IMPACT OF INTERACTIONS BETWEEN COMMON BOTTLENOSE DOLPHINS AND PURSE-SEINERS IN THE MOROCCAN MEDITERRANEAN REGION: CASE STUDY IN THE AL HOCEIMA FISHING GROUNDS

Issue: Impact of interactions between common bottlenose dolphins and purse-seiners

Background

The ACCOBAMS Secretariat received the study "Impact of interactions between common bottlenose dolphins and purse-seiners in the Moroccan Mediterranean region: case study in the Al Hoceima fishing grounds" from the Task Manager on Interactions with fisheries.

This study examines the effect of common bottlenose dolphins Tursiops truncatus on the purse-seine fishery for small pelagic fishes in the Mediterranean Sea and the economic consequences thereof. The investigation focused on the fleet registered at the port of Al Hoceima, Morocco, and used information collected from on-board observations and a semi-structured questionnaire with fishermen and ship-owners. A total of 121 dolphins were captured as bycatch during 48 fishing trips, with a mortality rate of 0.23 dolphins per fishing trip. In terms of damage to the fishing gear, the number of observed holes varied between 28 and 230 per net per incident. Though some tears were large, most were <35 cm in height. The cost of repairing the holes in the nets caused by these interactions was estimated at US$179.52 per mending event. The level of interaction between common bottlenose dolphins and the purse-seine fishery targeting small pelagic fishes is a challenge for both fishery management and dolphin conservation.

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Impact of interactions between common bottlenose dolphins and purse-seiners in the Moroccan Mediterranean region: case study in the Al Hoceima fishing grounds

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This study examines the effect of common bottlenose dolphins *Tursiops truncatus* on the purse-seine fishery for small pelagic fishes in the Mediterranean Sea and the economic consequences thereof. The investigation focused on the fleet registered at the port of Al Hoceima, Morocco, and used information collected from on-board observations and a semi-structured questionnaire with fishermen and ship-owners. A total of 121 dolphins were captured as bycatch during 48 fishing trips, with a mortality rate of 0.23 dolphins per fishing trip. In terms of damage to the fishing gear, the number of observed holes varied between 28 and 230 per net per incident. Though some tears were large, most were <35 cm in height. The cost of repairing the holes in the nets caused by these interactions was estimated at US$179.52 per mending event. The level of interaction between common bottlenose dolphins and the purse-seine fishery targeting small pelagic fishes is a challenge for both fishery management and dolphin conservation.

Keywords: bycatch, cetacean conservation, fishing gear damage, mortality, on-board observations, *Tursiops truncatus*, questionnaire

Introduction

The bycatch of non-target species in fisheries is a global concern because it influences fishery sustainability. Globally, the problem of bycatch concerns all cetacean species whose habitat overlaps with fishing operations (Northridge and Hofman 1999). Operational interactions include gear damage (Brotons et al. 2008), preying upon the fishing catch (Bearzi et al. 2009; Esteban et al. 2016) and unintentional cetacean mortality and disturbance (e.g. cetacean bycatch: Marçalo et al. 2015).

This interaction between dolphins and fisheries results in a loss of revenue for fishermen around the world (Wise et al. 2007). Based on sampling by independent observers, various studies have estimated the economic loss caused by common bottlenose dolphins *Tursiops truncatus* (hereafter 'bottlenose dolphins'). For example, this cost was estimated at between €500 and €2 000 per vessel in Mediterranean bottom-set trammel and gill nets annually/seasonally (Lauriano et al. 2004; Brotons et al. 2008; Gazo et al. 2008; Rocklin et al. 2009).

Interactions between bottlenose dolphins and fisheries gear have been observed in the Mediterranean coastal areas of Spain (Gazo et al. 2008) and Portugal (Marçalo et al. 2015). These interactions result not only in economic losses for fishermen but also in incidental captures of dolphins. This may cause mortality or physical injuries to bottlenose dolphins, which can have an impact at their population level (Pennino et al. 2015). Even so, the Mediterranean bottlenose dolphin subpopulation is listed as Least Concern on the IUCN Red List of Threatened Species (Natoli et al. 2021). This assessment was based on a minimum abundance estimate of approximately 60 000 individuals for the whole Mediterranean Sea (ACCOBAMS 2021) and no sign of a decreasing trend in the past three generations (Natoli et al. 2021).

In general, the negative perception by fishermen towards dolphins and their predatory interactions with fishery catches is amplified by the fact that many Mediterranean fish stocks are overexploited (FAO 2018) and fishermen blame dolphins for the collapse of fish stocks and for the decrease in their catch and income (Bearzi et al. 2010).

In Morocco's Mediterranean ports, fisheries for small pelagic fish provide the greatest socio-economic benefits for the Moroccan fishing industry (Darasi and Aksissou 2019). For the port city of Al Hoceima, the purse-seine fishery for small pelagic fishes plays an important role in the local economy by providing 315 direct jobs and 100 indirect jobs (Keznine et al. 2021); in 2010, landings were 8 971 tonnes and revenues were $8.56 million (ONP 2010). In 2020 there were 14 purse-seiners recorded in the port, but only four vessels have operated there more recently (Keznine et al. 2021).

