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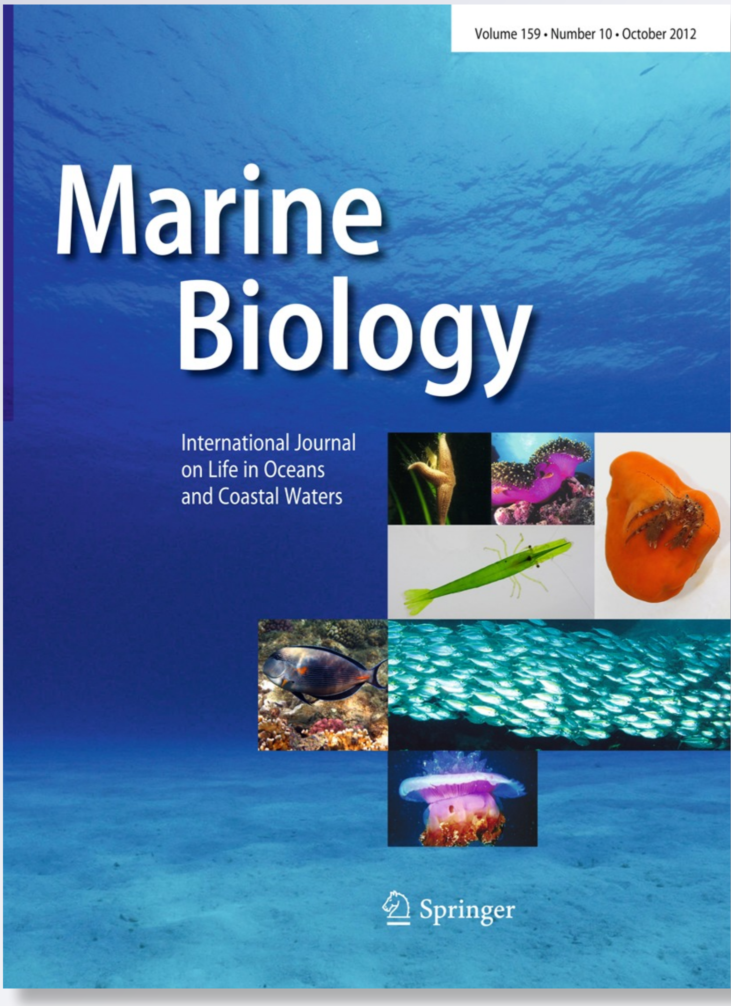
Bruno Díaz López

Marine Biology
International Journal on Life in Oceans and Coastal Waters

ISSN 0025-3162
Volume 159
Number 10

Mar Biol (2012) 159:2161-2172
DOI 10.1007/s00227-012-2002-x



Springer

Mar Biol (2012) 159:2161–2172
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ORIGINAL PAPER

Bottlenose dolphins and aquaculture: interaction and site fidelity on the north-eastern coast of Sardinia (Italy)

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Received: 17 September 2011 / Accepted: 26 June 2012 / Published online: 14 July 2012

Abstract Owing to the worldwide growth of aquaculture over the last years, new habitats have been created through the supplement of nutrients. This addition of nutrients affects the whole marine food web, resulting in predator species such as bottlenose dolphins becoming attracted to these areas. During this 5-year-long study that was carried out along the north-eastern coast of Sardinia (Italy), bottlenose dolphin's history of exposure to aquaculture perturbations and their effects was documented. The interaction with a fish farm was assessed by studying the site fidelity, group dynamics, and seasonal and yearly occurrence. In all, 1,838 hours were spent in the field. Behavioural observations showed that the predominant activity (89 % of the time) in the fish farm was foraging (predation and depredation). The occurrence of bottlenose dolphins appeared to be related with the seasons and with the fish farm harvesting operations. Thus, the peak dolphin occurrence in the fish farm area throughout Fall coincides with the period in which they spend most of their time foraging. A relatively small community remained resident interacting with the fish farm over a long period of time. Hence, these individuals gained intimate knowledge on how to capitalize on the fish farm industry. This heterogeneity in site fidelity and residence patterns is highly relevant when coastal management initiatives are considered.

Communicated by U. Siebert.

B. D. López (✉)
Bottlenose Dolphin Research Institute (BDRI), Via Diaz 4, Golfo Aranci (Sardinia), Italy
e-mail: bruno@thebdri.com

Introduction

Marine aquaculture, that is, the farming of plant and animal species from the sea, has shown a large worldwide expansion over the last years (FAO 2007). On a global basis, aquaculture products are worth nearly US$ 50,000 million annually, and the industry provides almost half the fresh fish and shellfish consumed by the public (FAO 1999). The aquaculture continues to grow more rapidly than all other animal food-producing sectors in the world. Thus, since 1970 the industry has an average annual growth rate of 8.8 % per year (FAO 2007). Furthermore, intensive fin fish farming is among the most rapidly growing segments of aquaculture (Naylor et al. 1998). This notable growth of the industry makes it vital to study the environmental effects associated with its presence.

The effects of aquaculture on the marine environment may be categorized into three types: eutrophication, sedimentation, and effects on the food web (reviewed in Pillay 1992; Black 2001; Fernandes et al. 2002; Cole 2002; Hargrave 2003; Díaz López et al. 2008). It has been noted that the type of cultivated organisms, the locations of cultivation, the cultivated biomass, the quality and quantity of supplied food, and management practices are the main factors in determining the extent of these effects (Beveridge 1996; Hargrave 2003; Pillay 2004; Machias et al. 2005).

