Interactions between common bottlenose dolphins (*Tursiops truncatus*) and the artisanal fishery in Asinara Island National Park (Sardinia): assessment of catch damage and economic loss

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ABSTRACT

In 1999, the Italian Central Institute for Applied Marine Research (ICRAM), in response to reports made by local fisheries, began a study into the interactions between common bottlenose dolphins (*Tursiops truncatus*) and the artisanal fishery in the Asinara Island National Park (Sardinia). Using onboard observers, fishing boat surveys were carried out to determine the frequency of interactions, variations in the catch of target species and damage to two different types of trammel net caused by dolphins. Interactions occurred primarily with trammel nets targetting striped red mullet (*Mullus surmuletus*; the less valuable peacock wrasse, *Simphodus tinca*, was also caught). Interactions also occurred with trammel nets set for lobster (*Palinurus elephas*), cuttlefish (*Sepia spp.*) and scorpionfish (*Scorpaena spp.*), but these were considered negligible. The target species, catch and damage inflicted on the catch was recorded, both in the presence and absence of dolphins, in an effort to ascertain associated damage and economic cost. Loss of catch was found to be significant only in the case of nets deployed during the red striped mullet fishing season. Although the level of interaction was high relative to the narrow red striped mullet fishery season, the overall economic impact on the fishing community was found to be modest. The presence and regulations of the national park area may provide an opportunity for investigating mitigation activities compatible with both cetacean conservation and the maintenance of the traditional fisheries.

KEYWORDS: FISHERIES; COMMON BOTTLENOSE DOLPHIN; COMPETITION; EUROPE

INTRODUCTION

Interactions between fisheries and marine mammals have been frequently reported and involve almost all existing fishing gears (e.g. Northridge and Hofman, 1999). Such interactions generally have negative consequences for both fishery economics and the conservation status of marine mammals (Perrin *et al*., 1994; Hall and Donovan, 2002). Two types of interaction can be distinguished: biological and operational. Biological interaction is the competition for the same biological resource, at the population level (Northridge and Hofman, 1999). Operational interaction is associated with individual animals causing direct damage by stealing fish from the gear or becoming entangled in gear (Harwood, 1992). This latter interaction can result in damage to the fishing gear, spoilt prey in the net, fish taken from the net and reduced catch rate. Bottlenose dolphin distribution is often related to the distribution of prey (e.g. Barros and Odell, 1990; Barros *et al*., 2000); interactions with fisheries will thus be more likely where the distribution of their preferred prey overlaps with the distribution of the target species of a fishery.

There are examples of competitive interactions with coastal fisheries from several European countries, e.g. Greece (Labropolou, pers. comm.; Casale *et al*., 1999), Croatia (Drasko Holcer, pers. comm.), Spain (Alonso *et al*., 2000; Lopez *et al*., 2000; Gazo *et al*., 2001), Tunisia (Naceur Lofti, 2000) and others. Within Italy descriptive studies have been conducted in Western Sicily (Quero *et al*., 2000) and Sardinia (Cannas *et al*., 1994). The common bottlenose dolphin (*Tursiops truncatus*) is the most frequently involved species, probably due to its coastal distribution and opportunistic feeding habits (Barros and Odell, 1990). Despite increased research effort, the nature and seasonality of the interactions and the damage to fisheries, through gear and loss of catch, have never been quantified. To evaluate the need for mitigation measures and/or economic compensation related to damage caused by the interactions, it is necessary to fill these knowledge gaps.

This study, conducted between 1999 and 2001, details the interaction between small-scale fisheries and common bottlenose dolphins in the Asinara Island National Park, northwest Sardinia. It evaluates the damage to the catch in order to estimate the magnitude of the impact on the local economy. This area was selected for the study for two main reasons: (1) reports and requests for help from the local fisheries; and (2) the relatively pristine nature of the area around Asinara Island due to the establishment of a penitentiary which had isolated it from the public since 1885 (Gessa, 1998). After the closure of the penitentiary in 1997, the area was designated as a national park. In the area, 39 dolphins have been photo-identified in a six year period; variability in re-sighting frequencies suggests that some individuals have a high site fidelity whilst others frequent the study area more sporadically (Lauriano *et al*., 2003). The frequency of newly identified individuals has decreased in recent years, suggesting that the majority of the population frequenting this area has been identified (Lauriano *et al*., 2003). Preliminary investigations, conducted through interviews with fishermen, had indicated that interactions occured predominantly with trammel nets; interactions with long-lines and creel traps were considered insignificant. Hence this study has focused on the trammel net fishery.

MATERIALS AND METHODS

Study area

The study area is approximately 480km² wide, comprising the Asinara National Park and its adjacent waters (Fig. 1). The western shore of the island is characterised by high rock cliffs and the sea floor drops quickly to a depth of 45m and

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is highly influenced by strong wave dynamics due to prevailing north and north-westerly winds (Delitala *et al.*, 1998). In contrast, the eastern coast has a wide continental slope extending across the Asinara Gulf. This eastern shoreline, sheltered from the prevailing winds and hence not subject to the strong 'wave movements' of the open sea, is dominated by a lush sea grass meadow (*Posidonia oceanica*).

Fishing operations

The fishing fleet of Stintino, the main fishing port within the study area, comprises 21 boats. The average gross tonnage is 3.41 (range 1.19-9.26), average overall length (LOA) is 7.36m (range 4.8–12.65) with an average engine power of 47.49hp (range 13.5–230). The fishery activities are conducted in accordance with park regulations; bottom-set fishing gear, such as trammel nets, are the main fishing gear whilst other gear, such as long—lines and traps, are sporadically used. The fishery is closed for 45 days every winter; apart from this restriction, fishing activity is carried out throughout the year. Two main types of trammel net are deployed separately, according to the period of the year, as described below.