This study focuses on the purse-seine fishery for small pelagic fishes at Al Hoceima, Morocco, in the western Mediterranean, ~150 km east of the Strait of Gibraltar. The area is particularly important in ecological terms, being inside the Alboran Sea and under the influence of the Western Anticyclonic Gyre (WAG). The WAG is formed by opposing circulatory movements of the Mediterranean Sea and Atlantic Ocean waters entering through the Strait

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of Gibraltar (Garcia-Lafuente et al. 2017). The exchange of these two water masses with different properties leads to high primary productivity in this area (Abdellaoui et al. 2017). This area is considered an important site for the conservation of marine mammals (Giménez et al. 2021; Vella et al. 2021), but also Al Hoceima is one of the three fishing areas along Morocco's Mediterranean coast that is characterised by coastal and artisanal fishing activity (García et al. 2012; Keznine et al. 2021). In the Al Hoceima region, there is also the marine protected area (MPA) of Al Hoceima Park, which is the only protected area in the Moroccan Mediterranean region (Par Ben Haj et al. 2009). This MPA was designated to protect fish stocks, improve fish recruitment in adjacent waters and facilitate the protection of endangered marine species.

The interactions between cetaceans and various fishing operations have been documented worldwide (Reeves and Leatherwood 1994). However, studies on interactions between Moroccan fisheries and cetaceans, including the quantification of cetacean bycatch, have been rare or have focused on driftnets (e.g. Tudela et al. 2005). Based on stranding data only, it has been suggested that bottlenose dolphins are commonly caught in coastal fisheries along Morocco's Mediterranean coast (Masski and De Stephanis 2015). The habitat preferences of bottlenose dolphins are largely dependent on prey availability (La Manna et al. 2016) and the dolphins tend to aggregate where prey species aggregate (Marini et al. 2015).

Operational interactions between cetaceans and fisheries have been reported in several regions, from the Straits of Gibraltar to the Black Sea (Northridge and Hofman 1999; Giménez et al. 2021), and these can have a negative effect on both marine mammal conservation and fishing activity. In Morocco, cetaceans are protected by national and international legislation (i.e. Law no. 2271-19 dated 15 July 2019, and the Agreement on the Conservation of Small Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area [ACCOBAMS] ratification law of 13 May 1999). A major challenge faced by the Moroccan Mediterranean fisheries sector is the lack of quantitative data on the interactions between bottlenose dolphins and purse-seiners. To identify the best and most equitable measures to mitigate this conflictual interaction, it is necessary to evaluate the potential impacts of these interactions on cetacean species and on the economic viability of the Moroccan purse-seine fishery targeting small pelagic fishes in the western Mediterranean region.

Materials and methods

Study area

This study was carried out in 2020 in Morocco's Al Hoceima fishing grounds, western Mediterranean Sea (Figure 1).

The Al Hoceima purse-seine fishery

Our previous study found that the Al Hoceima purse-seine fishery had 14 registered boats targeting the European pilchard *Sardina pilchardus*, which is the dominant species in the catch, followed by sardinella *Sardinella aurita*, horse mackerel *Trachurus trachurus*, mackerel *Scomber japonicus* and anchovy *Engraulis encrasicolus* (Keznine et al. 2021). Fishing operations occur at night and with the aid of a light boat to attract the fish, around which the net is set. In the Al Hoceima fishing area, the purse-seiners return to port to unload the fish after each set or fishing operation. There may be up to three sets per night, with the vessels leaving port at 18:00 for the first set. Each set lasts from 3 to 7 h depending on the quantity of the catch and the rate of damage caused by the dolphins.

The purse-seiners have an average gross register tonnage of 54 tonnes, an average length of 19 m and power of 360 horsepower (Keznine et al. 2021). The purse-seiners use nets that range in length from 200 to 620 m and with height ranging from 50 to 167 m. The mesh size is 11 mm in the pocket area. The fishing captains have a spare net ready in port in case the primary net is damaged and must be repaired.

In 2020, Al Hoceima purse-seiners made a total of 315 fishing trips, harvesting a total of 669 tonnes (ONP 2020), compared with 5 123 tonnes in 2015 (ONP 2015).

Data collection

On-board observations

Based on logistic and safety reasons an arbitrary selection of four fishing vessels was made to carry out on-board monitoring of the fishing operations, to quantify the level of the fish catch and dolphin bycatch and to obtain associated information on catches and interactions with bottlenose dolphins. Data were collected during 48 fishing trips (4 trips per month throughout 2020). Each trip consisted of 1 to 3 fishing operations depending on the purse-seine tear rate. The total of the observed fishing operations (i.e. sets) was 94.