A substantial amount of effluents, such as waste food, faeces, medications, and pesticides, are supplied by the marine fin fish farms. These can have undesirable impacts on the environment (Wu 1995; Lemarié et al. 1998; Read and Fernandes 2003). In addition, the effects on wild fish have been investigated at short spatial scales (Carss 1990, 1994; Dempster et al. 2004), indicating a considerable increase in wild fish abundance and biomass in the immediate vicinity of fish cages. As a consequence of the creation of new habitats through the supplement of nutrients, a bottom-up effect has been created through the marine food web. This has resulted in fish-eating predator species becoming concentrated in the vicinity of the fish farms, contributing to a conflict between the industry and the animals. Coastal marine fin fish farms attract a large range of species such as harbour seals (*Phoca vitulina*), grey seals (*Halichoerus grypus*), common bottlenose dolphins (*Tursiops truncatus*), cormorants (*Phalacrocorax carbo*), shags (*Phalacrocorax aristotelis*), grey herons (*Ardea cinerea*), otters (*Lutra lutra*), and minks (*Mustela vison*) (Ross 1988; Rueggeberg and Booth 1989; Carss 1994; Morris 1996; Beveridge 1996; Kemper et al. 2003; Díaz López et al. 2005; Díaz López 2006a; Díaz López and Shirai 2007).

The impact of marine mammals on this industry is economically significant (Nash et al. 2000). Aquaculturists estimate a loss of 2–10 % of their gross production owing to marine mammal predation, more particularly seals (Nash et al. 2000). However, the significance of other marine mammals in areas where seals are not present should not be dismissed (Würsig and Gailey 2002). During the last years in Mediterranean waters, a large top predator with opportunistic feeding behaviour is frequently appearing close to the fish farms (Díaz López 2006a; Díaz López and Shirai 2007; Bearzi et al. 2008). This top predator is the bottlenose dolphin that with its large size—suggesting that they must eat a great deal—has become a culprit behind the problems coastal fish farms are facing in the Mediterranean Sea (Díaz López and Shirai 2007; Bearzi et al. 2008; Díaz López and Mariño 2011). Bottlenose dolphins capture fish from pens, decimate, and could cause scarring of the farmed fish (Díaz López 2006a), increasing fish susceptibility to disease or decreasing growth owing to stress (Morris 1996).

Conversely, several potential direct hazards to bottlenose dolphins can be readily identified. Among these concerns are entanglement risk (Würsig and Gailey 2002; Díaz López and Shirai 2007), habitat exclusion that results from physical structures (Watson-Capps and Mann 2005), or aversive acoustic devices (Olesiuk et al. 2002; Fjälling et al. 2006; Díaz López and Mariño 2011). These hazards can lead to an important problem in cases where bottlenose dolphin populations are limited or endangered. This is important to take into consideration as it is widely believed that numbers of Mediterranean bottlenose dolphins have declined in recent decades as a consequence of human activities and habitat degradation (Bearzi et al. 2008). Mediterranean common bottlenose dolphin "subpopulation" is therefore qualified as "Vulnerable" according to the International Union for Conservation of Nature (IUCN) Red List criteria (Bearzi et al. 2008). As the hazards to bottlenose dolphins can already be identified, information on habitat use is a critical missing piece of the equation that can be used to determine the real risk fin fish aquaculture may pose to bottlenose dolphins or vice versa.

Many studies have investigated the effects of the aquaculture industry on marine fauna in general, based on either questionnaires filled by fish farm workers or short-term field studies that did not consider yearly and seasonal fluctuations in the presence of predators. Therefore, there is a paucity of long-term field studies examining the association between fin fish aquaculture and bottlenose dolphins.

The overall objectives of this 5-year-long study were the following: (1) to monitor, for the first time, the evolution of the interactions between bottlenose dolphins and the aquaculture industry on a yearly and seasonal basis; (2) to obtain information on bottlenose dolphin habitat use, group dynamics, and fish farm fidelity; and (3) to determine whether bottlenose dolphin occurrence could be related with harvesting activities in the fish farm.

Methods

Study area

The data for this study were collected as a part of an ongoing long-term study on the north-eastern coast of Sardinia, Italy (40° 59.98′N 9°37.09′E) (Fig. 1). The presence of a marine fin fish farm has since 1995 been linked with direct and indirect changes in the distribution and behaviour of bottlenose dolphins in the area (Díaz López 2006a, b, 2009; Díaz López and Shirai 2007; Díaz López et al. 2005).

Fieldwork was conducted from November 2004 to November 2009 in the 240 m^2 marine fin fish farm with caged sea bass (*Dicentrarchus labrax*), gilthead sea bream (*Sparus aurata*), and meagre (*Argyrosomus regius*). The fin fish farm consisted of 21 floating cages, grouped into three rows of seven cages. Each floating cage was constructed of nylon mesh netting and was 22 m in diameter and 15 m deep. The cages were floated in a minimum depth of 18 m and a maximum depth 26 m and were situated approximately 200 m from the shore. The sea bottom in the study area was characterized by mud with scattered areas of rock and sand. Wild fish species such as common grey mullets (*Mugil cephalus*), bogue (*Boops boops*), salema (*Salpa sarpa)*, garfish (*Belone belone*), and pilchard (*Sardina pilchardus*) were attracted to the fish farm (Díaz López 2006a).

Direct observation procedures

Year-round boat-based observations were undertaken in the fish farm area using a 5-m research vessel powered with a

