish farm. Around the Altea farm, aggregation of smaller individuals from <40 to 60 cm occurred, while the Guardamar farm aggregated fish of larger size (from 40 cm to 68 cm TL). Guardamar was most severely affected by bluefish incursions into the sea-cages; we hypothesise that this was related to the larger size of bluefish aggregated around this farm.

Bluefish aggregations at farms negatively impacted production when they entered the cages. Adult bluefish, normally bigger than 55 cm TL, entered "into" the cages and begin to prey upon the caged fish. The method of entry appears to be through holes in the netting that previously existed. Incursions were mainly reported for seabream cages; no reports of entry into seabass cages were recorded at SE Spain, although most farms having seabream and seabass cages side by side within the same complex. Several hypotheses (or even a synergistic combination) might explain this difference. First, bluefish may prefer to predate upon seabream compared to seabass. Second, access to seabream cages is easier than seabass cages. Seabream, compared to seabass, show a constant biting behaviour to the net, which can produce and/or increase the size of holes (Dempster et al., 2007). Holes may therefore be more frequent in seabream compared to seabass cages. Güçlüsoy and Savas (2003) also detected that the frequency of monk seal attacks on fish farms was higher on seabream cages. The level of fouling cover on the net may play an important role in the ability of bluefish to enter. Fouling of the net mesh is undesirable in cage aquaculture and forces frequent net changes in Mediterranean farms. The surveys indicated that incursions of bluefish into cages were more common after nets were changed, which could indicate that bluefish are in part visually attracted to seabream (farmers, pers. comm.). Changes in net colouring or configuration may therefore alleviate the problem; future testing in this area could provide a partial solution.

Inside the cages, bluefish successfully captured seabream regardless of size. Experiments that investigated bluefish predation on *Anchoa mitchilli* demonstrated that capture success remained high on relatively large prey sizes (>50% predator size), with bluefish exhibiting significantly higher attack rates on large bay anchovy (Scharf et al., 2002). This may indicate that the high density of seabream inside a cage favours bluefish attacks. Bluefish are also known to kill fish apparently far in excess of their feeding requirements (Collette, 1999) which can translate to high mortality of cultured seabream.

The entry of bluefish into cages, and the subsequent predation on the cultured fish, is likely to have several other non-lethal effects on the caged populations of seabream. For example, marine mammals that take finfish may scare some fish, thus increasing the susceptibility to disease and increasing stress levels, all of which lead to decreased growth rates (Morris, 1996). They can also destroy gear and produce fish escapes through torn pens (Sepulveda and Oliva, 2005). Bluefish do not appear to affect the fish farm structure, but it is a voracious predator (Buckel et al., 1999). Inside a cage, they cause numerous mortalities as their method of attack is to take the back half of its prey, which leads to high numbers of injured seabream. Seabream in cages containing bluefish stop eating at the normal rate, with an increase in stress levels, and consequently, tend to exhibit strong escape behaviour (pers. obs.). Bluefish incursions sometimes produce fish escapes through the same holes in the net that they entered through. Escapes of hundreds to 15,000 individuals were reported by farmers in conjunction with bluefish incursions. Fish farm managers have avoided problems caused by predators through several devices including barrier nets against bird and mammal predators, marine mammal harassment techniques, and non-lethal and lethal removal (Würsig and Gailey, 2002). Anti-predator nets against bluefish have also been used. One fish farm operator used a curtain type net, hung from the floating circular floating tubes down to near the sea bed, but without substantial results. Such measures introduce several other problems for production, such as overweighing the structures and mooring system, and reducing water flow and renewal through the cages. At present, no satisfactory measure exists to prevent incursions by bluefish into cages, except preventing the existence of holes by periodic diving inspection.

The present study is the first to demonstrate the entrance and predation by a wild fish within sea-cages. Other fish predators occur around Mediterranean fish farms, such as *Coryphaena hippurus*, *Seriola dumerili*, *Thunnus thynnus* and *Sphyraena sphyraena*, but without negative impacts to aquaculture (Dempster et al., 2002; Valle et al., 2007). Bluefish negatively affect seabream production, producing economic losses. However when compared to the impact of the multi-million dollar losses caused by marine mammals elsewhere (e.g. United States and Canada; Nash et al., 2000), the impact is moderate. Economic losses from bluefish could be inferred by the number of cages attacked annually, the cost of removing bluefish from inside cages, the number of escapes caused and the reduction in seabream production through mortality and reduced growth. The last two components, in particular, could be substantial, but are difficult to estimate. Losses could be large at specific farms with respect to the total production, when bluefish constantly affect a farm, and incursions involved hundreds of individuals. As cage sizes and numbers of seabream inside each cage continuously increase following current industry trends, removal of these predators from cages will become increasingly difficult. Additional research is necessary to accurately assess the true influence on production costs.