B-type[1] *nets*, with mesh size between 32 and 72mm, are used between January and April mainly to catch seabream (*Diploidae*), cuttlefish *(Sepiidae*) and scorpionfish (*Scorpaenidae*), and between May and August for lobster (*P. elephas*). This type of net is left soaking continuously and is inspected by fishermen every 24 hours. The average length was 823m and height 1.6m (Table 1).

[1] Large mesh size.

S-type[2] *nets*, with mesh size of 27mm, are used between September and December only and target striped red mullet (*M. surmuletus*). The net is set before dawn and haul starts at sunrise. The average length was 919m and height 1.6m (Table 1).

Table 1

Characteristics of fishing operations.

Net type	N	Mean depth (m)	Depth range (m)	Mean length (m)	Length range (m)	Mean duration of the fishing operation (mins)		
						Set-up	Soak	Haul
B	67	63±21	20-102	823±102	550-1,000	-	>1,200	56±18
S	88	31±12	10-65	919±362	500-2,000	22±8	172±74	42±15

Data collection

To collect data on fishing activities, observers were placed aboard up to three fishing boats each day. The following data were collected: mesh size; net length; time of net setting and hauling; catch composition; total weight of individual species; morphological damage to the fish; geographic location and depths at each net end; presence/absence of dolphins; the beginning and end of any interactions; and the number of dolphins sighted.

Interactions were defined as occasions when dolphins were observed within 400m of the nets. 'Set up duration' was defined as the time between the start and the end of the

[2] Small mesh size.

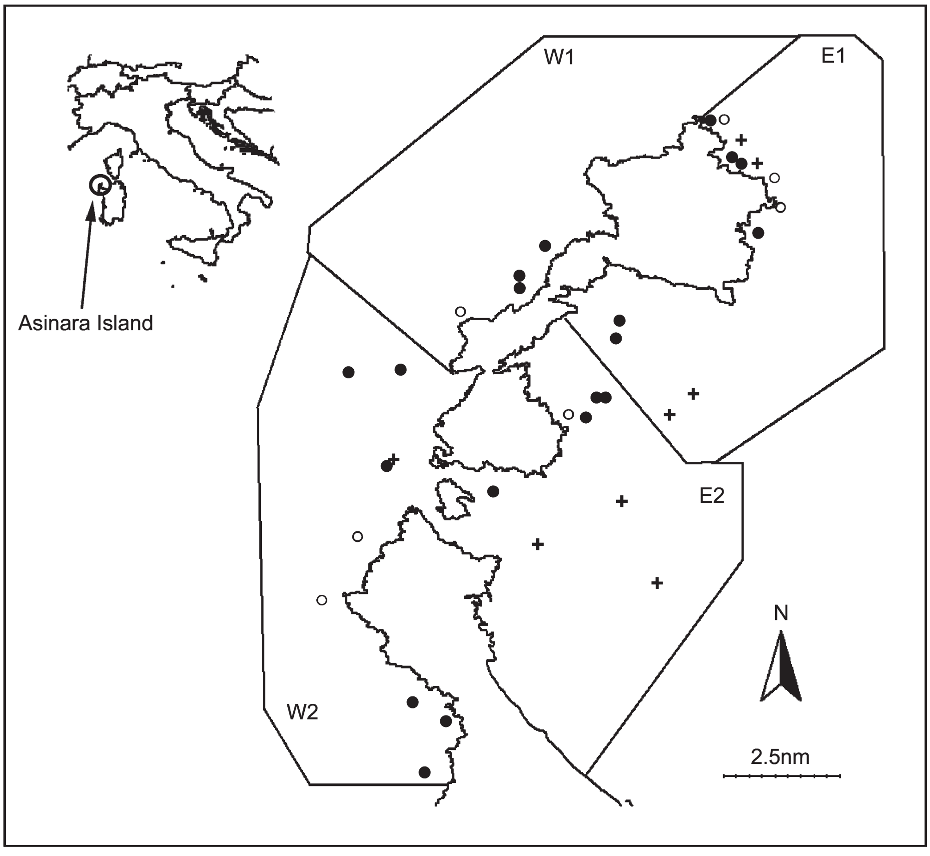

Fig. 1. The study area between 1999 and 2001 (solid circle = interactions S-type nets; open circle = interactions B-type nets; + sightings during the monitoring B-type net fishing season). E=East; W=West. S and B type nets are not overlapping; they are deployed in different seasons.

set up operation; 'Haul duration' as the time between start and end of the hauling operation; and 'Soak duration' as the time between set-up end and the start of the hauling time. Accordingly, the total fishing time was the sum of these three operations.

Each net monitored was considered to represent a fishing experiment; in a single day several fishing experiments could occur.

Catch-per-unit-effort (CPUE) was defined as the total catch (kg) divided by the length of the net (km). Analyses were performed for each type of net separately.

For those fish species recorded in more than 50% of the total observations, multiple regression analyses were carried out in order to evaluate factors affecting catches, in terms of both the CPUE and morphological damage. Independent variables – year, season, area, depth, presence/absence of dolphins, group composition – were tested for their unconditional interrelation. Explanatory variables were chosen using the Akaike Information Criterion, AIC (e.g. Akaike, 1974).

The economic damage caused by the loss of catch due to interactions, was calculated only for S-type nets by considering: (1) the average catch loss of the main target species per km of net; (2) the local commercial value of the target species per kg; (3) the mean net length used daily by each vessel; (4) the average number of fishing days during each fishing season; and (5) the overall frequency of interactions.

The annual frequency of interactions was estimated from the number of interactions observed during the overall number of fishery experiments. Data on the duration of the fishing season and the commercial value of each target species were provided by the local fishery consortium.

In order to assess damage to the catch, each specimen caught was analysed and the morphological damage classified into following five categories (Lauriano and Di Muccio, 2002): (a) 'Head', when only the head remained, the body removed at the level of the gills; (b) 'Tail', only the tail remained; (c) 'Bite', the specimen showed one or more parts removed; (d) 'Fragment', only parts of the specimen remain; (e) 'Vestigial', empty bodies with only the skin and bones left (see Fig. 2).