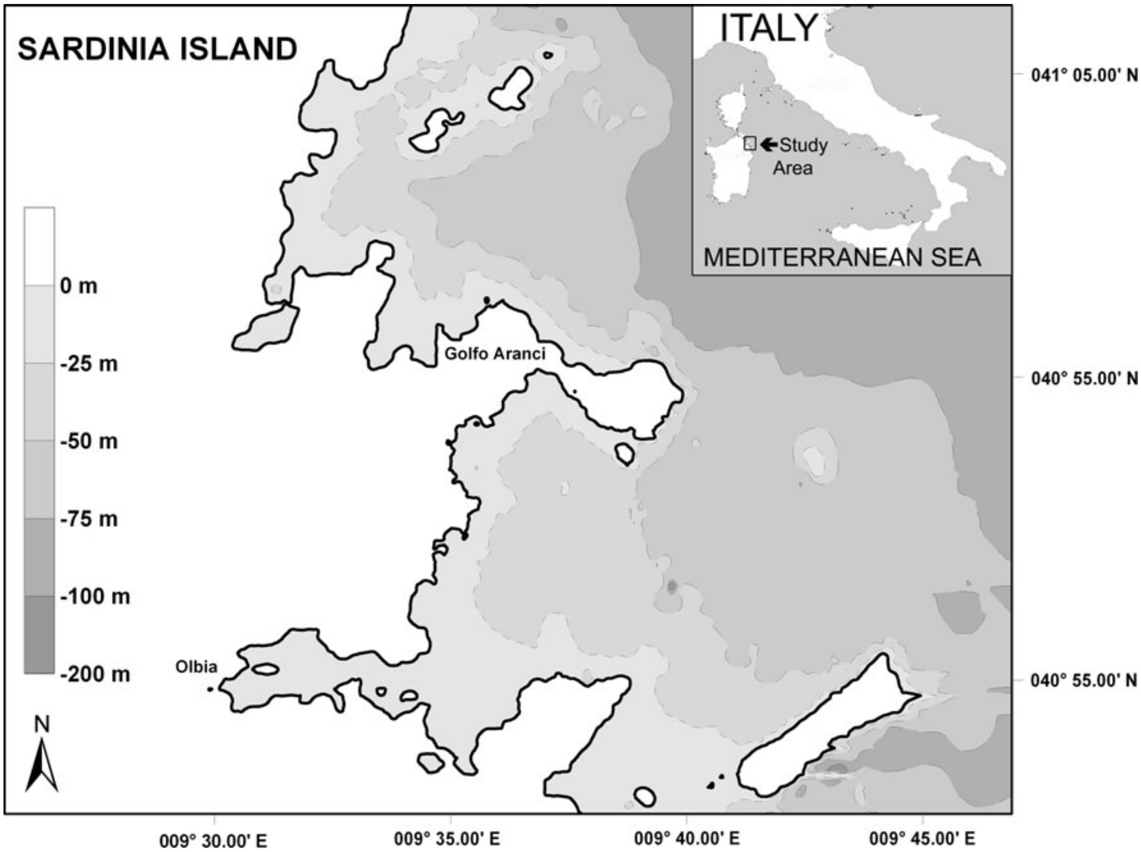

Fig. 1 Map of the north-eastern coast of Sardinia (Italy) showing the location of the marine fin fish farm

40-hp outboard motor. To minimize the effect of the observers' presence on dolphin activity and occurrence, data were collected when the boat engine was off. The fish farm area was surveyed during daylight with at least three experienced observers scanning the sea surface in search for dolphins (with the naked eye and/or with 10 × 42 and 10 × 50 binoculars). By the use of night vision binoculars (8 × 40) and an omni-directional hydrophone (with a frequency response of 0.02–100 kHz), both observations and passive acoustic monitoring were carried out to obtain information about dolphin presence during the night.

Presence of bottlenose dolphins in the fish farm area

To obtain information about whether or not bottlenose dolphins were present in the fish farm, 20-min instantaneous sampling (Altmann 1974) was used. These sets were also used to take into consideration the possibility that dolphins' presence could be related with harvesting activities in the farm. The variables that were taken into consideration in the sets were both environmental (wind speed, sea state, water temperature, and visibility) and anthropogenic (number and type of vessels in the proximity of the fish farm). Immediately at the beginning of each instantaneous set, potentially confounding variables that were beyond the control of the observers but which may have influenced the presence, relative abundance, or sightability were recorded. Sets were considered satisfactory when the visibility was not reduced by rain or fog, and sea conditions were <4 on the Douglas sea force scale (approximately equivalent to the Beaufort wind force scale).

In order to analyse the seasonality of bottlenose dolphins in the study area, four seasons were defined: Winter (January–March), Spring (April–June), Summer (July–September), and Autumn (October–December). Further, to analyse circadian fluctuations in the presence of bottlenose dolphins, a day was divided into three different moments of the same duration based on an average of the total daylight hours of the month (morning, afternoon, and evening hours). The hours included between the sunset and sunrise were considered as night. Local time was converted to solar time when appropriate, to account for daylight saving.

A contingence table analysis (based on the chi-square test) was used to investigate the relative frequency of occurrence of bottlenose dolphins (presence vs. absence) in relation to the different temporal variables (years, seasons, and moments of the day). Likewise, the contingence table analysis was used to control if the harvesting operations in the fish farm could affect the presence of bottlenose dolphins in the fish farm area.

Group dynamics

At the beginning of each 20-min set, bottlenose group size was estimated based on the initial count of individuals observed at one time in the fish farm area.

Bottlenose dolphin group composition was determined by counting the number of adults, calves, and newborns present. Age class definitions followed those by Mann et al. (2000) and Díaz López (2006b), where dolphins were classified as either: (1) newborns, dolphins estimated be smaller than one metre based on size relative to the mother, evident foetal folds, and erratic surfacing behaviour; (2) immatures, dolphins two-thirds or less the length of an adult they consistently swam beside and slightly behind; or (3) adults, those estimated to be longer than 2.5 m. Sex was determined primarily by observations of the genital region. Males were identified by a gap between the urogenital slit and the anus, lack of mammary slits, or observation of an erection. Females were identified by observation of mammary slits and in some cases reliable presence of a dependent newborn.

The Kruskal–Wallis test was performed to test the equality of medians of several group size samples. If the test showed significant inequality of the medians, a Mann–Whitney's post hoc comparison was performed (Zar 1999).

Photo-identification of bottlenose dolphins

During each bottlenose dolphin encounter, attempts were made to photograph all members of the group present in the fish farm area. This was done in order to determine individual identification using photographs of their dorsal fins and surrounding area as unique natural markers (Würsig and Jefferson 1990). Digital photographs were taken using DSLR cameras Nikon D70 and Nikon D300 equipped with Nikkor ED 70–300 mm (f:4–5.6D) and Sigma 70–200 (f:2.5) telephoto zoom lens. Capturing as many animals as possible was a good way to get close to representative samples and minimize the problem of heterogeneity of capture probabilities (Hammond 1986).

