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Impact of the Bottlenose Dolphins (*Tursiops truncatus*) Depredation on Purse-Seine Fishery in the Region of M'diq (Northwestern Morocco)

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ABSTRACT

Interactions between bottlenose dolphins (*Tursiops truncatus*) and fishing gear have negative impacts on both dolphins and fisheries. Therefore, the damage and economic loss caused to the purse seine fishery were evaluated on a spatio-temporal scale, and the catch composition was addressed. Face-to-face interviews were conducted with the fishers, and observations aboard the boat were recorded between August 2018 and July 2019 in the M'diq region, northwestern Morocco. Throughout the study period, the frequency of fishing trips attacked by bottlenose dolphins was 44.75% (n=324), and the catch damage was 33%. In addition, depredated fishing operations were significantly lower in CPUE than unattacked ones. The total mending cost was 35,533.3$, with a difference between months and seasons. Bottlenose dolphins (*Tursiops truncatus*) attacked 32.2% of the fishing operations. However, this frequency of fishing operations depredated by depth was not significant. The current study proved that these interactions inflict substantial economic losses on the fishers of this region.

INTRODUCTION

The bottlenose dolphin (*Tursiops truncatus*) belongs to the family Delphinidae, which frequently interacts with inshore fisheries **(Reeves *et al*., 2001; Bearzi, 2002; Gonzalvo *et al*., 2008)**. It can be found within temperate to tropical marine oceans and in the semi-closed sea worldwide. In the Mediterranean Sea, bottlenose dolphins are heterogeneously distributed along the entire coastline from the Strait of Gibraltar to the Black Sea **(Reeves & Notarbartolo di Sciara, 2006)**.

A decline in fish stocks observed in the Mediterranean **(FAO, 2011)** obliges dolphins to search for better food sources (**Reeves *et al*., 2001**), and thus to learn new strategies for exploiting these alternative resources. For this reason, dolphins use fishing nets as an easily exploitable additional food source **(Reeves *et al*., 2001; Birkun, 2002)**. The use of fisheries increaeses the availability of abundant quantities of fish, which consequently reduces the energy exerted by dolphins searching for preys **(Fertl & Leatherwood 1997)**.

Historically, bottlenose dolphins in the Mediterranean have frequently interacted with fisheries **(Bearzi, 2002)**. Several studies have revealed that this species was in direct trophic competition with fisheries to exploit the same fishery resource **(Lauriano *et al*., 2004; Zahri *et al*., 2004; Gazo *et al*., 2008; Benmessaoud *et al*., 2011)**. This competition was due to their opportunistic diet **(Blanco *et al*., 2001)** and inshore distribution **(Gannier, 2005)**. Many studies in several countries in the Mediterranean have reported negative interactions between cetaceans and fisheries **(Bearzi, 2002; Díaz López, 2006; Lauriano *et al*., 2004)**. These interactions, which involve the depredation of captured fish, produce adverse effects for the family Delphinidae. Mainly through their bycatch in fishing nets and injury or death **(López *et al*., 2003; Kock *et al*., 2006; Garrison, 2007; Kiszka *et al*., 2009)**, with low results catch for the fishers **(Lauriano *et al*., 2004; Waples *et al*., 2013; Marçalo *et al*., 2015)**. The depredation also caused substantial damage in the form of rips in fishing nets, leading to increased economic losses (e.g., mending costs of damaged nets), as well as a reduction in total catches due to the escape of fish through these rips **(Bearzi, 2002; Lauriano *et al*., 2004; Zahri *et al*., 2004; Díaz López, 2006; Brotons *et al*. 2008; Bearzi et *al*., 2010)**.

In Morocco, the first observations of interactions between bottlenose dolphins (*Tursiops truncatus*) and the purse-seine fishery on the Mediterranean coasts date to the 1980s. However, since the beginning of the twenty-first century, this occurrence has become a real problem for the local fishers. The fishermen have frequently reported concern about the negative impacts of bottlenose dolphins on fishing operations (e.g., reduced catches, damaging fishing nets, and their mending, generating additional costs for the fishers), suggesting that conflicts with this species may be significant in this fishery. Furthermore, many skippers have tested the famous acoustic deterrent devices for bottlenose dolphins without any effective results.