Observers scanned the operation area continuously from the bow of the vessel and ensured that they had a clear view of all potential interactions during the fishing operation. The GPS position of the vessel was recorded every 15 min. For every observation of delphinids, the observer noted latitude and longitude, the initial and final time, the water depth, the species and the estimated group size.

During the encircling, hauling and catch-sorting phases, the observer recorded: (i) the presence or absence of bottlenose dolphins inside or outside the net and their status (i.e. dead, alive or wounded); and (ii) their effect on fishing operations (e.g. reduction of catch, scattering of fish causing the end of the set, or damage to fishing nets).

The mortality rate was based on estimates of the total number of dolphins that died relative to the total number of fishing trips.

Observations of stranded common bottlenose dolphins

During the study period, we monitored the number of bottlenose dolphins along Morocco's Mediterranean coast that were stranded, and we searched for external signs of lethal interactions with fishing gear (e.g. fishing gear tied around a dolphin's tail, knife cuts, or removed dorsal, caudal and/or pectoral fins).

Questionnaire design

Interviews with fishermen and ship-owners in Al Hoceima port were carried out to: (i) investigate the dolphin-handling

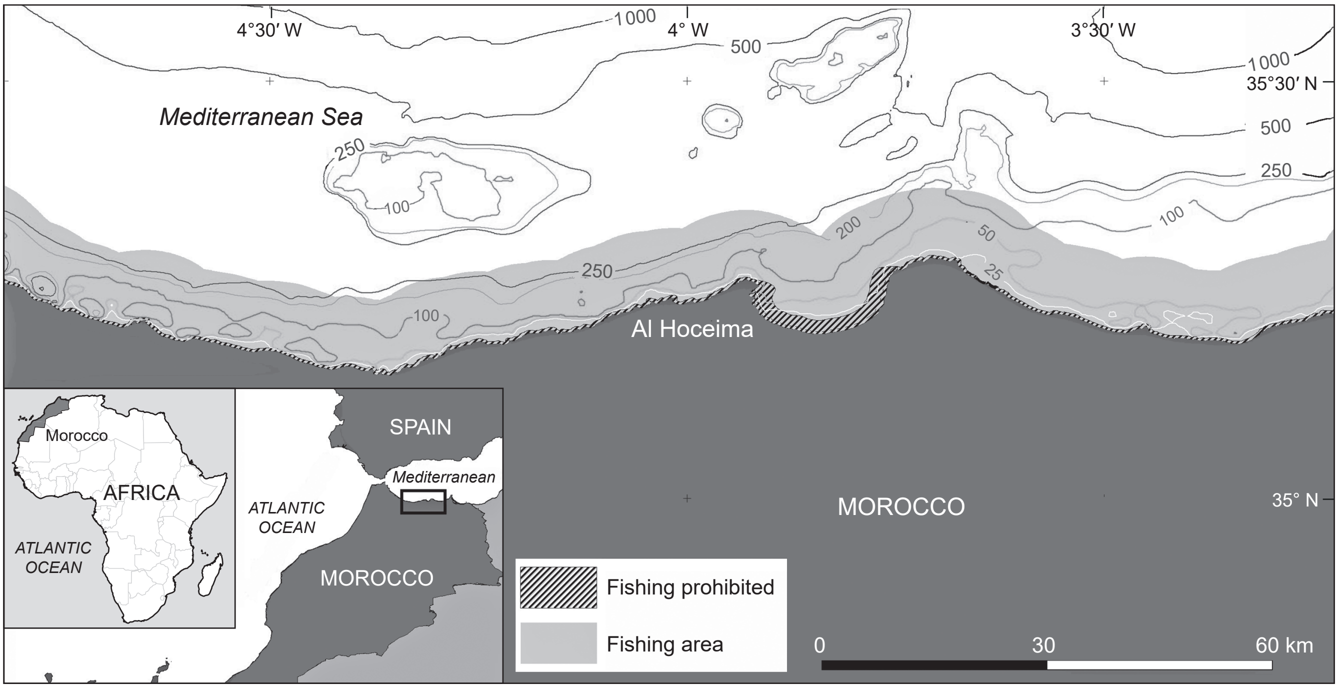

Figure 1: Location of the study area—the Al Hoceima fishing grounds, Morocco, western Mediterranean Sea

techniques employed by fishermen during accidental captures; and (ii) gather information from shipowners on the costs of repairing nets as well as the increased fuel costs attributed to the additional transits to and from the port in the event of net replacement. A total of 40 interviews were conducted randomly during 2020. This corresponds to 13% of the potential pool of people, based on the number of vessels listed in the port. These interviews were based on a semi-structured questionnaire. To reduce the 'group effect bias', fishermen and ship-owners were interviewed individually. At the beginning of each interview, respondents were informed of the general objectives of the study and reassured of their anonymity.