Photographs were separated into two different categories ("good" and "poor"), based on their quality. Only "good"-quality photographs (in focus, with the dorsal fin perpendicular to the plane of the photograph and with the dorsal fin large enough to identify small notches) were used for subsequent analyses. Individual dolphins were identified from photographs based primarily on the size, location, and pattern of notches on the trailing edge of the dorsal fin and on the back, directly behind the dorsal fin. Features such as body and dorsal fin scars, lesions, and tooth-rakings were used as secondary characteristics, thereby reducing the possibility of false positives (Wilson et al. 1999). Thus, a marked individual was considered one that is recognized not by a single feature, but by a matrix of marks which form a distinctive "face" for the individual. Whilst bottlenose dolphins could acquire new marks as they get older, a year-round study allowed us to monitor small and gradual changes in these distinctive marks. "Poor"-quality photographs or not marked individuals were excluded from the analysis to minimize the bias of confusion.

The total number of individuals included in the photo-identification catalogue pertains only to the number of marked animals that visited the fish farm area. Mark rate, defined as the percentage of permanently marked individuals for each year, was estimated by counting the number of "good"-quality photographs of recognisable individuals and dividing by the total number of "good"-quality dorsal fin photographs taken (Williams et al. 1993).

Behavioural sampling

Behavioural data were collected using focal group continuous sampling (Altmann 1974; Mann et al. 2000), whilst "ad libitum" sampling (Altmann 1974) was used during underwater observations. Underwater observations of the focal group were carried out by one observer (the author) with snorkel gear. The more detailed descriptions of underwater behaviour, sex determination, and events were later compared with the collected surface behaviour.

During focal observation sessions, selected focal groups were observed for extended periods, often during the course of several hours. A potential problem with focal group sampling noted by Mann et al. (2000) is that group composition may change. This needs to be guarded against by adopting an appropriate protocol for occasions when groups split (Mann et al. 2000). Thus, during this study, we distinguish the term group as either a solitary animal or any aggregation of dolphins in the visual area, usually involved in the same activity, following Díaz López (2006a). At least three experienced observers monitored the focal group and recorded position and behaviour in order to control changes in group composition. The encounter continued until the focal group changed composition or was lost; a group was considered lost after 15 min without a sighting (Díaz López 2006a).

The group size was assessed visually in situ, and the data were later verified with photographs and videos taken during each sighting. The long-term nature of this study allowed the confirmation that the field data collection and observational studies did not induce significant behavioural changes or stress to the study animals. The bottlenose dolphins present in the fish farm area have been under study since 1999 and are well habituated to human observers. To minimize the effect of the research vessel on dolphin behaviour, data were collected when the engine was off. Behavioural data were also collected when the boat drifted between the fish farm cages without an anchor.

Similarly, a standard criterion was used (Díaz López 2006b, 2009) to make the effects of the underwater observer on the dolphins' behaviour standard across samples. Observed behaviours were divided into "Predation", "Depredation", "Travelling", "Socializing", and "Resting". The first four categories were described by Díaz López and Shirai (2010), "Predation" refers to bottlenose dolphins preying on free-ranging prey, whereas "Depredation" refers to dolphins taking, or attempting to take, prey that are confined in fish farm cages or that have been caught in fishing nets. "Travelling" involved swimming on a consistent course, with all the members of the group generally spaced within a few body lengths of each other, with rhythmic surfacings followed by shallow dives. "Socializing" animals were involved in active surface and underwater behaviour that included interactions with other group members (body contact, erection, charge, slapping, intromission, petting, etc.) and aerial activity. "Resting" refers to one or more individuals swimming slowly (approximately <1 knot) with shallow dives or floating. When several individuals are resting, they swim in synchrony (Connor et al. 2006). The dolphins do not engage in any other activities during the resting behaviour.

The definition and duration of each behavioural category was attempted a posteriori following data analysis strictly based on objective, non-discrete parameters, including specifically observed behavioural events, area, dive duration, swimming direction and speed, contact among individual dolphins, presence of fishing gears, and other variables (Díaz López 2006a).

A contingence table analysis (based on the chi-square test) was used to determine the predominant behaviours during the observations in the fish farm area.

Bottlenose dolphins fish farm fidelity and use of habitat

To investigate the presence of identified individuals in the fish farm area over time, two different temporal sighting rates were calculated on a seasonal and yearly basis (Parra et al. 2006). A seasonal occurrence rate was defined as the number of seasons a recognisable dolphin was identified as a proportion of the total 21 seasons. A yearly occurrence rate was defined as the number of calendar years a dolphin was identified as a proportion of the five surveyed years. The Kruskal–Wallis test was used to compare the temporal occurrence rates between identified males and females.

Statistical significance was tested at the $p < 0.05$ level. The data are presented as mean ± SE.

Results

Survey effort

The field effort in the marine fin fish farm entailed five consecutive years of fieldwork (November 2004–November 2009). In all, 57 months (611 days during 21 consecutive seasons) were spent in the field. On average, 122 ± 3 days per year and 32 ± 4 days per season were spent conducting observations in the fish farm area. A total of 1,838 h were spent in satisfactory conditions (corresponding with 5,515 instantaneous 20-min sets). Tables 1 and 2 show the observation effort for all surveyed years across seasons and moments of the day, respectively.

Bottlenose dolphins' occurrence: seasonal and yearly fluctuations

Bottlenose dolphins were observed during every year surveyed, in all seasons of the year and moments of the day. The dolphins' frequency of occurrence appears to be related with the seasons, with a peak presence in Fall and a

Table 1 The observation effort in number of 20-min instantaneous sets, number of days, and hours spent in the fin fish farm for each surveyed season

Seasons	No. of 20-min instantaneous sets	No. of days	No. of hours	% dolphins occurrence*
Winter	1,030	126	343.3	46.3
Spring	1,769	185	589.7	33.1**
Summer	1,860	200	620	41.0
Fall	856	127	285.3	48.2**
Total	5,515	611	1,838.2	41.2

* Percentage of 20-min instantaneous sets with dolphins' presence in the fish farm

** Contingency table χ^2, $p < 0.05$

Table 2 The observation effort in the number of 20-min instantaneous sets, number of days, and hours spent in the fin fish farm for each surveyed moment of the day

Moments	No. of surveys	No. of days	No. of hours	% dolphins occurrence*
Morning	2,003	126	667.6	44.0
Afternoon	2,219	185	739.6	41.5
Evening	1,064	200	354.7	36.8**
Night	229	127	76.3	41.2
Total	5,515	611	1,838.2	41.2