In this context, the National Institute of Fisheries Research (INRH) has conducted several studies on the mitigation of interactions between the bottlenose dolphins and the purse-seine fishery **(unpublished Data)** within the framework of a study program to provide a better understanding of this phenomenon in the Moroccan Mediterranean coasts. To assess the damage caused by these interactions on the fishers' livelihoods, the present work used an approach that combined both face-to-face interviews with fishers and boarded the boat. In the present study, we aimed to spatiotemporally quantify the interactions between the bottlenose dolphins and purse-seine fishery in the M'diq region (north-western off the Mediterranean coast of Morocco).

MATERIALS AND METHODS

1. Study area

The interactions between the bottlenose dolphin and purse seine fishery can be found throughout the Moroccan Mediterranean Sea, from the frontiers with Algeria to Ceuta. The present study took place in the port of M'diq (northwestern Mediterranean coast of Morocco) between August 2018 and July 2019 (**Fig. 1**). The choice of the port of M'diq based on:

1) Previous monitoring reports of bottlenose dolphin purse-seine fishery interactions conducted by INRH (unpublished data);

2) The insufficient number of observers to survey the entire Moroccan Mediterranean;

3) in addition, the port of M'diq was the most representative in terms of purse seine fishing effort on the northwestern Mediterranean of Morocco **(INRH/DP, 2017)**.

2. Survey and data collection

To evaluate the interactions between the bottlenose dolphins and the purse seine fishery during the study period, we conducted 73 fishing trips onboard boats and 636 surveys in the port the day after the fishing trip with the skippers. The duration of each fishing trip was one day. In this study, the same data were collected by an observer on board and in the port using survey sheets containing the following information (see appendix): date of the trip, fishing area, time of the depredation event, total catch by species, depth, duration of the fishing operation, presence or absence of signs of depredation, the total number of rips and their size classes and the number of menders expected. In this case, evidence of depredation means the direct observation of bottlenose dolphins in the vicinity of the net and the presence of tears caused by this species **(Lauriano *et al.*, 2004; Brotons e *et al.*, 2008)**.

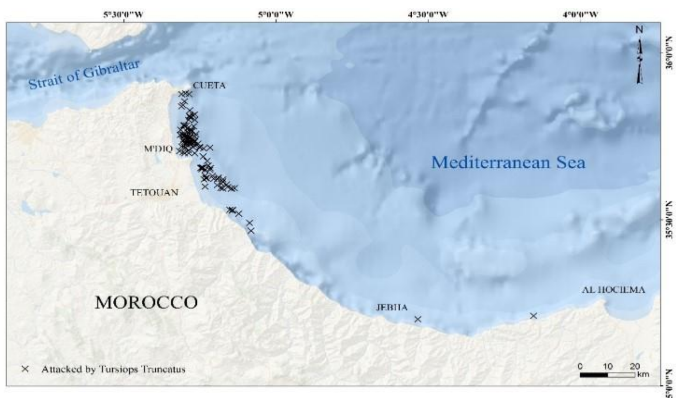


Fig. (1). Map of the study area including the spots of depredation event by bottlenose dolphins.

3. Data Analysis

We requested the skippers for the Global Positioning System (GPS) coordinated for each attack to map the spatial distribution of the depredation events. The spots of depredation event by bottlenose dolphins were represented on the map using ArcGIS Desktop version 10.8. To verify whether the frequency of depredation events was dependent on the timing of fishing activity or not, we used the Kruskal-Wallis test (non-parametric test) because of the assumptions of normality (Shapiro-Wilk test) and homoscedasticity (test of equality of variances) were not respected. All statistical analyses were conducted in the Statistical Package for the Social Sciences (SPSS) software version 24.0.

The Monthly depredation event frequency of these interactions was determined using the method proposed by **Zahri *et al.* (2004)**: Depredation event frequency = $[(FT_{att\ i}) / FT_t]*100$. Where, FT att i: Number of fishing trips or fishing operations depredated during the month (i) / FT t: Total number of fishing trips or fishing operations made.

To assess the net damage depredated by bottlenose dolphins, we requested the skippers to estimate the total number of rips in the net. We then counted sampling tears at the port after each fishing trip and on board the boat after each fishing operation. We classified into three size classes: Small <20 cm; 20<Medium<40 cm; Large >40 cm according to **Brotons *et al*. (2008)**. We calculated the operation attacked frequency by month and fishing area. To determine if the depredation frequency depends on depth, we analyzed the difference in the frequency of fishing operations depredated by fishing area using the Mann–Whitney non-parametric test. The fishing areas were subdivided into three zones according to sea depth: Z1 (depth <50m); Z2 (50<depth<100m); Z3 (depth>100m). The mending costs of the damaged nets were calculated based on the number of menders employed to fix these nets. Whereas, one mender employed for one day had cost 22.2$.