In conclusion, predation by bluefish within sea-cages is presently a problem of local concern, restricted to the SW Mediterranean Sea and Turkey. It produces economic losses and creates technical difficulties in the production process. Bluefish may use farms as feeding areas, which may be related to a reduction in trophic resources for these predators due to overfishing of their normal pelagic fish prey stocks. As bluefish are widely distributed, increased placement of sea-cages in coastal and offshore areas will likely increases interactions. Development of a suite of management measures, and technological innovation to avoid incursions into cages, is necessary to diminish and avoid the problem.

Acknowledgements

We wish to thank the farm managers for providing information, and especially to the staff at the Basademar (Altea), Cudomar (El Campello) and Martorres (Guardamar) fish farms for the logistic supply and help. We also thank the Tevfik Ceyhan (Ege University), Joseph Borg (University of Malta), Ioannis Karakassis (University of Crete) and Paolo Tomassetti (ICRAM) for their assistance with the farms interviews. The study forms part of the ACUFISH project and was funded by Spanish Ministry of Science grant MYCT-REN2003-00794. Three anonymous reviewers provide constructive comments on a previous draft.

References

Bayle-Sempere, J.T., Valle, C., Verdu, A., 2001. ecoCEN: a database for fish counts. FAO—AECI, Alicante, Spain. (http://www.ua.es/ecocen).

Boyra, A., Sanchez-Jerez, P., Tuya, F., Espino, F., Haroun, R.J., 2004. Attraction of wild coastal fishes to an Atlantic subtropical cage fish farms, Gran Canaria, Canary Islands. Env. Biol. Fish. 70, 393–401.

Buckel, J.A., Fogarty, M.J., Conover, D.O., 1999. Mutual prey of fish and humans: a comparison of biomass consumed by bluefish, *Pomatomus saltatrix*, with that harvested by fisheries. Fish. Bull. 97, 776–785.

Chiarella, L.A., Conover, D.O., 1990. Spawning season and first-year growth of adult bluefish from the New York Bight. Trans. Amer. Fish. Soc. 119, 455–462.

Collette, B.B., 1999. Pomatomidae. Bluefishes. In: Carpenter, K.E., Niem, V. (Eds.), FAO Species Identification Guide for Fishery Purposes, Vol. 4, p. 2650. Bony fishes part 2 (Mugilidae to Carangidae).

Costa-Pierce, B.A., Bridger, C.J., 2002. The role of marine aquaculture facilities as habitats and ecosystems. In: Stickney, R.R., McVey, J.P. (Eds.), Responsible Marine Aquaculture. CABI Publishing, New York, pp. 105–144.

Dagorn, L., Josse, E., Bach, P., Bertrand, A., 2000. Modeling tuna behaviour near floating objects: from individuals to aggregations. Aquat. Liv. Resour. 13, 203–211.

Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J.T., Giménez-Casalduero, F., Valle, C., 2002. Attraction of wild fish to sea-cage fish farms in the south-western Mediterranean Sea: spatial and short-term temporal variability. Mar. Ecol. Prog. Ser. 242, 237–252.

Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J., Kingsford, M., 2004. Extensive aggregations of wild fish at coastal sea-cage fish farms. Hydrobiologia, 525, 245–248.

Dempster, T., Fernandez-Jover, D., Sanchez-Jerez, P., Tuya, F., Bayle-Sempere, J.T., Boyra, A., Haroun, R., 2005. Vertical variability of wild fish assemblages around sea-cage fish farms: implications for management. Mar. Ecol. Prog. Ser. 304, 15–29.

Dempster, T., Moe, H., Fredheim, A., Sanchez-Jerez, P., 2007. Escapes of marine fish from sea-cage aquaculture in the Mediterranean Sea: status and prevention. CIESM Workshop Monogr. 32, 55–60 www.ciesm.org/online/monographs/Lisboa.html.

Díaz-López, B., Bernal-Shirai, J.A., 2007. Bottlenose dolphin (*Tursiops truncatus*) presence and incidental capture in a marine fish farm on the north-eastern coast of Sardinia (Italy). J. Mar. Biol. Ass. U.K. 87, 113–117.

FAO, 2007. Cage aquaculture. Regional reviews and global overview. FAO Fisheries Technical Paper No. 498. FAO, Rome. 241 pp.