To collect data on dolphin behaviour and movements during interactions, a 5.8m rigid inflatable boat (RIB) was towed by the fishing boat and used by an independent team of researchers in order to avoid interference with fishing activities and dolphin behaviour. Successive boat locations recorded from the RIB, using a GPS receiver, were assumed to describe the locations of the dolphins being observed.

Due to the different soak times for B- and S-type nets, the monitoring of fishing operations was conducted in two different ways.

S-type net. The observation (by on-board observers) of S-type nets was continuous during the entire fishing operation, starting from the set up to the end of hauling. In order to achieve maximum coverage of the fishing area (such as a bottom rocky area) the nets were set in a winding pattern resulting in a smaller length than it would be if deployed straight. Since one end was anchored, with other was attached to the fishing boat, observers were able to listen for dolphins in the area around the net or to see them after sunrise. No fishing operations were performed in poor sea conditions (sea $\leq$ 2 on the Douglas sea and swell scale[3]).

[3] e.g. see http://www.dcmnr.ie/display.asp?pg=1093

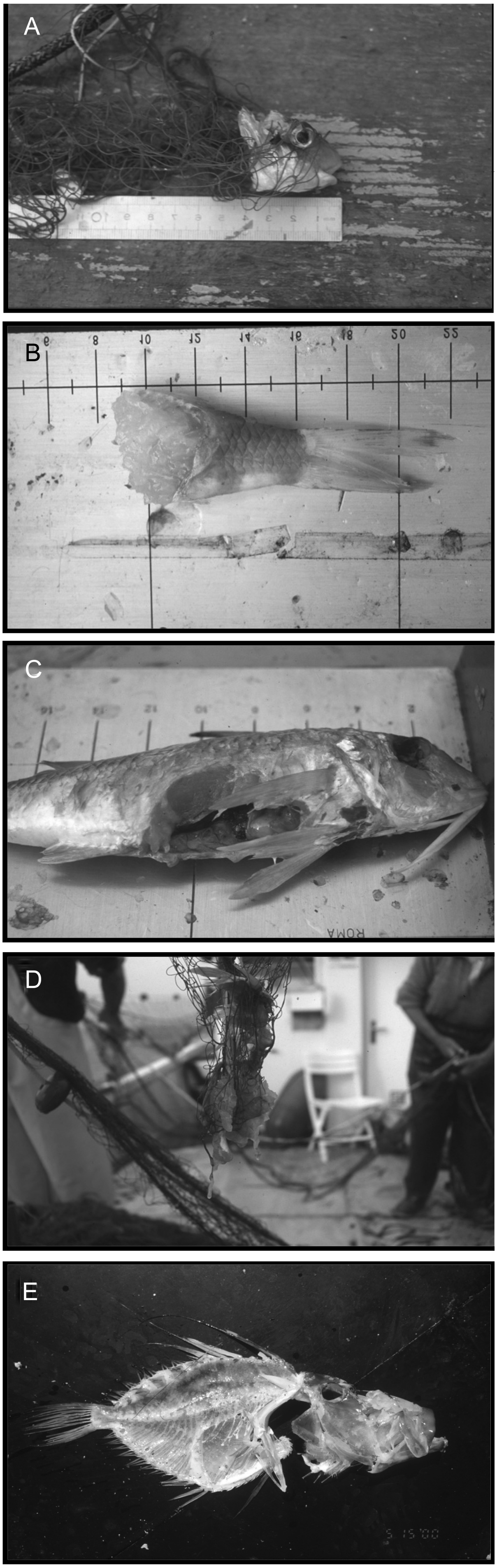

Fig. 2. Photographs of categories of morphological fish damages. (A) Head. (B) Tail. (C) Bite. (D) Fragment. (E) Vestigial.

B-type net. By contrast, B-type nets were monitored only during the set up/hauling period. However, during the day, since the interactions could occur at any time during the 24-hour fishing period, the fishing area was also monitored with the RIB ('Monitoring surveys'). During these monitoring surveys, the number of nets in the study area and the presence/absence of dolphins were recorded. Data were only considered for analysis when the sea state was ≤ 3 Beaufort scale[4].

Data were georeferenced using a Geographic Information System (GIS). The study area was subdivided into four sectors (Fig. 1) of equal dimensions (E1, E2, W1,W2) and the relative densities of dolphins and buoys for each sector were calculated in order to establish the possible overlap between dolphins and fishing areas. The relative density was expressed as the total numbers of encounters weighted by effort (n/km), in each sector.

RESULTS

S-type net

Composition of the catch

A total of 88 fishing experiments were conducted between October 1999 and October 2001 on 24 different days. Of these, 41 took place off the eastern and 47 off the western coasts of the island.

Catches were characterised by the overwhelming predominance of striped red mullet over forkbeard (*P. phycis*), pandora (*Pagellus spp.*), seabream (*Diplodus spp.*) and scorpionfish. Species caught more than three times are indicated in Table 2.

Bottlenose dolphin frequency during fishing operation (Hauling/setting and soak)

Bottlenose dolphins were recorded interacting with the fishing operations on 29 occasions out of 88 experiments (0.33). The annual frequencies of interactions, during year 1999, 2000 and 2001, were 0.27 (n=11), 0.25 (n=51) and 0.50 (n=26) respectively. The first sightings occurred between 05:55 and 09:57 hrs. The dolphins arrived 12 times during soaking time and 17 times during hauling. When interactions occurred, dolphins spent a mean of 20 minutes (SD=27, n=29) around the nets. The mean group size was 6.8 (SD=3.04, range 1-12) and calves were present on eight occasions.

Factors affecting catch levels

Table 3 shows the significant results of multiple regression analysis of explanatory variables explored; the total catch of fish was negatively correlated with the duration of the soak time and dolphins interactions, but was positively correlated with depth.