For studying the temporal distribution of depredation event frequency, we categorized them by months and seasons. We determined the seasons as the following: winter (December to February), spring (March to May), summer (June to August), and autumn (September to November).

Since there was considerable variation in catch data between boats, we calculated the catch per unit effort (CPUE, in kg/fishing operation) for each species as the total catch (kg) in a fishing operation (absence or presence of depredation event). Then, we calculated the species occurrence for each fishing operation depredated as the following:

$$\textbf{Species occurrence} = \textbf{CPUE}_{\textbf{species}} / \textbf{CPUE}_{\textbf{total catch}}$$

For assessing the impact of dolphin depredation events on CPUE and catch composition, we utilized the Mann-Whitney test (non-parametric) to analyze this impact because the data did not fulfill the conditions for normality (Shapiro-Wilk normality test or homoscedasticity, p-value < 0.05 for both).

RESULTS

1. Purse seine landings in the port of M'diq

During the study period, the purse seine fishery production in the port of M'diq was approximately 741.033 tons. Purse seine landings during the entire period indicated that *Sardina pilchardus* was dominating (54.4%), followed by *Trachurus spp*. (21.9%). The other small pelagic species as *Scomber colias*, *Sardinella aurita*, and *Boops boops*, constituted 23.4% of the catch (**Fig. 2**).

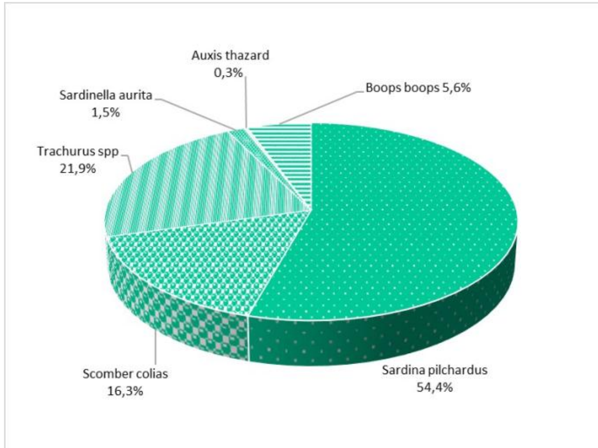


Fig. (2). Species composition catches during the study period.

2. Depredation

A total of 1,270 fishing operations were recorded throughout the study period, whereas 409 fishing operations were depredated by bottlenose dolphins, corresponding to a depredation frequency of 32.2%. This depredation frequency varied between months, with an average of 33%, a maximum in April (75%) and a minimum in March (22%) (**Fig. 3**). In some cases, the bottlenose dolphin attacked all fishing operations during the same fishing trip, with an average of 2 to 3 fishing operations.

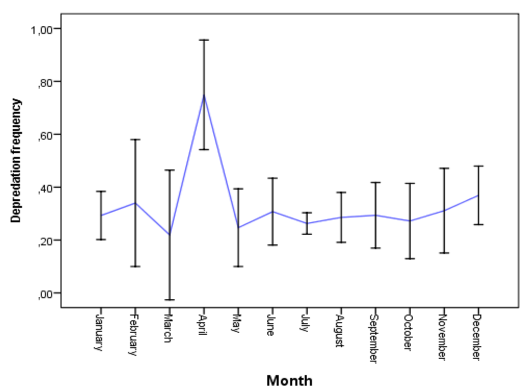


Fig. (3). Monthly depredation frequency of fishing operations. Error bars indicate standard deviations.

The next day of the depredation event, the skippers called the menders to repair damaged nets, thus requiring additional charges. In cases the rips are significant during the fishing trip, fishers should repair their nets on board the boat with a white thread to facilitate the identification of these rips by the menders at the port **(Fig. 4)**. However, that was not the rule every time. In addition, some skippers are obliged to work with the damaged net that has not been correctly repaired because of the high number of boats attacked on the previous fishing trip and the insufficient number of menders in the port. These factors involve the reduction of catches.

Fig. (4). Fishers mend their nets on board the boat with a white thread.

In addition, between 8 PM and midnight, 47% of these fishing operations were recorded. This peak goes down to 9% between 2 and 4 AM. There was a nocturnal effect with two depredation peaks between 8 PM and midnight (24% and 23%, respectively), and a diurnal effect (24%) between 4 and 6 AM (**Fig. 5**). However, the minimum of these depredation events recorded at the fishing trip's end (3%). The results revealed that the number of attacked fishing operations by bottlenose dolphins changes depending on the time of the depredation event (Kruskal–Wallis test, p-value=0.0004).