* Percentage of 20-min instantaneous sets with dolphins' presence in the fish farm

** Contingency table χ^2, $p < 0.05$

Table 3 Number of 20-min instantaneous sets with dolphins' presence and absence among the 6 years of study

Years	Presence of dolphins	Absence of dolphins	Total 20-min sets	% dolphins occurrence*
2005	365	914	1,279	28.5
2006	247	795	1,042	23.7
2007	549	700	1,249	43.9
2008	542	491	1,033	52.5**
2009	570	342	912	62.5**
Total	2,273	3,242	5,515	41.2

* Percentage of 20-min instantaneous sets with dolphins' presence in the fish farm

** Contingency table χ^2, $p < 0.05$

Table 4 Number of 20-min instantaneous sets with dolphins' presence and absence during harvesting operations in the fish farm

Years	Presence of dolphins	Absence of dolphins	Total 20-min sets	% dolphins occurrence*
2005	47	76	123	38.2
2006	24	98	122	19.7
2007	98	113	211	46.4
2008	70	68	138	50.7**
2009	134	53	187	71.6**
Total	373	408	781	47.7

* Percentage of 20-min instantaneous sets with dolphins' presence in the fish farm

** Contingency table χ^2, $p < 0.05$

minimum in Spring (contingency table χ^2, $p < 0.05$; Table 1). Furthermore, the occurrence seems to be related to the moments of the day (contingency table χ^2, $p > 0.05$; Table 2), with a minimum during the evening hours.

Furthermore, there were yearly fluctuations in the presence of bottlenose dolphins in the fish farm area (contingency table χ^2, $p < 0.05$; Table 3). Thus, a drastic increase in the presence of the dolphins during the last 2 years of research was observed. Moreover, it was throughout these 2 years that the dolphins' frequency of occurrence increased during fish farm harvesting operations (contingency table χ^2, $p < 0.05$; Table 4).

Group dynamics

Group dynamics were examined for 560 independent groups of bottlenose dolphins encountered between 2004 and 2009. Group size ranged from 1 to 16 individuals (mean ± SE = 3.51 ± 0.1; median = 3), with most encountered groups ($n = 509$, 91 %) containing <7 animals. Of the individuals encountered, 85 % were deemed adults, 8 % were immatures, and the remaining 7 % were categorized newborns. Moreover, 24 % were solitary animals, 11 % were calves (immatures and/or newborns), and 65 % groups were only adults. Adults and immatures were recorded throughout all the survey months; newborns, however, were only observed in June, July, August, and September. Groups containing calves had a considerably higher mean group size (4.9 ± 0.18 groups containing calves vs. 2.4 ± 0.07 groups containing adults only; Kruskal–Wallis, $p < 0.001$), and this tendency was consistent throughout the study period.

The results revealed that group size did not change during the 5 years of research (Kruskal–Wallis, $p > 0.05$; Table 5). On the other hand, a higher number of newborns were observed during the last 2 years of research (Kruskal–Wallis, $p < 0.001$). Group size did not exhibit any seasonal variations (Kruskal–Wallis, $p > 0.05$). However, the number of newborns showed a seasonal fluctuation with a peak in the Spring, Summer, and Fall months.

Recognisable bottlenose dolphins and fish farm fidelity

Overall, 16,871 were "good"-quality photographs (7,951 pictures of the left side and 8,920 pictures of the right side). The pictures were obtained from 531 dolphin groups (accounting for 95 % of all encounters) occurring between November 2004 and November 2009. A photo-identification catalogue was developed, resulting in 49 uniquely marked individuals visiting the fish farm. These individuals consisted of 42 adults (15 males, 11 females, and 16 unsexed), 2 immatures (2 males), and 5 newborns. On the basis of the percentage of the marked individuals visiting the fish farm (mark rate = 91.2 ± 0.6 %), it was possible to estimate the presence of approximately 54 both marked and unmarked individuals.

The average number of photographic recaptures per individual was 34.3 ± 8.7 (from 1 to 245, $n = 49$), with 19 individuals (38.7 %) resighted over 10 times. Particularly, 11 common bottlenose dolphins (four adult males, five adult females, and two immature males), accounting for 22 % for all identified individuals, were identified more than 50 times throughout the study period. However, 11 common bottlenose dolphins (22 %) were identified only once throughout the study period. This shows that some individuals interacted with the marine fin fish farm on a regular basis, whilst others were present less often.

Relative to the total number of seasons surveyed ($n = 21$), most bottlenose dolphins identified were sighted occasionally (mean ± SE = 0.26 ± 0.04 resightings per season). However, yearly occurrence rates (mean ± SE = 0.46 ± 0.04) indicated that many of the bottlenose dolphins identified were seen in the fish farm in more than two

Table 5 Mean group size, mean number of adults, immatures, and newborns in each season of every year of research