The questionnaire was composed of three sections. The first covered the characteristics of the vessel (e.g. tonnage, power), the gear (e.g. net size, mesh size) and the primary target species. The second focused on how bottlenose dolphins affected their fishing operations. The third posed more-detailed questions in order to estimate the economic impact from bottlenose dolphin interactions (e.g. mean percentage of catch lost per haul caused by rips and holes in the net webbing, the number of fishing sets affected per night, the monthly number of fishing days with catch losses, the frequency of net holes and the costs associated with repairing the damage or purchasing new fishing gear).

Frequency of dolphin–fishery interactions

The mean frequency of bottlenose dolphin interactions with purse-seine nets was calculated following Brotons et al. (2008) (see also Bearzi et al. 2011; Gönener and Özdemir 2012; Maccarrone et al. 2014):

$$\text{Freq} = \left[\left(\frac{\text{Ft att}}{\text{Tf}}\right)\right] \times 100$$

where Ft att_m is the number of fishing sets or trips attacked by month, and Tf is the total number of fishing sets or trips made by the seiner.

Estimated costs of damage to the fishing gear

The number and length of holes was measured once a purse-seiner arrived at the port to replace a damaged net. Shipowners usually hire a number of menders proportional to the damage of the net (e.g. number of reparable holes). To verify and economically quantify the total damage, we used the following formula:

$$\text{Total net damages} = \sum_{i=1}^{n} \text{mender daily wage} \times \text{number of menders}$$

where n is the number of days necessary for the repair. The daily wage of net menders was US$21–23.

Statistical analyses

To test whether the frequency of interaction depended on the fishing season, we applied the nonparametric Kruskal–Wallis test because the assumptions of homoscedasticity (equality of variance test) and normality (Shapiro–Wilk test) were not met. Differences in damage caused by bottlenose dolphins between fishing seasons were tested using the Kruskal–Wallis test. A Spearman rank-correlation test was carried out to investigate the relationship between hauls attacked by dolphins and catch weight. All statistical tests in this study were conducted using SPSS 20 software, at the 0.05 level of significance.

Results

Table 1 summarises the main data of our monitoring programme. Purse-seiner interactions occurred with two cetacean species: the common bottlenose dolphin *Tursiops truncatus* and the common dolphin *Delphinus delphis*. However, given the relatively few observations of common dolphins, statistical analyses were performed only for the bottlenose dolphin.

Fishery statistics and monitoring

In 2020, the Al Hoceima purse-seine fishery totalled 247 fishing days and 365 sets. Of these, 48 fishing trips by four different boats were monitored, amounting to 94 fishing sets.

Frequency of interaction between nets and bottlenose dolphins

The bottlenose dolphins interacted with purse-seine nets during 64 of 94 sets (Table 1), amounting to an overall frequency of attacks of 68% (SD = 19%, range = 30–100%). The monthly frequency varied, with minimum frequency in September (30%) and maximum frequency in December (100%). However, the difference in frequency among months was not significant (Kruskal–Wallis test, $p = 0.43$).

Bycatch and mortality of bottlenose dolphins

A total of 121 bottlenose dolphins were captured accidentally during the observed sets, during 64 different events. The large majority of dolphins were released alive or escaped ($n = 110$ individuals) but 11 died (Table 1). The mean (standard deviation) group size of captured bottlenose dolphins was 1.89 (±0.80) individuals ($n = 121$ individuals, range 1–4 dolphins per group) and most commonly were composed of 2 or 3 dolphins.

The incidence of 'dolphin presence only' (no interaction with the purse-seine net) varied each month, with a mean occurrence of 32% (SD 0.19) ($n = 30$ incidents, range 0–0.7 incidents per set).

Of the 110 surviving captured dolphins, 25 were entangled in the net and were then released alive by the fishermen, 46 escaped without observable injuries, and 9 narrowly escaped with physical injuries. The health status of the remaining 30 dolphins that escaped is unknown.

Bycatch rates per monitored set and per fishing trip was 1.89 individuals (range 0.75–4.50 individuals per set) and 2.52 individuals (range 1.25–4.50 individuals per trip), respectively. The observed mortality rates of bottlenose dolphins per set and per fishing trip were 0.12 (range 0.00–0.33 individuals per set) and 0.23 (range 0.00–0.50 individuals per trip), respectively (Table 1).

Economic loss from damage to fishing gear

The field investigation revealed different types of net damage and economic losses to the fishermen (loss of catches and increased fuel usage) as a result of bottlenose dolphins preying on the fish caught in the purse-seine nets.