Multiple linear regression analyses were performed on the catch rate of nine main species (Table 4): striped red mullet (97% of the total catch on discrete occasions), common seabream (85%), black scorpionfish (*S. porcus*) (76%), large-scaled scorpionfish (65%), annular seabream (*D. annularis*) (65%), comber (*S. cabrilla*) (64%), common pandora (*P. erythrinus*) (59%), common cuttlefish (*S. officinalis*) (58%), and peacock wrasse (*S. tinca*) (51%). Only for striped red mullet and peacock wrasse were the total catches significantly affected by dolphins.

[4] e.g. see http://www.dcmnr.ie/display.asp?pg=1094

Effect of dolphins on catches

LEVEL OF CATCHES

When dolphin interactions occurred, the total CPUE (kg/km) was reduced from 17.68 (SD=12.12) to 10.27 (SD=11.66) for all years combined (t-value=2.73, df=86, p=0.008). The red striped mullet CPUE decreased from 7.63 (SD=6.35) to 4.15 (SD=6.73) in the presence of dolphins for all years combined (t-value=2.37, df=86, p=0.02). The average red striped mullet CPUE with and without bottlenose dolphins varied by year and was 1.98 and 11.51 in 1999, 5.36 and 7.69 in 2000 and 3.45 and 5.06 in 2001 respectively. For peacock wrasse, with or without interactions, the CPUE was 0.20 and 0.52 in 1999, 0.30 and 0.19 in 2000 and 0.41 and 0.21 in 2001 respectively.

DAMAGE

Damage of various kinds were detected on fourteen species (Figs 3 a, b). Of those variables examined, only the presence of dolphins showed a positive correlation (see Table 5). The 'Head' damage category was observed only for striped red mullet (15 cases) and comber (1 case only): 'Bites' were the most common form of damage irrespective of the presence of dolphins (Figs 3a and b). It is notable that 'Head' and 'Fragment' damage were both positively correlated with the presence of dolphins (p=0.007; and p=0.001, respectively) and negatively correlated with the year (Head-Year2000: p=0.003; 'Year2001': p=0.002; and Fragment-'Year2000': p=0.00003; 'Year2001': p=0.00000003). 'Head' damage was also positively correlated with the presence of groups composed by adults ($p=1.3^{-11}$) while 'Fragment' was positively correlated with the presence of sub-adults in the group (p=0.002).

Estimate of Economic Damage (ED)

The economic reduction of the net fishing yield was mainly related to the red striped mullet catch. This species has a much higher commercial value than the peacock wrasse (on average €9.90/kg compared to €1.03/kg) and economic loss was only calculated for the most valuable species. The estimated economic loss per boat per season varied quite widely with the annual mean for the three year period being over €1,100 (see Table 6).

B-type net

Composition of the catch

Sixty-seven fishing operations were carried out in 17 days; of these, eleven took place off the eastern shore and 56 off the western shore of the island. Catches mainly comprised lobster, large-scaled scorpionfish (*S. scrofa*), common octopus (*Octopus vulgaris*) and skate (*Raja spp.*). The species caught are listed in Table 2.

Bottlenose dolphin frequency during fishing operations (hauling/setting nets)

Dolphins were recorded during fishing operations (hauling/setting nets) on 7 out of 67 (0.10) fishing experiments. The frequencies for 2000 and 2001 were 0.17 (out of 35) and 0.3 (out of 32) respectively. The first sightings occurred between 05:22 and 09:30hrs. During the hauling/setting operation dolphins spent an average of eight minutes (SD=5) around the nets. The mean group size was 1.6 (SD=0.55, range 1-2) and groups comprised only adults.

Factors affecting catch levels

Correlations among explanatory variables on total catch are show in Table 7.

Table 2

Fish catch checklist in each net type (species caught less than 3 times are not reported).