	2005	2006	2007	2008	2009	Total
Winter						
Group	3.35 ± 0.12	2.93 ± 0.18	2.85 ± 0.15	2.65 ± 0.16	4.14 ± 0.15	3.18 ± 0.17
Adults	2.78 ± 0.10	2.85 ± 0.15	2.75 ± 0.13	2.45 ± 0.13	3.48 ± 0.12	2.86 ± 0.15
Immatures	0.17 ± 0.05	0.07 ± 0.07	0.08 ± 0.04	0.20 ± 0.10	0.20 ± 0.12	0.14 ± 0.04
Newborns	0	0	0	0	0	0
Spring						
Group	3.26 ± 0.16	4.13 ± 0.17	2.58 ± 0.20	4.15 ± 0.16	4.22 ± 0.12	3.66 ± 0.19
Adults	2.93 ± 0.18	3.87 ± 0.21	2.48 ± 0.15	3.33 ± 0.12	3.45 ± 0.13	3.20 ± 0.16
Immatures	0.23 ± 0.08	0.16 ± 0.13	0.02 ± 0.01	0.34 ± 0.10	0.32 ± 0.09	0.21 ± 0.03
Newborns	0.10 ± 0.02	0.11 ± 0.07	0.08 ± 0.01	0.47 ± 0.11*	0.42 ± 0.11*	0.23 ± 0.03*
Summer						
Group	3.53 ± 0.17	3.5 ± 0.18	3.34 ± 0.16	3.25 ± 0.21	2.85 ± 0.18	3.29 ± 0.16
Adults	3.26 ± 0.15	3.12 ± 0.12	3.22 ± 0.16	2.44 ± 0.12	2.15 ± 0.15	2.83 ± 0.14
Immatures	0.04 ± 0.05	0.22 ± 0.11	0.10 ± 0.06	0.06 ± 0.02	0.08 ± 0.02	0.10 ± 0.02
Newborns	0.23 ± 0.01	0.15 ± 0.07	0.14 ± 0.01	0.75 ± 0.13*	0.59 ± 0.04*	0.37 ± 0.05*
Fall						
Group	3.88 ± 0.19	3.14 ± 0.13	3.64 ± 0.15	5.39 ± 0.25	3.45 ± 0.13	3.9 ± 0.20
Adults	3.27 ± 0.20	2.98 ± 0.10	3.32 ± 0.20	3.74 ± 0.17	2.27 ± 0.16	3.1 ± 0.19
Immatures	0.24 ± 0.12	0.12 ± 0.09	0.36 ± 0.10	0.46 ± 0.24	0.59 ± 0.32	0.35 ± 0.07
Newborns	0.16 ± 0.09	0.04 ± 0.01	0	0.79 ± 0.17*	0.20 ± 0.04*	0.24 ± 0.04*
Total						
Group	3.50 ± 0.2	3.42 ± 0.30	3.10 ± 0.16	3.86 ± 0.24	3.66 ± 0.2	3.51 ± 0.10
Adults	3.06 ± 0.17	3.20 ± 0.26	2.94 ± 0.15	2.99 ± 0.18	2.83 ± 0.16	3.0 ± 0.17
Immatures	0.17 ± 0.05	0.14 ± 0.05	0.14 ± 0.04	0.26 ± 0.10	0.29 ± 0.18	0.20 ± 0.05
Newborns	0.12 ± 0.03	0.07 ± 0.01	0.06 ± 0.01	0.50 ± 0.14	0.30 ± 0.12	0.21 ± 0.08

* Kruskal–Wallis, $p < 0.05$

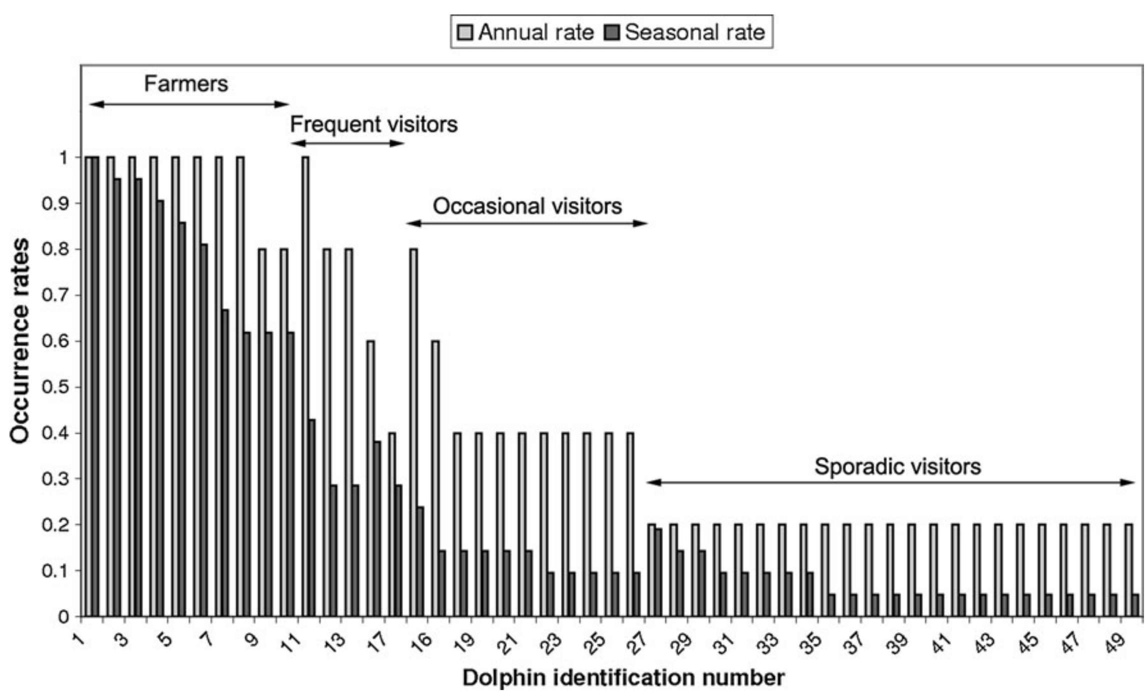

Fig. 2 Frequency distribution of the number of seasons and years a dolphin was identified as the proportion of the total number of seasons ($n = 21$) and years ($n = 5$) surveyed

calendar years. Figure 2 shows the annual and seasonal occurrence rate for all 49 identified individuals.

No significant differences in the yearly occurrence rates (Kruskal–Wallis, $p > 0.05$) nor in the seasonal occurrence rates (Kruskal–Wallis, $p > 0.05$) were found between adult males and females ($n = 31$ sexed dolphins).

Individual dolphins were divided subsequently into five arbitrary categories based on their temporal occurrence rates (Fig. 2):

1. "Farmers" category: bottlenose dolphins seen in the fin fish farm most often, with both annual and seasonal occurrence rates higher (or equal) than 0.5. This category contained 10 identified adult bottlenose dolphins (3 males and 7 females), accounting for 20 % of the total 49 identified individuals.
2. "Frequent visitors" category: bottlenose dolphins with seasonal occurrence rates lower than 0.5 and higher (or equal) than 0.25. This category contained five identified bottlenose dolphins (2 adult females and 1 adult male, one male calf, and one newborn), accounting for 10.1 % of the total 49 identified individuals.
3. "Occasional visitors" category: bottlenose dolphins with seasonal occurrence rates lower than 0.25 but yearly occurrence rates higher than 0.25. This category contained 10 identified bottlenose dolphins (7 adult females, one male, and two immatures), accounting for 20 % of the total 49 identified individuals.
4. "Sporadic visitors" category: bottlenose dolphins rarely seen in the study area, with both annual and seasonal occurrence rates lower than 0.25. This category contained 24 bottlenose dolphins (20 unsexed adults, 2 male immatures, and 2 newborns), accounting for 49.9 % of the total 49 identified individuals.