There was a strong correlation between reduction of catches and bottlenose dolphins preying on the fish caught in the purse-seine nets ($r = 0.97$, $p < 0.001$). These predation events were carried out at the time of encirclement and capture of the fish by groups of 3–14 dolphins (mean 8.92 dolphins per group [SD 2.88], $n = 94$ monitored sets). On one fishing occasion, a group of 11

Table 1: Summary of the monitored purse-seine operations (sets), observed dolphin interactions, and common bottlenose dolphin bycatch data, out of the port of Al Hoceima, Morocco, western Mediterranean Sea, in 2020

Months	J	F	M	A	M	J	J	A	S	O	N	D	Total
Monitoring effort													
Monitored trips	4	4	4	4	4	4	4	4	4	4	4	4	48
Monitored sets	6	12	11	6	6	6	9	6	10	6	8	8	94
Common bottlenose dolphins													
Attacked sets	3	9	8	4	5	5	4	4	3	4	7	8	64
Frequency of interaction per set (%)	50.0	75.0	72.7	66.7	83.3	83.3	44.4	66.7	30.0	66.7	87.5	100	68.1
Presence of non-interacting dolphins	3	3	3	2	1	1	5	2	7	2	1	0	30
Frequency of non-interaction per set (%)	50.0	25.0	27.3	33.3	16.7	16.7	55,6	33.3	70.0	33.3	12.5	0	31.9
Bycatch events	4	7	4	5	3	5	6	6	4	4	8	8	64
Captured individuals	13	10	6	15	9	7	5	8	8	18	7	15	121
Dead individuals	2	1	0	2	1	0	1	2	0	1	0	1	11
Released individuals	0	2	1	3	0	2	3	0	4	6	1	3	25
Escaped individuals	7	6	3	4	6	2	1	4	4	7	1	10	55
–without injuries	4	6	3	4	6	1	0	2	3	6	1	10	46
–with injuries	3	0	0	0	0	1	1	2	1	1	0	0	9
Individuals with unknown health status OR individuals with unknown fate	4	1	2	6	2	3	0	2	0	4	5	1	30
Common dolphins													
Attacked sets	0	3	2	0	1	1	0	0	0	0	1	0	8
Bycatch events	0	2	1	0	2	2	0	0	0	0	1	0	8
Captured individuals	0	3	2	0	4	5	0	0	0	0	1	0	15
Dead individuals	0	2	0	0	3	2	0	0	0	0	0	0	7
Released individuals	0	1	0	0	1	0	0	0	0	0	0	0	2
Escaped individuals	0	0	2	0	0	3	0	0	0	0	1	0	6

bottlenose dolphins preyed upon the catch and this enabled the fish to escape through the holes in the purse-seine nets (see examples in Figure 2).

The attacks made by bottlenose dolphins caused holes in the nets, which were usually smaller than 88 cm in height (mean 15.07 cm [SD 9.01], range = 4–88 cm; n = 6 467 holes) and located on the last section of the net, which forms the 'pocket' containing the catch.

A total of 90 depredated nets were inspected and were found to have been repaired throughout the year in the port of Al Hoceima (Table 2). These interactions resulted in numerous holes at different locations. The number of holes per net varied from 28 to 230, with a mean of 78 holes per net (SD 53.92, range 28–230 holes per net; n = 90 nets). These holes showed significant vertical variation ($p < 0.001$) where the largest mean number of holes was recorded at the pocket level (mean 23.34 cm [SD 14.02], n = 3 666 holes, range 8–69 holes per net) and the smallest mean at the belts (mean 13.08 cm [SD 7.51], n = 1 495 holes, range 7–45 holes per net). The same was true for the variation in perforation size, which was statistically significant ($p < 0.001$).

Repairing these holes had a cost. For large holes the repair took from 24 to 72 h. While large holes were being repaired, the fishermen continued fishing by using their spare net. Repairs required the hiring of 3–11 net menders depending on the size and number of holes.

The mean cost of repairing a tear was estimated to be $179.52 per mending event (SD 206.48, range = $21–$1 000; n = 90 nets). The highest repair cost was recorded in January and the lowest in February (Figure 3), but the monthly variation in repair cost was not statistically significant (Kruskal–Wallis test, $p = 0.41$).

Ship-owners pointed out that these repairs weakened and/or misshaped the nets, and that after multiple repairs the purse-seine net lost its original shape and fishing efficiency.

In terms of reactions to dolphin interactions, the interviews revealed that 30 fishermen out of 40 reported that when the dolphin interactions occurred they retrieved the net and then moved to another fishing area. In contrast, the other 10 fishermen reported that they would stop fishing altogether in anticipation that the dolphins would move out of the fishing area only after a few days.

To reduce the interaction of dolphins on-site, fishermen adopted different methods. In most cases, they would generate noise by hitting the boat or use lights to scare away the dolphins. However, these traditional methods did not show much success. In some cases, fishermen stated that they would adopt aggressive methods to keep dolphins away from their fishing gear. For instance, they might use hard, sharp objects to scare the dolphins, but this could sometimes lead to dolphin mortalities.

In terms of handling procedures used to release any captured dolphins alive, fishermen reported that usually dolphins are released without any checks, but that sometimes dolphins are left on the deck of the boat until the fishing operation is over.