N	Class	Family	Species	Net B No. obs.	Net B CPUE	Net S No. obs.	Net S CPUE
1	Osteichthyes	Carangidae	*Seriola dumerilii* (Risso, 1810)	3	0.450	3	0.011
2		Centracanthidae	*Spicara maena* (Linnaeus, 1758)	1	0.003	32	0.155
3		Congridae	*Conger conger* (Linnaeus, 1758)	1	0.010	5	0.036
4		Gadidae	*Phycis phycis* (Linnaeus, 1766)	25	0.816	40	0.906
5			*Trisopterus minutus capelanus* (Linnaeus, 1758)	3	0.006	8	0.115
6		Labridae	*Labrus bimaculatus* (Linnaeus, 1758)	2	0.018	4	0.006
7			*Labrus merula* (Linnaeus, 1758)	1	0.030	18	0.099
8			*Labrus viridis* (Linnaeus, 1758)	0	0.000	12	0.129
9			*Symphodus mediterraneus* (Linnaeus, 1758)	0	0.000	5	0.012
10			*Symphodus roissali* (Risso, 1810)	0	0.000	25	0.136
11			*Symphodus tinca* (Linnaeus,1758)	0	0.000	45	0.252
12		Lophiidae	*Lophius piscatorius* (Linnaeus, 1758)	18	0.732	0	0.000
13		Mullidae	*Mullus surmuletus* (Linnaeus, 1758)	3	0.013	85	5.301
14		Sciaenidae	*Sciena umbra* (Linnaeus, 1758)	3	0.043	36	0.164
15		Scomberesocidae	*Scomberesox saurus* (Walbaum, 1792)	3	0.015	2	0.007
16		Scorpaenidae	*Scorpaena porcus* (Linnaeus, 1758)	13	0.165	67	0.560
17			*Scorpaena scrofa (*Linnaeus, 1758)	45	1.613	57	0.651
18		Serranidae	*Serranus cabrilla* (Linnaeus, 1785)	6	0.017	56	0.446
19		Soleidae	*Solea impar* (Bennett,1831)	6	0.077	0	0.000
20			*Solea vulgaris* (Quensel, 1806)	4	0.024	0	0.000
21		Sparidae	*Boops boops* (Linnaeus, 1758)	2	0.003	13	0.025
22			*Dentex dentex* (Linnaeus, 1758)	5	0.322	22	0.134
23			*Diplodus annularis* (Linnaeus, 1758)	0	0.000	59	0.200
24			*Diplodus puntazzo* (Cetti, 1789)	2	0.009	16	0.044
25			*Diplodus sargus* (Linnaeus, 1758)	3	0.042	8	0.034
26			*Diplodus vulgaris* (E.Geoffrey Saint-Hilaire, 1817)	6	0.039	75	0.479
27			*Pagellus acarne* (Risso, 1826)	9	0.034	7	0.077
28			*Pagellus erythrinus* (Linnaeus, 1758)	16	0.219	52	0.415
29			*Sarpa salpa* (Linnaeus, 1758)	0	0.000	10	0.027
30			*Spondyliosoma cantharus* (Linnaeus, 1758)	12	0.164	35	0.120
31		Sphyraenidae	*Sphyraena sphyraena* (Linnaeus, 1758)	0	0.000	4	0.033
32		Trachinidae	*Trachinus araneus* (Cuvier, 1829)	13	0.168	2	0.010
33			*Trachinus draco* (Linnaeus, 1758)	12	0.102	8	0.030
34			*Trachinus radiatus* (Cuvier, 1829)	6	0.053	2	0.004
35		Triglidae	*Trigloporus lastoviza* (Brûnnich, 1768)	3	0.013	16	0.032
36		Uranoscopidae	*Uranoscopus scaber* (Linnaeus, 1758)	22	0.359	15	0.055
37		Zeidae	*Zeus faber* (Linnaeus, 1758)	14	0.148	15	0.046
38	Chondrichthyes	Rajidae	*Raja asterias* (Delaroche, 1809)	22	2.468	0	0.000
39			*Raja brachyura* (Lafont, 1873)	6	2.087	1	0.007
40			*Raja clavata* (Linnaeus, 1758)	3	0.109	2	0.012
41			*Raja miraletus (*Linnaeus, 1758)	16	0.439	0	0.000
42			*Raja* sp.	4	1.497	0	0.000
43			*Dasyatis pastinaca* (Linnaeus, 1758)	1	0.024	4	0.020
44		Scyliorhinidae	*Scyliorhinus canicula* (Linnaeus, 1758)	20	0.179	8	0.516
45	Cephalopoda	Loliginidae	*Loligo vulgaris* (Lamark, 1798)	0	0.000	7	0.024
46		Octopodidae	*Octopus vulgaris* (Cuvier, 1797)	16	1.330	19	0.258
47		Sepiidae	*Sepia elegans* (Blainville, 1827)	0	0.000	4	0.032
48			*Sepia officinalis* (Linneus, 1758)	5	0.138	51	0.438
49			*Sepia orbignyana* (Ferussac, 1826)	0	0.000	28	0.094
50	Crustacea	Palinuridae	*Palinurus elephas* (Fabricius, 1787)	59	3.197	9	0.044
51		Majidae	*Maja squinado* (Herbest, 1788*)*	3	0.091	1	0.001

No significant differences ($p>0.05$) were found in the total catch for when dolphins were or were not present during the hauling/setting operation (CPUE=17.11; n=7; SD=13.96 and CPUE=17,81; n=60; SD=15.16, respectively).

Damage

A total of 248 fish (33 species) showed damage. The most frequent category (77%) was 'Vestigial' damage (n=190), followed by (18%) 'Bites' (n=44). The remainder accounted for only the 6% of the total.

The number of damaged specimens was positively correlated only with the year (hauling/setting operations only) (p=0.020). 'Bite' (p=0.032) and 'Vestigial' ($p=1.7^{-11}$), were positively correlated with depth.

Monitoring of the study area from the rigid inflatable boat (January-August)

During 50 days of field work days, 1,758km were covered and a total of 903 buoys were recorded; on only 10 occasions were bottlenose dolphins encountered. On three of these they were following working bottom trawlers, and these encounters are not included in Fig. 1. The mean group size was 4.0 (range 1-9, SD=2.79, n=10), with an average of 1.7 sub-adults per group. Buoy and relative sighting density, weighted by effort (km covered within each quadrant), are

Table 3

S-type net: multiple regressions analysis on total catch.

	Estimate	SE	t-value	p[1]
(Intercept)	10.06378	3.43266	2.932	0.00434 **
Durat. exp.	-1.62088	0.80258	-2.020	0.04662 *
Depth	0.25663	0.08861	2.896	0.00481**
Dolphins	-5.10512	2.06585	-2.471	0.01549 *
Residual SE	277.7	DF	79	
F-statistic	5.908	DF	3 & 79	0.001044 **

[1]Level of significance. ***=0.001 ; **=0.01 ; *=0.05.

Table 4

S-type net: multiple regressions analysis on species' catch.