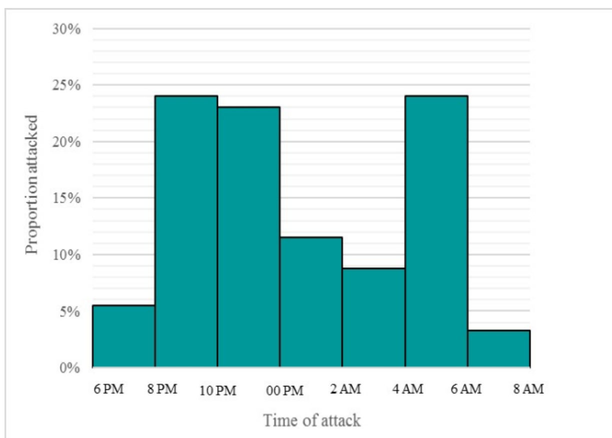


Fig. (5). Fishing operations depredated proportion by fishing time.

3. Holes and rips assessment

The Bottlenose dolphins damaged 44.75% (324 nets) of nets throughout the research period. This species made different holes and rips, with a holes/tears number reported by fishers ranging from 1 to 400 per depredated fishing trip. We measured a sample of 2621 holes/tears at the mending of the nets. Holes and tears measuring more than 40 cm accounted for 63.5% (n= 1664), 19.5% for sizes between 20 and 40 cm and 17% for sizes less than 20 cm (**Fig. 6**).

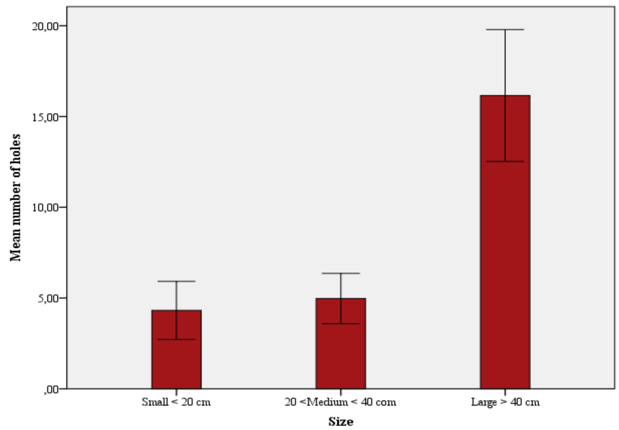


Fig. (6). Average number of holes/tears / different sizes (Error bars represent standard error of the means).

4. Damage and mending costs assessment

A total of 409 fishing operations depredated; a high proportion of these operations were reported in zone 1 (69%; n=284), while 25% (n=102) and 6% (n=23) of operations depredated in zones 1 and 2, respectively. Although, with this variation in the number of operations attacked, the difference in the frequency of attacks between zones was insignificant (Kruskal-Wallis test, p-value = 0.082; **Fig. 7**).

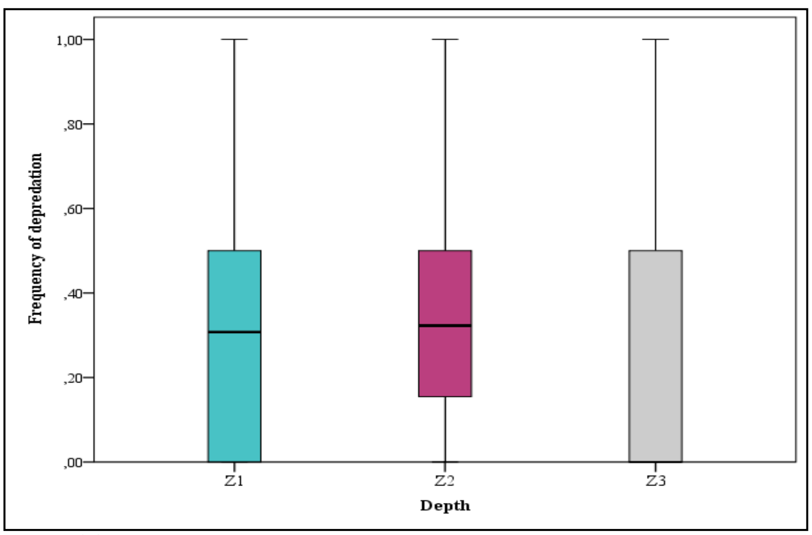


Fig. (7). Frequency of fishing operations attacked by depth (Z1< 50 m, 50 ≤ Z2 ≤ 100 m and Z3> 100 m).