Observations of stranded bottlenose dolphins

Three bottlenose dolphins were found stranded on Morrocco's Mediterranean coast in 2020. Some of these

Figure 2: Examples of holes caused by common bottlenose dolphins in purse-seine nets at Al Hoceima, Morocco, Mediterranean Sea

Table 2: Purse-seine catches of small pelagic fishes by vessels at the port of Al Hoceima, Morocco, western Mediterranean Sea, in 2020, and the number and sizes of holes in the nets inspected

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
No. of nets inspected	8	7	7	8	8	8	8	8	7	7	7	7	90
Catch (kg)													
Mean	895	562.86	505.71	862.50	1 125	445	462.50	62.50	57.14	522.86	520	120	520.44
Min.	120	120	0	200	0	0	0	0	0	120	80	80	0
Max.	2 700	1 800	1 400	3 000	6 000	2 000	1 200	120	400	1 600	2 000	200	6 000
SD	845.81	498.85	407.09	775.33	1 528.77	534.46	367.05	49.38	103.28	456.21	517.46	68.95	649.35
No. of holes													
n	604	519	361	339	553	837	493	432	314	514	602	899	6 467
Mean	75.50	74.14	51.57	42.38	69.13	104.63	61.63	54	44.86	73.43	86	128.4	71.85
Min.	45	30	30	30	40	30	36	28	40	39	32	60	28
Max.	143	130	89	60	120	200	110	140	49	115	205	230	230
SD	45.26	36.77	23.69	9.18	29.99	68.68	25.61	36.76	3.63	33.05	60.45	67.14	46.53
Size of holes (cm)													
Mean	15.61	12.77	25.37	21.67	12.68	17.11	13.08	17.56	12.89	12.14	13.36	11.58	15.07
Min.	7	7	8	4	7	7	7	7	7	7	7	7	4
Max.	45	31	69	88	31	69	31	69	31	31	31	31	88
SD	7.06	5.34	15.85	9.39	5.13	12.38	5.54	12.75	5.35	4.81	5.76	4.27	9.01

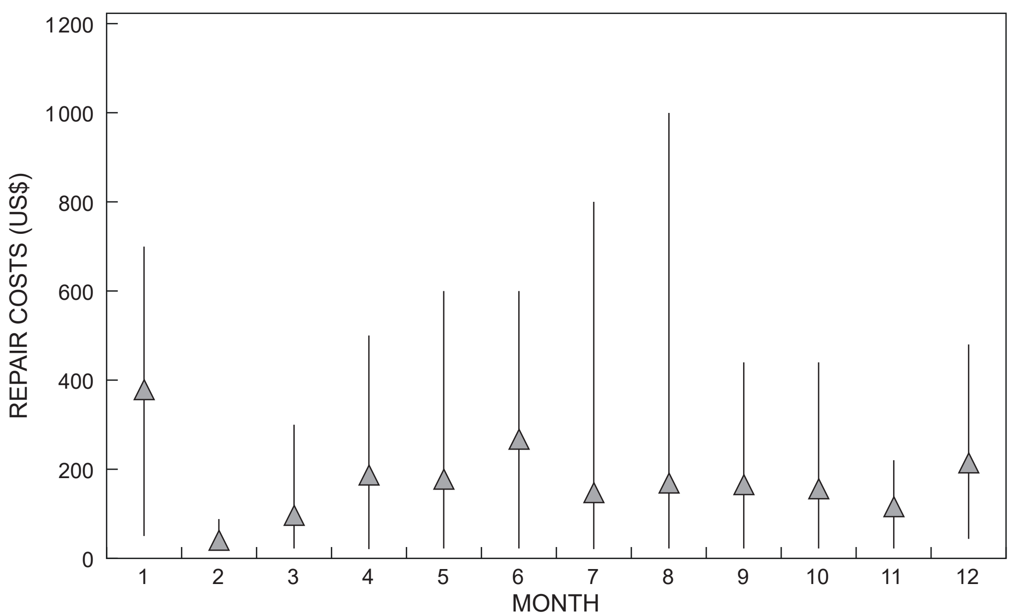

Figure 3: Average costs of seine-net repairs for vessels at the port of Al Hoceima, Morocco, in 2020 (bars represent range)

showed signs of lethal interactions with fisheries. This included signs of entanglement, ropes tied around the tail, and the removal or cutting of the caudal fin or pectoral fins (Figure 4).

Discussion

Interactions between dolphins and fisheries represent a problem requiring urgent attention in the Mediterranean Sea because of economic, social and ethical implications (Marçalo et al. 2015; Revuelta et al. 2018). These interactions have been recorded in several countries around the Mediterranean Sea, including Algeria (Di Natale and Notarbartolo di Sciara 1994), France (Rocklin et al. 2009), Italy (Lauriano et al. 2009; Bearzi et al. 2011), Spain (Gazo et al. 2008) and Tunisia (Aïssi et al. 2011). Despite this, only a few Mediterranean studies contain sufficient information to evaluate both the bycatch and the so-called 'depredation' issues.[1]

The purse-seine fishery for small pelagic fishes is one of the main economic activities in the Al Hoceima region, although in recent years we have witnessed a large decrease in the number of purse-seiners in the region (Keznine et al. 2021). The damage caused by dolphins preying on fishery catches may partly explain the migration

[1] We note that Bearzi and Reeves (2022) caution against use of the term 'depredation' to describe the removal of prey from fishing gear.