	Estimate	SE	t-value	p[1]
P. erithrynus				
(Intercept)	-0.4896	0.5053	-0.969	0.3355
Year 2000	-0.6904	0.3252	-2.123	0.0368*
Year 2001	-0.3671	0.3037	-1.209	0.2303
Area E2	0.5332	0.2699	1.975	0.0516
Area W1	0.3003	0.3008	0.998	0.3210
Area W2	-0.1412	0.2876	-0.491	0.6248
Depth	0.0414	0.0099	4.181	7.3^{-5}***
Residual SE	24.61	DF	79	
F-statistic	8.22	DF	6 & 79	5.91^{-6} ***
S. porcus				
(Intercept)	5.2289	1.4399	3.631	0.0005 ***
Year 2000	-1.5758	0.9483	-1.662	0.1003
Year 2001	0.0964	0.9340	0.103	0.9181
Depth	-0.1042	0.0274	-3.809	0.0003 ***
Dolphins	-1.2722	0.5921	-2.149	0.0516
Residual SE	76.67	DF	79	
F-statistic	4.981	DF	4 & 79	0.0012 **
S. cabrilla				
(Intercept)	-1.5630	0.5635	-2.774	0.0068 **
Year 2000	-0.3402	0.3711	-0.917	0.3619
Year 2001	0.1812	0.3655	0.496	0.6213
Depth	0.0809	0.0107	7.553	5.01^{-11} ***
Dolphins	-0.3273	0.2297	-1.425	0.1581
Residual SE	30.01	DF	79	
F-statistic	24.64	DF	4 & 79	1.829^{-13} **
S. tinca				
(Intercept)	1.0308	0.2364	4.360	3.79^{-5} ***
Area E2	-0.1078	0.1851	-0.583	0.5615
Area W1	0.3512	0.2001	1.755	0.0830
Area W2	0.6378	0.1811	3.523	0.0007 ***
Durat.exp	-0.0706	0.0483	-1.462	0.1476
Depth	-0.0218	0.0062	-3.515	0.0007 ***
Dolphins	1.0308	0.2364	4.360	3.79^{-5} ***
Residual SE	16.12	DF	79	
F-statistic	5.834	DF	6 & 79	5.834^{-5} **
D. annularis				
(Intercept)	0.4496	0.1521	2.956	0.0041 **
Area E2	0.0761	0.1252	0.608	0.5450
Area W1	0.0584	0.1418	0.412	0.6815
Area W2	0.2976	0.1317	2.259	0.0265 *
Depth	-0.0108	0.0045	-2.470	0.0156 *
Residual SE	11.86	DF	79	
F-statistic	3.789	DF	4 & 79	0.00706 **
M. surmuletus				
(Intercept)	2.7816	1.6935	1.643	0.1042
Depth	0.1306	0.0492	2.653	0.0095 **
Dolphins	-3.0560	1.2727	-2.401	0.0187 *
Residual SE	156.3	DF	79	
F-statistic	5.776	DF	2 & 79	0.0045 **
S. officinalis				
(Intercept)	0.5044	0.2293	2.200	0.03062 *
Area E2	0.9873	0.2378	4.152	7.94^{-5} ***
Area W1	0.1525	0.2411	0.632	0.5289
Area W2	0.6593	0.2405	2.741	0.0075 **
Durat.exp	-0.1891	0.0635	-2.979	0.0038 **
Residual SE	21.7	DF	79	
F-statistic	7.757	DF	4 & 79	2.32^{-5} ***

[1]Level of significance. ***=0.001 ; **=0.01 ; *=0.05.

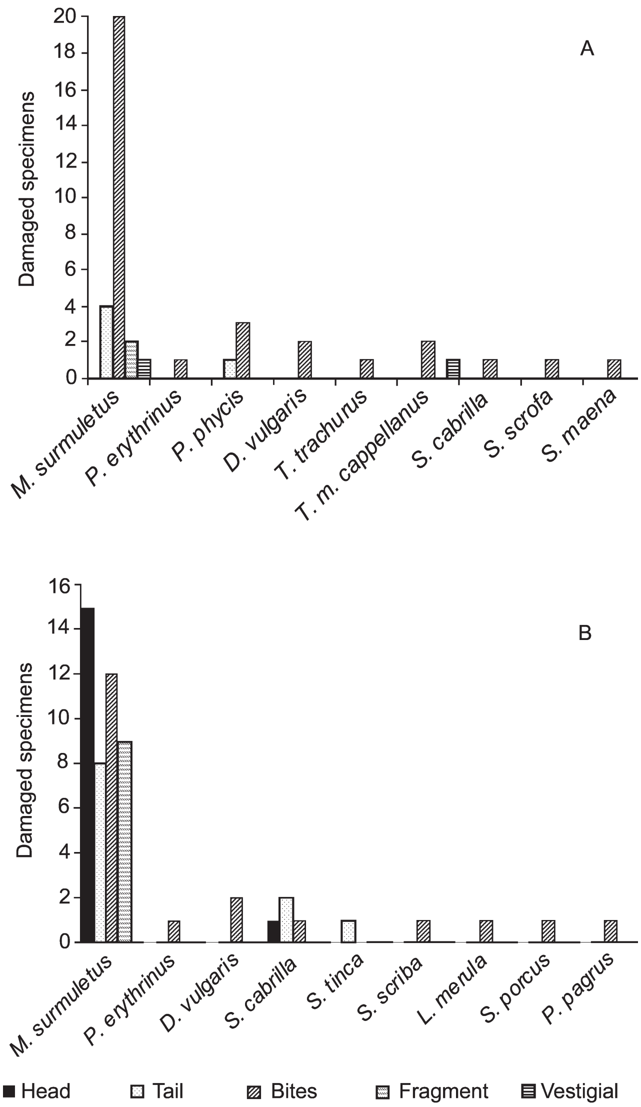

Fig. 3. Fish damage categories and damaged specimens without (A) and with (B) interaction.

Table 5

S-type net: multiple regressions analysis on morphological damages.

	Estimate	SE	t-value	p[1]
(Intercept)	0.3873	0.1396	2.773	0.00684 **
Dolphins	0.3156	0.1049	3.008	0.00347 **
Year 2000	-0.1377	0.1508	-0.913	0.36386
Year 2001	0.1669	0.1584	1.054	0.29495
Residual SE	13.78	DF	83	
F-statistic	5.563	DF	3 & 83	0.0001819 ***

[1]Level of significance. ***=0.001 ; **=0.01 ; *=0.05.

Table 6

Economic damage (ED) in euro (€) of red striped mullet catch (1999-2001). L=mean catch loss (kg) per species per km of net; l=mean length of net used by each boat daily; F=frequency of interaction; D=mean fishing season (days) for red striped mullet.