Bottlenose dolphin behaviour

A total of 739.2 h were spent observing the behaviour of 560 groups of bottlenose dolphins visiting the fish farm area. The dolphins were mostly engaging in foraging activities (78 % of the time; contingency table χ^2, $p < 0.05$; Table 6) followed by travelling (17 %), socializing (5 %), and resting (1 %). During the foraging activities, the dolphins did not show any evident preferences between the predation and depredation categories (57 and 43 % of the feeding time, respectively; contingency table χ^2, $p > 0.05$).

The behaviour of bottlenose dolphins was not related with the group size (contingency table χ^2, $p > 0.05$), or with the moments of the day (contingency table χ^2, $p > 0.05$). On the other hand, there was a seasonal fluctuation in the dolphin's behaviour, where they spent more time foraging during the fall months compared to the other activities (89 % of the time; contingency table χ^2, $p < 0.05$; Table 6).

Table 6 Percentage of time spent engaging in different activities in the fish farm area for each surveyed season

Seasons	Foraging (Depredation/ Predation)	Travelling	Socializing	Resting
Winter (%)	78 (60/40)	17	5	1
Spring (%)	67 (54/46)	21	10	2
Summer (%)	68 (52/48)	19	10	2
Fall (%)	89* (61/39)	9	1.5	0.5
Total (739.16 h) (%)	75.5* (57/43)	16.5	6.6	1.4

* Contingency table χ^2, $p < 0.05$

Bottlenose dolphin mortality in the fish farm

The mean number of known mortalities was 0.8 ± 0.37 dolphins per year, representing a mean annual mortality rate of 1.5 ± 0.01 % for the community. This value is a minimum, and the fact that not all dolphins that died were observed and recovered is taken into consideration. Five bottlenose dolphins were found entangled in predator nets around the fish farm cages (two in 2005, two in 2006, and one in 2008).

Discussion

Long-term, year-round research on top predators allows one to document the history of their exposure to ecosystem perturbations produced by human activities. Results of this study describe for the first time the bottlenose dolphins temporal fluctuations, behaviour, and fidelity for a coastal area impacted by the aquaculture industry. Furthermore, these kinds of monitoring programmes play a key role in providing values information about aquaculture management options.

By examining the results of this study, it is clear that the presence of bottlenose dolphins is regular and year round in the fish farm area. The dolphins were observed during every year surveyed, in all seasons of the year and moments of the day. The repeated observations of a number of known dolphins suggest individual preferences for the fish farm. Some of these individuals were present in the study area before the beginning of the fish farm activities in 1995 (Díaz López et al. 2005).

The presence of dolphins interacting with marine fin fish farms has become a frequent phenomenon not only in Mediterranean waters, but worldwide (Würsig and Gailey 2002; Díaz López, et al. 2005; Díaz López and Shirai 2007; Bearzi et al. 2008). As a result of this, many fish farm managers in Italy, Spain, Malta, Greece, and Israel claim that these animals are causing a negative impact on their industry through depredation on the farmed fish as well as causing them stress (Díaz López, pers. Observation). Thus, the interaction between this species and marine aquaculture is a very important matter to monitor in order to determine its causes and consequences.

Besides the bottlenose dolphins, yellow-legged seagulls (*Larus michahellis*), shags, and grey herons were observed interacting with the fish farm year round. Other species as common terns (*Sterna hirundo*), cormorants, hooded crows (*Corvus cornix*), bluefin tuna (*Thunnus thynnus*), and greater amberjack (*Seriola dumerili*) were observed seasonally and sporadically in low densities (Díaz López pers. observation).

Why do bottlenose dolphins interact with the fin fish farm?

During the period of this study, the bottlenose dolphins exhibited great flexibility in their foraging strategies, particularly when using anthropogenic food sources as a result of the interaction with aquaculture (Díaz López 2006a, 2009). Results of this study show that the bottlenose dolphins spent most of their time engaging in foraging activities in the fish farm area. The predominant activities were more specifically predation on wild fish and depredation on farmed fish. Wild fish concentrated in the fish farm serve together with the farmed fish as a powerful attraction to dolphins that normally feed on similar or the same fish species in nature. Hence, the various pelagic fish, especially zooplanktivorous fish species (i.e. bogue, pilchard, and garfish) and common grey mullets concentrated around the fish farm cages (Díaz López 2006a, b, 2009), were observed to serve as a regular prey for the studied bottlenose dolphins (Díaz López, 2006a, 2009).

Many wild fish species change their distribution and movement patterns seasonally, moving into deeper waters in response to extremely cold or extremely warm temperatures (Giovanardi 1990). Thus, the peak dolphin occurrence in the fish farm area throughout Fall coincides with the period in which they spend most of their time foraging. This type of interaction may be related to that the dolphins build up fat stores in preparation for the winter months (Shane 1990). During these months, water temperatures drop significantly and the presence of wild fish species decreases considerably (Giovanardi 1990, local fishers pers. Communication). Hence, the observed seasonal pattern seems to be related to both prey distribution changes and seasonal changes in metabolic needs. Moreover, a possible explanation for the circadian fluctuations of dolphins' occurrence in the fish farm is that the abundance of preys (wild fish around the fish farm cages) did not keep uniform throughout the day. Hence, every evening many species of zooplankton and zooplanktivorous fish come to the surface, and to shallow waters as a consequence of diel vertical migration (Wiebe et al. 1990). This migration could be an explanation of the low dolphins's occurrence in the fish farm during evening hours.