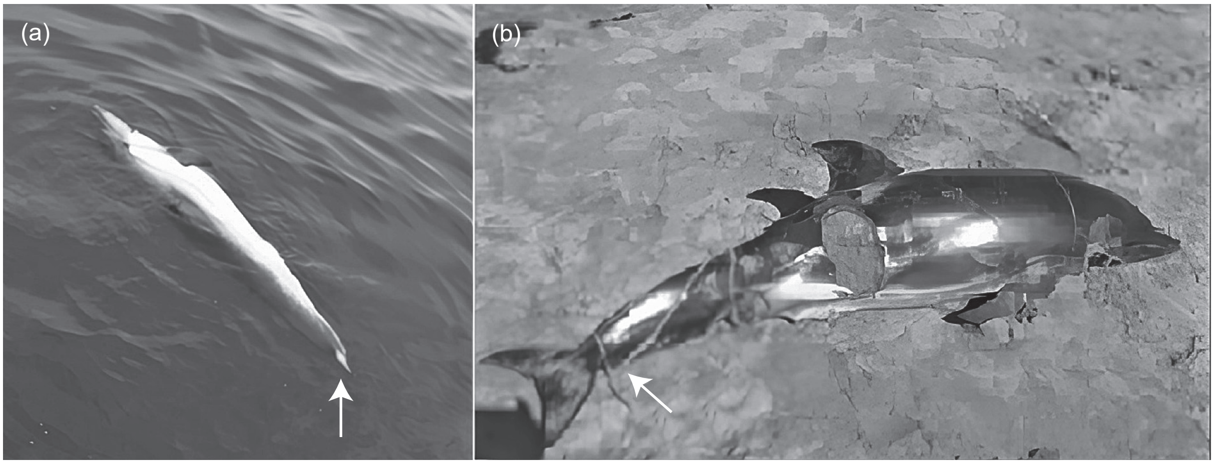

Figure 4: (a) A dead bottlenose dolphin found in Moroccan Mediterranean coastal waters in 2020, with tail fluke amputated, likely by fishermen; (b) a bottlenose dolphin entangled in fishing gear

of sardine fishermen from Nador (a city near Al Hoceima) to the Atlantic Ocean (Zahri et al. 2004). However, fishing boats may have moved to Morocco's Atlantic coast because fishing is more profitable there that in a depleted Mediterranean Sea (Zahri et al. 2004). This results in a loss of access to local food resources and income for the Al Hoceima public (menders excluded) and fishermen. Moroccan fishermen perceive the interaction between fisheries and bottlenose dolphins as a major problem. The investigations carried out in this study revealed that bottlenose dolphin predation on purse-seine catches leads to various types of loss and damage, including partial loss of the catch (owing to disturbance of the fish school and holes in the fishing net), reduced fishing activity (due to net damage and additional trips for net replacement and repairs) and increased fishing costs (e.g. additional fuel and menders). These issues have already been reported by previous studies in the Moroccan Mediterranean (Kaddouri et al. 2022). Similar impacts from this type of interaction by bottlenose dolphins have also been described for other Mediterranean fishing efforts, mostly involving passive gears (Marçalo et al. 2015; Pennino et al. 2015).

The average cost of replacing net panels is less than the cost of repairs. In addition, repairs reduce the life of a net and increase its depreciation. However, the decision to repair or replace damaged fishing gear is influenced by a variety of logistic factors, including the extent of the damage, the availability of the replacement material, and the cost and availability of labour/menders for repairs. Hence, even if replacement of the whole gear could cost less, repairs may still be preferred or necessary under local circumstances (e.g. when replacements are not available in the local market).

This study reveals a high rate of interactions (almost 70% of monitored sets were attacked by dolphins) in the Moroccan Mediterranean Sea. This is much higher than what was reported in a study of this region by the National Institute for Fisheries Research (INRH) in 2004 (Zahri et al. 2004). It is also higher than rates reported for local trammel-net fisheries at Corsica (12%: Rocklin et al. 2009) and Sardinia (10%: Lauriano et al. 2004). The interactions are also a source of incidental mortality for bottlenose dolphins (Northridge and Hofman 1999). The results of this study confirm that Moroccan purse-seiners contribute to bycatch and mortality of dolphin species, as also occurs in fleets from the coasts of southern Spain, southern Italy and Portugal (Marçalo et al. 2015). The observed mortality rate of 0.23 bottlenose dolphins/fishing trip in the Al Hoceima purse-seine fleet is greater than in a similar fishery in Portugal (Marçalo et al. 2015).