During the study period, the total mending cost of the damaged nets was 35,533.3$, corresponding to 1599 menders employed. The mending costs varied between months, with a maximum in August (7,511.1$) and a minimum in October (888.9 $). In the same period, the average repair cost per boat was 247.14$, with a maximum in June (444.4 $) and a minimum in October (88.9$) (**Fig. 8**).

5. Changes in the catch and species due to depredation

In the fishing operations depredated by bottlenose dolphins (n=409), the most frequent species depredated were *Sardina pilchardus* (64.8% of the CPUE attacked), *Trachurus spp.* (15.4%) and *Scomber colias* (11.5%), and in a lower proportion, *Boops boops* (5.7%), *Sardinella aurita* (1.4%), and *Auxis thazard (*1.1%; **Fig. 9**).

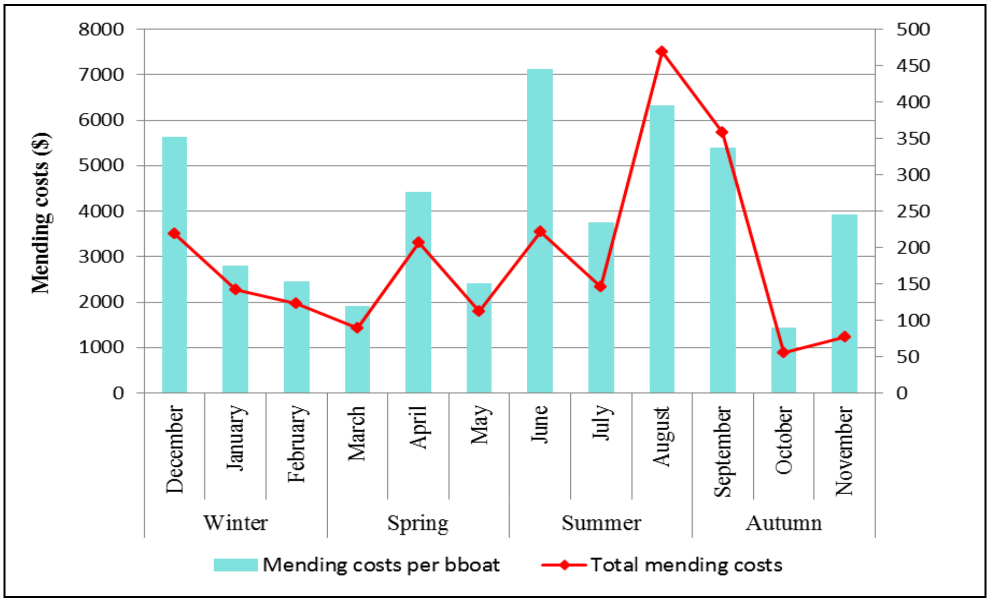


Fig. (8). Variation of mending costs by month and per boat.