Furthermore, as a consequence of the presence of the fish farm, resource availability varies both spatially (e.g. concentration of wild fish species around the fish farm cages) and temporally (e.g. food patches that only occur at certain times of the day, such as harvesting operations in the fish farm and/or discarded farmed fish). Thus, the dolphins can reduce the proportion of time spent searching for food and possibly increase the quantity and quality of the food consumed. A clear example of this is the interaction between the dolphins and specific fish farm activities (such as harvesting operations) which have increased throughout the last years. During these operations, dolphins obtained fast and easy benefits in the form of discarded or escaping fish. The fish farm activities are becoming an attraction to the bottlenose dolphins and induce interaction with the industry. In particular, this interaction was more evident with the individuals that visited the fish farm more regularly ("farmers").

Presence of bottlenose dolphins in the fish farm area

This study reveals that a proportion (30.1 %) of all identified bottlenose dolphins exhibit high site fidelity to the marine fish farm. These individuals were included into the categories "Farmers" and "Frequent visitors". Long-term interaction leads to individuals having intimate knowledge of the habitat, and therefore knowledge about where and when food resources are most likely to be found and how to obtain them. The high proportion of individuals that spend most of their time outside the fish farm area (69.4 %) indicates different individual foraging strategies. These individuals were included into the categories "occasional" and "sporadic" dolphins and should not be considered as direct predators in the fish farm.

Strong individual differences in foraging strategies have been documented both in this area (Díaz López and Shirai 2008; Díaz López 2009) and in other parts of the world (Florida, Nowacek 2002; Shark Bay, Australia, Mann and Sargeant 2003; Sargeant et al. 2007). These strategies may be perpetuated by transmission of information within a generation (among similar-age peers) and from generation to generation (from mothers and from older non-relatives) by, in a broad sense, culture (Rendell and Whitehead 2001). The presence of females can be explained by the fish farm serving as a high-quality food resource. Moreover, the presence of males could be also explained by both the high-quality food resource and the females' distribution (Connor et al. 2000).

The observed individual preferences for the fish farm might increase direct competition between individuals for limited resources, which in turn would limit group size (Gowans et al. 2008). The long-term residency and repeated interaction between "Farmer" and "Frequent visitor" dolphins observed in this study may lead to the development of social relationships (e.g. acquaintances, feeding associates, and affiliates; Díaz López and Shirai 2008). In this case, it is possible to hypothesize that dolphins may have established territories related to the food patches created by the aquaculture, and certain individuals (or groups) may have had greater access to the resources than others. Thus, area defence by individuals or social groupings could explain some differences in fish farm fidelity and temporal occurrence rates observed in this study. It may be possible for these individuals or groups to defend resources (food and females) concentrated in a small-sized area as a marine fin fish farm.

Conflict between bottlenose dolphins and the aquaculture

The problems that the aquaculture industry faces which has resulted from the presence of bottlenose dolphins in the farming areas are both market- and production related. As this interaction affects the quality of the product it is market-related, and as it affects daily operations it is production related. Firstly, as observed during this study, there is direct predation which is difficult to estimate with bottlenose dolphins (Díaz López 2006a, 2009; Díaz López and Mariño 2011). Secondly, lost production is in the form of lost body weight of the fish. The stress on a population of fish subjected to repeated attacks by predators such as the bottlenose dolphins shows itself in poor feed conversion efficiency; hence, the weight at harvest is not maximized (Nash et al. 2000). Moreover, as observed with other predators (Price and Nickum 1995), the continued presence of dolphins may also worsen a disease outbreak by increasing the fish stress levels.

To curb predation, the fish farm deployed control methods during 3 months to exclude or harass the dolphins. The antipredator control methods used by the fish farm were (1) underwater nets and (2) acoustic harassment devices (AHDs). Although bottlenose dolphins benefit from feeding around the fish farm cages, this interaction can be harmful due to the antipredator nets employed (Díaz López and Shirai 2007). Both incidental captures of bottlenose dolphin observed in this area and precedent records of bottlenose dolphins becoming entangled in the predator nets around tuna cages in South Australia (Kemper et al. 2003; Würsig and Gailey 2002; Díaz López and Shirai 2007) confirm that the major problems for bottlenose dolphins in marine fin fish farms are entanglement in the large mesh predator nets. Moreover, the use of acoustics harassment devices did not appear to be effective to keep bottlenose dolphins away from fish farms (Díaz López and Mariño 2011).

Conclusion

During the last years, marine aquaculture has generated a worldwide interest as a result of the overexploitation of wild stocks combined with a growing international demand for fish and seafood products (FAO 2007). Thus, the expansion of marine aquaculture industries has caused growing concern regarding their environmental impact. This study provides new data on the interaction between a marine top predator (bottlenose dolphin) and a fin fish farm during five consecutive years, and for all the seasons of the year. The interaction between predators and the fish farm industry and the consequences derived are of great importance for both the aquaculture and coastal conservation management.

The observed individual preferences for the fish farm are highly relevant as the studied bottlenose dolphins may have established territories related to the food patches created by this industry. Area defence by individuals or social groupings has not been commonly observed in bottlenose dolphin populations (Gowans et al. 2008). Results of this study might be a good example of area defence, and it could explain some differences in fish farm fidelity and temporal occurrence rates observed during the 5 years of observations.

Moreover, whether the impacts associated with marine aquaculture on predators as bottlenose dolphins are positive or negative, they are different between individuals of the same regional population. These differences result from the variation of fish farm fidelity between the individuals. One example of this is the use of acoustic harassment devices that are designed to keep marine mammals away from fin fish cages. These devices are likely to have greater impacts on certain individuals (or groups) than others. Therefore, strategies for the management of both the aquaculture industry and marine mammal populations must take these results into consideration. Furthermore, future studies are needed to estimate whether the bottlenose dolphin's impact on fish farms is economically significant.

Acknowledgments Funding for this research came from the Bottlenose Dolphin Research Institute—BDRI. This study would not have been possible without the willingness of the fish farm manager Dr. Graziano and fish farm workers, and I wish to thank them for their help and cooperation. Heartfelt thanks are extended to the BDRI member Selma Bajraktarevic who helped with the manuscript and all the volunteers and internships who gave generously of their time to help with field work. Data collection complies with the current laws of the country in which it was performed, Italy.

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