Masski and De Stéphanis (2015) studied trends in strandings of bottlenose dolphins along the Mediterranean coast of Morocco. They found an increase in the number of stranded carcasses, with clear signs of bycatch.

Indirect and direct evidence of dolphin–fisheries interaction (both in the form of bycatch and predation upon a fishery catch) calls for more proactive measures if contracting parties of ACCOBAMS and the General Fisheries Commission for the Mediterranean (GFCM) are to ensure cetacean conservation and implementation of sustainable fisheries in the Alboran Sea. Therefore, we stress the need to focus on improved fisheries monitoring and on implementation of bycatch/depredation mitigation measures.

Acoustic devices have been tested to prevent 'depredation' by reducing the number of animals in the proximity of fishing gear or to decrease the number of incidental captures (Buscaino et al. 2021; Moan and Bjorge 2021; Kolipakam et al. 2022; ICES 2023; La Manna et al. 2023). Pingers are low-intensity acoustic signal generators producing medium- to high-frequency sounds and represent a possible solution (La Manna et al. 2023). Trials demonstrated that pingers can be successful in decreasing the bycatch rates of certain cetacean species and mitigate damage from interactions with bottlenose dolphins (Gönener and Özdemir 2012; Bruno et al. 2021; La Manna et al. 2023). However, these devices do not always work to prevent so-called depredation by bottlenose dolphins (e.g. McPherson et al. 2004). They may be efficient for limited periods in mitigating damage caused by the dolphins' predatory behaviour as well as the frequency of interactions with fishing vessels, but with time their efficiency decreases owing to habituation (Bruno et al. 2021). Therefore, the deployment of pingers needs to be evaluated on a case-by-case basis as they may work for some fisheries and not others.

In Morocco, acoustic devices have been tested by the INRH to reduce bottlenose dolphin interactions with seine nets, but with unsatisfactory results (Zahri et al. 2004). Although the initial results were acceptable, there was a considerable drop in their effectiveness with time (Zahri et al. 2004). Hence, newer acoustic deterrent devices for dolphins might prove more efficient.

Modifying fishing gear is also an alternative way to keep dolphins away from the catches in nets. Recently, the INRH tested a new seine prototype to reduce these interactions. This is a new fishing net made of pure polyamide nylon with a density of 1.14 g cm^{-3}, with perfect elasticity and very good resistance, which makes it more resistant to attacks by bottlenose dolphins (ACCOBAMS 2022). Other possible solutions relate to fishing practices: for example, adjusting the set duration, increasing hauling speed, or moving away from areas with bottlenose dolphins. These fishing tactics have all been found to be effective to some extent (i.e. their level of efficacy as mitigation methods is considered 'medium').

The provision of compensation is another way of mitigating economic losses associated with dolphin interactions and improving the relationship between fishermen and dolphins. In various countries, the government refunds farmers and shepherds the costs of damage caused by large predators (Schwerdtner and Gruber 2007; Watve et al. 2016). In Morocco, the Ministry of Agriculture has compensated farmers for damage caused by the sessile parasitic insect *Dactylopius coccus*. This principle should also be applied to maritime and fisheries policies. In particular, the Moroccan authorities should consider ways to economically assess and compensate seiners for damage caused by bottlenose dolphins. As regards all the management strategies suggested above, managers, scientists and political decision-makers should focus on establishing close collaboration with fishermen, providing guidance and training on managing conflict with dolphins and conserving these protected mammals.

We call for further monitoring and research efforts to better understand all aspects of this phenomenon, including dolphin behaviour and operational characteristics of the fishery, to mitigate the impacts on both sides. We also recommend organising awareness campaigns for fishermen and skippers on techniques for handling bottlenose dolphins caught accidentally to ensure that the animals are released unharmed from the fishing net.

Conclusions

This study presents evidence gathered in 2020 on the impact of bottlenose dolphins on the Al-Hoceima purse-seine fishery targeting small pelagic fishes (e.g. Najih et al. 2011), which results in a significant financial burden for fishermen. It also provides information on the increased risk of injury and mortality for bottlenose dolphins interacting with this fishery. The interaction between bottlenose dolphins and purse-seiners is increasingly a subject of interest for scientists and fishery management organisations (e.g. the GFCM depredation project to mitigate dolphin depredation in Mediterranean fisheries, with a focus on strengthening cetacean conservation and sustainable fisheries). The Moroccan fishermen who fish along the Mediterranean coast are frustrated by the negative impacts that dolphin behaviour has on their industry. Further research on bottlenose dolphin behaviour and mitigation strategies (including deployment of acoustic devices and alternative fishing techniques), and implementation of a compensation scheme, are all necessary both to devise effective conservation strategies and to improve the ecological and economic sustainability of the purse-seine fishery.

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