Fernandez-Jover, D., Lopez-Jimenez, J.A., Sanchez-Jerez, P., Bayle-Sempere, J., Gimenez-Casalduero, F., Martinez-Lopez, F.J., Dempster, T., 2007. Changes in body condition and fatty acid composition of wild Mediterranean horse mackerel (*Trachurus mediterraneus*, Steindachner, 1868) associated with sea cage fish farms. Mar. Environ. Res. 63, 1–18.

Freitas, D., Gomes, J., Sales-Luis, T., Madruga, L., Marques, C., Baptista, G., Rosalino, L.M., Antunes, P., Santos, R., Santos-Reis, M., 2007. Otters and fish farms in the Sado estuary: ecological and socio-economic basis of a conflict. Hydrobiologia 587, 51–62.

Güçlüsoy, H., Savas, Y., 2003. Interaction between monk seals *Monachus monachus* (Hermann, 1779) and marine fish farms in the Turkish Aegean and management of the problem. Aqua. Res. 34, 777–783.

Juanes, F., Hare, J.A., Miskiewicz, A.G., 1996. Comparing early life history strategies of *Pomatomus saltatrix*: a global approach. Mar. Freshwater Res. 47, 365–379.

Kingsford, M., Battershill, C., 1998. Studying temperate marine environments: a handbook for ecologists. Canterbury University Press, Christchurch. 335 pp.

Machias, A., Karakassis, I., Labropoulou, M., Somarakis, S., Papadopoulou, K.N., Papaconstantinou, C., 2004. Changes in wild fish assemblages after the establishment of a fish farming zone in an oligotrophic marine ecosystem. Estuar. Coast. Shelf Sci. 60, 771–779.

Morris, D.S., 1996. Seal predation at salmon farms in Maine, an overview of the problem and potential solution. Marine Technology Society Journal 30, 39–43.

Nash, C.E., Iwamoto, R.N., Mahnken, C.V.W., 2000. Aquaculture risk management and marine mammal interactions in the Pacific Northwest. Aquaculture 183, 307–323.

Sabatés, A., Martin, P., 1993. Spawning and distribution of bluefish *Pomatomus saltatrix* (L.) in the northwestern Mediterranean. J. Fish Biol. 43, 109–118.

Salerno, D.J., Burnett, J., Ibara, R.M., 2001. Age, growth, maturity, and spatial distribution of bluefish, *Pomatomus saltatrix* (Linnaeus), off the northeast coast of the United States, 1985–96. J. Northwest Atl. Fish. Sci. 29, 31–39.

Scharf, F.S., Buckel, J.A., Juanes, F., 2002. Size-dependent vulnerability of juvenile bay anchovy *Anchoa mitchilli* to bluefish predation: does large body size always provide a refuge? Mar.Ecol. Prog. Ser. 233, 241–252.

Sepulveda, M., Oliva, D., 2005. Interactions between South American sea lions *Otaria flavescens* (Shaw) and salmon farms in southern Chile. Aquaculture Research 36, 1062–1068.

Tortonese, E., 1954. The recent numerical increase of the percoid fish *Pomatomus saltator* L. in the Tyrrehenian and Ligurian seas. Rapports et Procès-Verbaux des Réunions. Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée 12, 113–115.

Tortonese, E., 1986. Pomatomidae. In: Whitehead, P.J.P., Bauchot, M.L., Hureau, J.C., Nielsen, J., Tortonese, E. (Eds.), Fishes of the Northeastern Atlantic and Mediterranean, vol. II. UNESCO, Paris, pp. 812–813.

Tuya, F., Sanchez-Jerez, P., Boyra, A., Haroun, R.J., 2005. Non-metric multivariate analysis of the demersal ichthyofauna along soft bottoms of the Eastern Atlantic: comparison between unvegetated substrates, seagrass meadows and sandy bottoms under the influence of sea-cage fish farms. Mar. Biol. 147, 1229–1237.

Underwood, A.J., 1997. Experiments in Ecology. Their Logical Design and Interpretation. Cambridge University Press, UK. 453 pp.

Valle, C., Bayle-Sempere, J.T., Dempster, T., Sanchez-Jerez, P., Giménez-Casalduero, F., 2007. Temporal variability of wild fish assemblages associated with a sea-cage fish farm in the south-western Mediterranean Sea. Estuar. Coast. Shelf Sci. 72 (1–2), 299–307.

Würsig, B., Gailey, G.A., 2002. Marine mammals and aquaculture: conflicts and potential resolutions. In: Stickney, R.R., McVey, J.P. (Eds.), Responsible Marine Aquaculture. CABI Publishing, New York, pp. 45–59 pp.