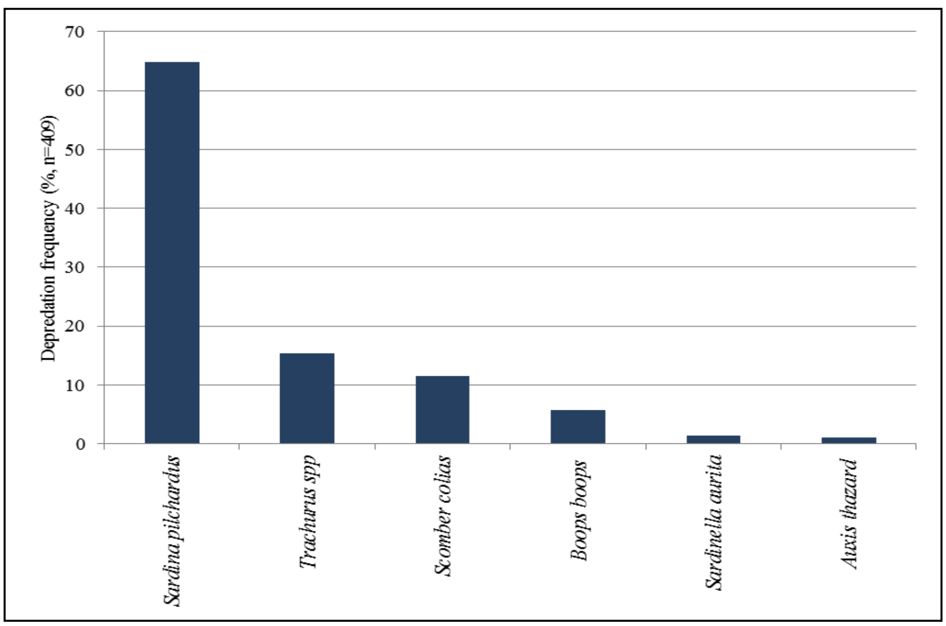
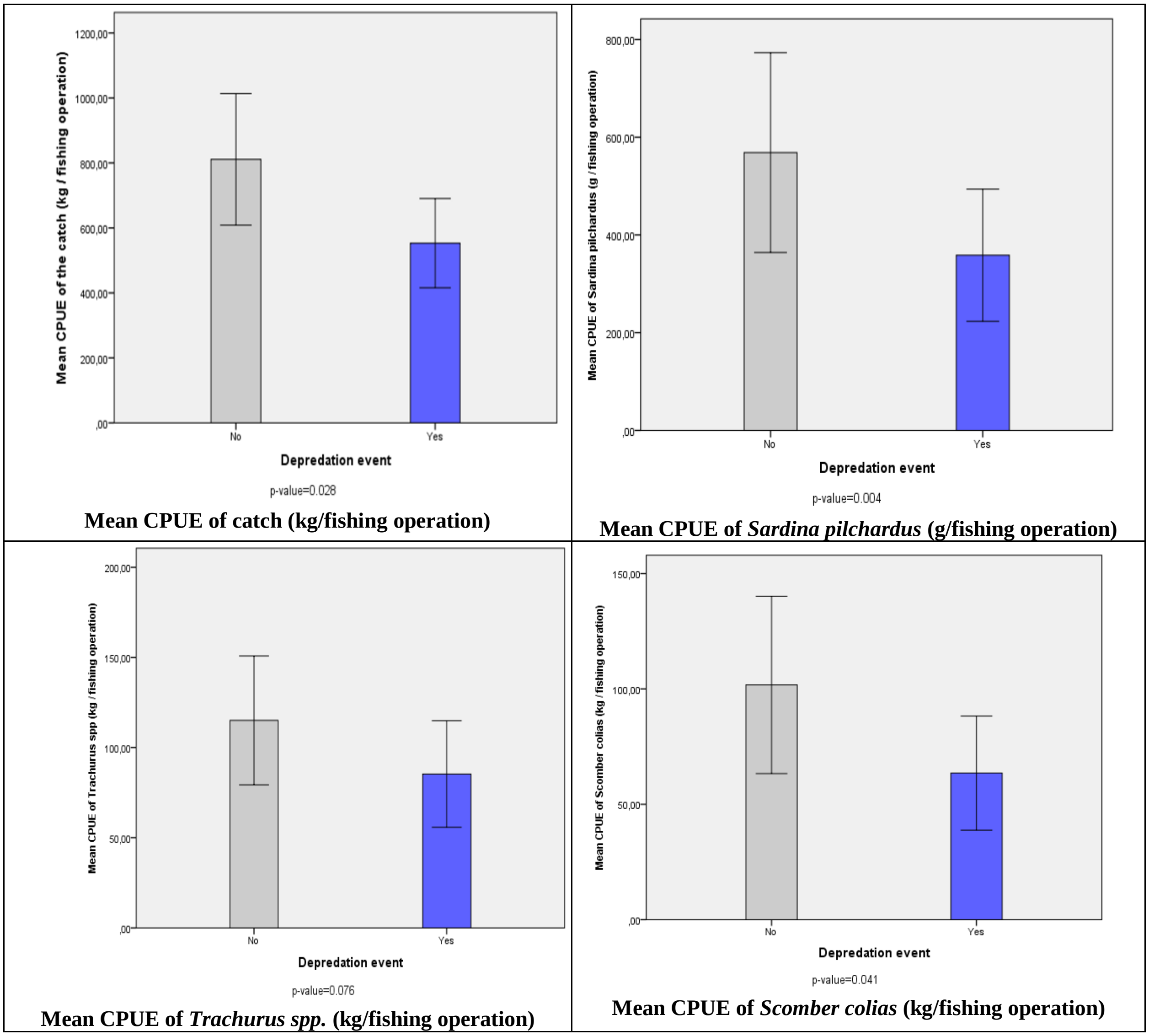


Fig. (9). Species depredated by the common bottlenose dolphin from purse-seine nets.