Year	L (kg/km)	l (km)	F	D (days)	Kg price (€)	ED per boat (€)
1999	9.53	2.63	0.27	30	9.81	1,992.26
2000	2.33	2.64	0.25	38	9.81	573.42
2001	1.61	3.13	0.50	37	10.07	939.03
Total mean economic damage (€)						**1,168.24**

Table 7

B-type net: multiple regressions analysis on catch.

	Estimate	SE	t-value	p[1]
(Intercept)	5.397e+03	1.920e+04	0.281	0.779636
Season SU	9.370e+00	1.053e+01	0.890	0.376994
Season W	-1.896e+01	9.286e+00	-2.042	0.045642 *
Area W1	2.428e+00	5.241e+00	0.463	0.644796
Area W2	-3.219e+00	5.727e+00	-0.562	0.576238
Depth	-3.016e-01	8.034e-02	-3.753	0.000401 ***
Dolphins	-4.392e+00	5.223e+00	-0.841	0.403812
Residual SE	348	DF	59	
F-statistic	2.83	DF	7 & 59	0. 013 *

[1]Level of significance. ***=0.001 ; **=0.01 ; *=0.05.

shown in Table 8. The highest relative density of common bottlenose dolphin encounters was found in fishing area E1 followed by W2. Buoy relative density was higher along the western shore of Asinara (W1 followed by W2).

Table 8

Daylight monitoring of fishing areas (B-type net season).

Area	E2	E1	W1	W2
Buoys	193	197	217	296
Effort (km)	867	371	164	356
Sightings	1	3	1	2
Buoys density	0.222	0.531	1.323	0.831
Dolphin density	0.001	0.008	0.006	0.007

DISCUSSION AND CONCLUSION

This study represented the first attempt in the Mediterranean basin to quantify depredation by bottlenose dolphins to artisanal fisheries. Despite widespread complaints in the region, an increase of attention to the problem and persistent requests for subsidy, little if any detailed information was available on this topic. A wide range of fishing gears is deployed in different regions and seasons and it is possible that different species of cetaceans may be involved in others kinds of competitive interactions.

This study highlights the existence of what was called ‘operational competitive interaction’ (Northridge and Hofman, 1999; Reeves *et al*., 2001) between bottlenose dolphins and fishermen. Nevertheless, striking differences were revealed in the type and importance of interaction in the two types of trammel net. Because of differences in the operational activity and consequently in methodology, detailed analysis of the interaction was possible for trammel S-type nets only, whereas the level of the interaction for trammel B-type nets could only be inferred. Nevertheless, all evidence suggests a low degree of depredation with trammel B-type net in comparison to trammel S-type net.

S-type net

S-type nets showed a high frequency of interactions (up to half of the experiments in 2001) and the relatively prolonged mean duration of the interactions (20 mins) was consistent with active exploitation of the catch by the dolphins.

The diversity of fish species in the catch decreased in the presence of dolphins and the total CPUE showed a significant reduction. Of the nine fish species analysed, however, only catches of striped red mullet and peacock wrasse were adversely affected by dolphins.

On a closer investigation of the damage to the fish, the ‘Head’ category was recorded only for nets for which the presence of dolphins had been noted; it was particularly associated with all-adult groups. Such remains can be associated with the bottlenose feeding strategy and the mode of entanglement of the fish species. In fact, fish are entangled in the medium panel of the trammel net (Anon., 1998; Ferretti *et al*., 2002) such that only the rear portion is left exposed and open to a predator. It is also believed that, when a large amount of prey is available, marine mammals have the ability to select the most nutritious portion of the prey (Harwood, 1992). Thus a trammel net may represent a ‘supermarket’ for the dolphins characterised by a high concentration of preferred prey, allowing for a selection of both the species and the ‘best bite’. This is consistent with the fact that only striped red mullet heads were recorded when an interaction occurred. In addition, the frequency of ‘fragments’ was correlated with the number of sub-adults which may reflect the lack of skill of sub-adults to most effectively exploit the catch. Despite the clear impact of dolphin presence on the total catch of striped red mullet, the number of ‘Heads’ recorded was relatively low (n=15). This suggests the possibility of a more complex feeding strategy, not only restricted to the use of the nets as a ‘supermarket’, but also as a barrier to stop fleeing prey, as described for Mauritanian bottlenose dolphins (Brusnell, 1973) and killer whales (Similä and Ugarte, 1993).

The morphological damage category ‘Bite’, with its characteristic shape and size, seems more attributable to the action of other predators such as cuttlefish (*Sepia spp.*), common octopus (*O. vulgaris*), european conger (*Conger conger*) and Mediterranean moray (*Murena helena*) (Lauriano and Di Muccio, 2002). Interestingly, the frequency ‘Bites’ decreased when dolphins were present, which may reflect an impact of the presence of a top predator on other predators.

B-type nets

Bearing in mind the difference in monitoring methodology linked to the particular fishery activities, the rate of dolphin interaction during the hauling and setting operations was negligible. The total catch seemed not to be affected by the presence of dolphins but rather by environmental and temporal factors, e.g. depth and season, as possible consequence of fish ecology and different conservation status of fish stocks around Asinara Island (Tunesi *et al*., 2001).

None of the morphological damage categories detected on the specimens caught in B-type nets was correlated with the presence of dolphins. In these nets the most frequent category, ‘Vestigial’, was rather related to ‘Depth’ and ‘Season’ and was probably caused by scavenging organisms (mostly Isopoda). The category ‘Head’ detected in the S-type nets and considered as a proxy of dolphin depredation was never recorded for B-type nets. We would have expected that such damage would have been recorded if interactions had occurred during unmonitored phases of the fishing process. Finally from the data collected during the monitoring survey and despite the high density of B-type nets in certain areas and their daily availability to dolphins, no evidence of direct competitive interactions with dolphins was observed.