CPUE of the total catch differed significantly with and without the depredation event (CPUE, mean with = 553.1±68.7 kg/operation, mean without = 810.9±101.2

kg/operation, Mann-Whitney test, p-value = 0.028), while this CPUE was significantly lower in the presence of depredation events than in the absence. Two species that showed significant differences in CPUE values in the presence and absence of depredation were Sardina pilchardus and Scomber colias (Mann-Whitney test, p-value < 0.05). Its mean catch per fishing operation showed a significant reduction in the depredation presence. The other species showed no significant difference in CPUE between the absence and presence of depredation events (Mann-Whitney test, p-value > 0.05; **Fig. 10**).

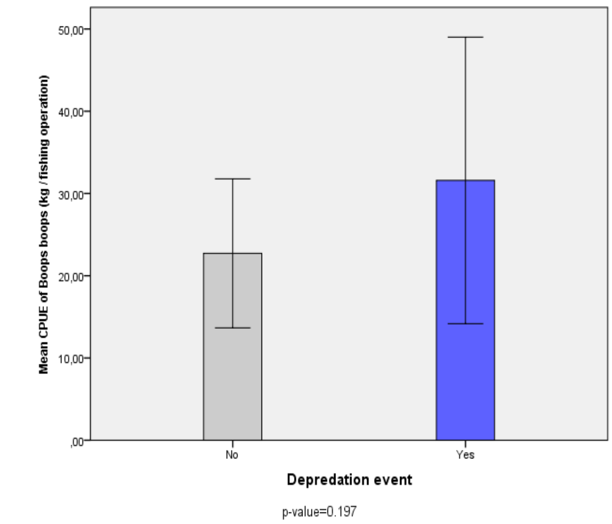


Mean CPUE of catch (kg/fishing operation)

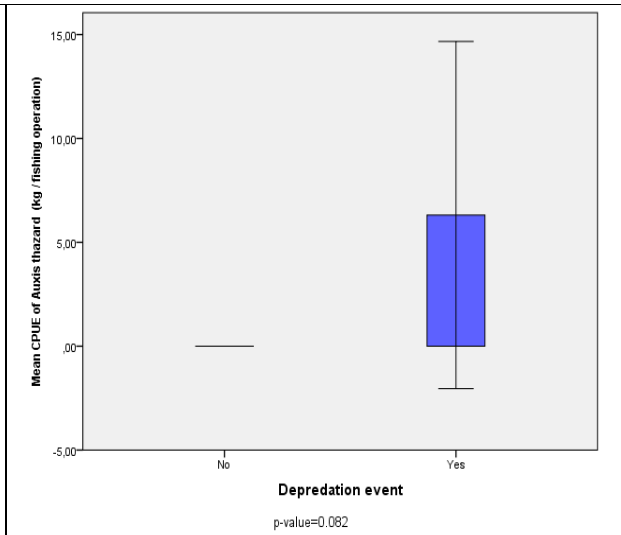
Mean CPUE of *Sardina pilchardus* (g/fishing operation)

Mean CPUE of *Trachurus spp.* (kg/fishing operation)

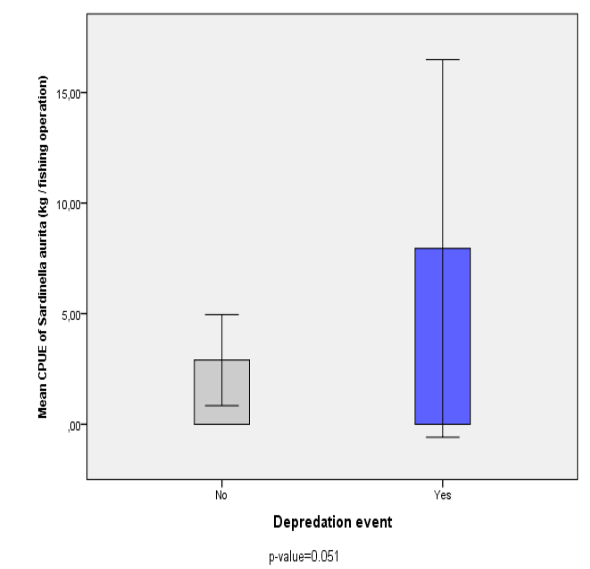
Mean CPUE of *Scomber colias* (kg/fishing operation)



Mean CPUE of *Boops poops* (kg/fishing operation



Mean CPUE of *Auxis thazard* (kg/fishing operation



Mean CPUE of *Sardinella aurita* (kg/fishing operation)

Fig. (10). Species mean CPUE in the absence (grey bars) and presence (blue bars) of bottlenose dolphin depredation. (The value below each plot is a p-value of the Mann-Whitney test. Error bars represent the standard error).

DISCUSSION

During the current study, the interactions between bottlenose dolphins and the purse seine fishery were frequent enough to pose a problem for fishers in the M'diq region because the depredation frequency was 44.75% (n=324 fishing trips) of monitored fishing trips throughout the study period. Nevertheless, although the interaction frequency was relatively high, no by-catch in fishing nets was recorded. These interactions may be due to a decline in fish stocks or an increase in bottlenose dolphin abundance **(Whitehead**

***et al.*, 2004)**. Moreover, all fishermen have reported that bottlenose dolphin abundance has increased from previous years, and there is a sedentary population in the area.

This species occurred and has often interacted with fishing nets throughout the year in the study area. This result aligns with the results found by **Bearzi *et al.* (2011)** and **Waples *et al.* (2013)**. Currently, no study exists on the population of bottlenose dolphins in the Moroccan Mediterranean (e.g. movement, structure and behavior). Therefore, we strongly recommend that researchers investigate the bottlenose dolphin population in this area to understand the possible reasons for this depredation event frequency pattern and design mitigation measures.

Our results showed quantitative differences in catch composition in the fishing operations depredated but not the species composition. An increase or decrease in the cpue of nets without changes in the catch composition may be related to the variability in fish availability in the fishing area. However, there were found from other studies that quantitative and qualitative differences in catch composition occurred **(Rocklin *et al.*, 2009; Pennino *et al.*, 2015)**. In the presence of depredation events, the nets depredated had significantly lower CPUE. This finding is similar to previous studies, which showed a significant reduction in the catch when bottlenose dolphins attacked the gillnets **(Lauriano *et al.*, 2004; Brotons *et al.*, 2008; Gazo *et al.*, 2008**; **Waples *et al.*, 2013; Pennino *et al.*, 2015)**. Due to their presence at the fishing operation, bottlenose dolphins disperse the fish near the fishing nets or eat those from the fishing nets, which lead to a significant reduction in the total catch **(Lauriano *et al.*, 2004; Gazo *et al.*, 2008; Pennino *et al.*, 2015)**.

Furthermore, the skippers must cancel fishing operations or change the fishing area when bottlenose dolphins are abundant in the fishing area. As a result, additional charges will appear. For example, avoiding depredation can lead to lost time, increased costs (such as fuel waste) and direct economic losses for the fishermen **(Zahri *et al.*, 2004; Gönener & Özdemir, 2012; Goetz *et al.*, 2014; Pennino *et al.*, 2015)**. On the other side, rips and tears caused to fishing nets by bottlenose dolphins **(Brotons *et al.*, 2008; Gazo *et al.*, 2008)** have reduced the efficiency and the fishing nets' capturability **(Bearzi, 2002; Gazo *et al.*, 2008; Goetz *et al.* 2014)**, and also substantial mending costs for the fishers **(Gönener & Özdemir, 2012)**.

The Spatio-temporal overlap between bottlenose dolphins and fishing activity during the exploitation of the same resource determines the probability of these interactions **(Brotons *et al.*, 2008; Matthiopoulos *et al.*, 2008)**. In the present study, the spatial assessment of these interactions showed that area 2 (50<depth<100m) where the highest probability of interaction with bottlenose dolphins in terms of damage and retrieval costs. Moreover, we noticed a clear relationship between the dolphin interaction probability and depth. This finding is similar to pinioning results of studies conducted in the other regions **(Cañadas *et al.*, 2002; Gonzalvo *et al.*, 2008)**, which have shown that depth is a determining factor in the distribution of dolphins. Considering the temporal scale, when most boats were in fishing activity, two peaks of depredation (nocturnal and diurnal) were recorded.

CONCLUSION

In this paper, we proved that these interactions result in substantial economic losses for the fishers and a high frequency of depredation in M'diq study area. Moreover, bottlenose dolphins were present and often interacted with purse seiners during the study period (August 2018 to July 2019). Consequently, the M'diq area can be considered high-risk for interactions between the bottlenose dolphins and purse seine fishery.

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