General

Our results suggest that in this area, bottlenose dolphins are adapting their feeding strategies to the red mullet fishery – this may reflect their energetic requirements in different seasons and years (e.g. the calving period) and availability. In the Gulf of Asinara, there is also an intense and profitable trawling activity all year around, except for September.

Trawlers usually harvest red mullet (*Mullus barbatus*), European hake (*Merluccius merluccius*) (Ardizzone and Corsi, 1997) and other sandy and mud bottom circumlittoral species that have been reported in the Mediterranean bottlenose dolphin diet (Miokovic *et al*., 1997; Relini, O.L. *et al*., 1994). It has been suggested that bottlenose dolphins in this area take advantage of the presence of trawlers (Lauriano, 1997), as described in other regions (Fertl and Leatherwood, 1997). When trawling ends due to the closure of the fishery, the bottlenose dolphins seem to switch their attention to the trammel net fishery for striped red mullet, which at that time of the year becomes gregarious and coastal (Pipitone *et al*., 1995; Relini, G. *et al*., 1999). In this context, we propose that the bottlenose dolphins augment their energy intake by taking advantage of these particular two fisheries. A positive balance between the cost and benefits of feeding activities related to the exploitation of certain fisheries compared to 'no-aided' free ranging hunting strategies (Fortuna *et al*., 1998), the possible ease of hunting and/or a risk minimisation due to the gear characteristics, also reflected by the presence of calves in the group (Ashford *et al*., 1996), and the higher concentration of preferred prey around the fishing gear, might explain the bottlenose dolphins preferences for small mesh size nets and trawlers, compared to large mesh size nets or long-lines.

Mitigation

Recognising the existence of competitive interactions between bottlenose dolphins and fishermen is considerably easier than devising a strategy to minimise such interactions. Considerable flexibility of approach in addressing this issue will be required. The nature and level of interactions will be dependent on several factors and the bottlenose dolphin is well known to be extremely adaptable. A single, one-time solution is unlikely to be found; a combination of mitigation methods seems to be the best approach.

Dolphins approached S-type nets mainly during the hauling period. This suggests that dolphins might be reacting to a cue which attracts them to full nets. Characteristic noises (the 'dinner bell' theory), whilst setting and hauling the net, such as the low engine revolutions or the noise of the winch may represent such cues. This hypothesis is consistent with a lack of interactions with the long-line fishery, where the fishing gear is hauled manually. Bottlenose dolphins have been reported to be able to distinguish operational noises of shrimp fishing boats produced by winch and engine and adjust their behaviour accordingly (Gunther, 1954 as cited in Shane *et al*., 1986; Norris and Prescott, 1961; Gruber, 1981 as cited in Shane *et al*., 1986). A cue effect of winch noise has also been demonstrated for killer whales (Matkin, 1986; Yano and Dahlheim, 1995). Another potential cue could be the collective noise of several fishing boats leaving the harbour at the same time at night. With respect to that possibility, local fishermen also pointed out the general absence of interactions after a period of fishing inactivity due to bad weather, they suggested some correlation between previous fishing activity and the presence of dolphins.

One approach to consider, therefore, is to develop fishing strategies that reduce possible cues. This could be achieved, for example, by introducing: (i) modifications to the fishing gear; (ii) time/area closures; and (iii) greater fishing area and gear turnover, and/or (iv) through a process of 'stealth fishing', as suggested by Tregenza (2001). It has also been suggested that a parsimonious use of pingers could also help to ease this problem. However, the cost of untested new technologies, such as the deployment of 'pingers' in this case should be considered (Reeves *et al*., 2001) along with a risk assessment to investigate possible negative effects on dolphins and the habitat. It should be noted that these fisheries operate in marine protected areas; the use of the deterrent devices may thus be inconsistent with the main aim of the marine reserve which is the preservation of the habitats and biodiversity.

It is also important to note that the overall economic damage caused by dolphins to the fishery, at least as calculated in this initial study, is small, affecting only on strictly seasonal activity. Despite this, the interaction represents a strong psychological factor in the perception of the fishermen because almost every year it affects up to a third of their income during the two months of the striped red mullet fishery. Our data also highlight annual differences in economic damage according to the total catch, frequencies of interaction and mean length of net.

We recognise that in order to develop a complete estimate of the economic damage, gear damage and the consequent reduced catching capacity should be considered. In this context it should be noted that tears in the net are not sewn up daily, but only when serious damage occurs and meticulous repairs are only made in autumn during the biological fishing closure.

Provided an agreed mechanism to estimate economic costs could be agreed, the National Park Authority could support a compensation scheme for predator damage. In addition or alternatively, it could assist with mitigation research. This approach has been tested at the national level in Sweden for terrestrial mammals (Swedish Environmental Protection Agency – *http://www.internat.naturvardsverket.se/*). In fact some economic refunds are already established by a regional law[5], provide reimbursement for damage caused by dolphins. Reimbursement is intended for net damage only, and requires the fisherman to hand in the net to the coastguard who must verify the extent of the damage. This practice interrupts fishing activities, and is inconvenient for fishermen who wish to apply.

Whatever other approach is adopted, public awareness programmes, should also be established. For example, in this study several factors were found to be correlated with the decrease in fish catches (for example season, depth, area, and other predators). Nevertheless, fishermen perceived that only dolphins were detrimental to their activities. In the past this attitude has lead to extreme 'solutions'. For example until the 1950s in Italy and former Yugoslavia, rewards were paid for killed dolphins, considered as vermin to be eradicated (Holcer, 1994).

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[5] Regione Autonoma della Sardegna. Decreto A.D.A. no. 2923 del 21/12/1996. Agevolazioni per danni provocati dai delfini alle attrezzature retiere in periodo successivo al 27 marzo 1997, data di entrata in vigore del provvedimento.

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