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Evaluating dolphin damage in trammel net fisheries in the Valencia region: Insights to improve management

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ABSTRACT

Interactions between dolphins and trammel net fisheries have been described in the Mediterranean Sea as having negative consequences for both cetaceans and fishers. There is a need for studies that evaluate the economic costs caused by dolphins feeding from entangled fishes in trammel nets since most cetacean species involved in these interactions are endangered. This study aims to evaluate the economic impact of the interaction between dolphins and trammel nets fisheries in the coastal waters of the Valencian region in the western Mediterranean Sea. We conducted at-port visual inspections of nets from April 2018 to March 2019, which included 1,849 fishing operations with trammel nets, and we recorded damages to the net and catch and the value of the fishery. Thirty-two interactions were detected during the year of the study. The only observed species interacting was the common bottlenose dolphin. No bycatch of dolphins was reported. The interactions have been impacted seasonally and most of them took place in February and March. There were no significant differences in catch when comparing sets with and without depredation or damage in nets due to depredation by dolphins. Also on average, no differences were found in the value of the catch when comparing sets with or without damage caused by dolphins. The main cost to the fisher was the cost of repairing the nets. The estimated financial loss per vessel and year was €556 (95%CI: €303–€809). This represents less than 1% of the total yearly income of each vessel in our area. We suggest implementing tools to economically compensate artisanal vessels for any damage caused by dolphins in order to avoid increasing the hostile feeling of fishers towards dolphins and to apply conservation measures to protect this cetacean species.

1. Introduction

Interactions between cetaceans and fisheries usually have negative consequences for fishers, which may create hostility in fishers towards cetaceans and directly or indirectly hinder conservation efforts (DeMaster et al., 2001; Milani et al., 2019; Read, 2008; Reeves et al., 2003). It is important to understand the nature of marine mammal interactions with fishing activities (DeMaster et al., 2001) and to find solutions in order to provide threatened marine mammal species with adequate protection and to support fishing economies (Carpentieri et al., 2021).

The main problem addressed in this paper is the depredation by dolphins of fishes that are entangled in the fishing nets of fishers. This problem has been observed in many countries. Snape et al. (2018) presented a review about Mediterranean and Black Sea locations where these types of interactions occurred (see also Bengil et al., 2020; Pardalou et al., 2022; Pardalou and Tsikliras, 2020; Revuelta et al., 2018). Although the occurrence of these interactions is documented, the economic loss to artisanal fisheries, which may be relatively high and impair fishing viability, is not well documented. When the economic costs of these interactions were evaluated, large differences were found ranging from €155 to €20,000 per vessel annually (Alexandre et al., 2022; Bearzi et al., 2011; Brotons et al., 2008a,b; Gonzalvo et al., 2015; Revuelta et al., 2018; Snape et al., 2018). The cost usually is attributed to catch losses and/or damage to nets. Although some studies were based on observed data (e.g., Brotons et al., 2008a; Snape et al., 2018), in most studies, economic damage estimations were based on interviewing fishers (e.g. Alexandre et al., 2022; Revuelta et al., 2018). Consequently, studies based

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on direct observations are needed to estimate damages to nets and catch loss.

The close interaction between cetaceans and trammel nets in the Mediterranean Sea might lead to the accidental death of marine mammals (Brotons et al., 2008b; Gomercic et al., 2009; Milani et al., 2019; Revuelta et al., 2018), which can have serious implications for their conservation (Bearzi et al., 2011; Brotons et al., 2008a; Lopez, 2006). The species involved in this interaction in the western Mediterranean Sea is generally the bottlenose dolphin (*Tursiops truncatus*), whose Mediterranean subpopulation is now assessed as "*Least Concern*" in the IUCN Red List of Threatened Species (Natoli et al., 2021).

Fishing is an important activity in the Valencian region of Spain. The artisanal fleet in this region is comprised of 301 vessels that implement a wide variety of *métiers*, using gear types such as trammel nets, pots, basket traps, and gill nets, depending on the time of year. Nowadays, artisanal fishing represents nearly 54% of the total fishing fleet (total fleet = 557) in the Valencian region (Spanish Government, 2019). The Valencian region is a key area for bottlenose dolphins in the western Mediterranean Sea (Gomez de Segura et al., 2006; Raga and Pantoja, 2004; Revuelta et al., 2018). Interactions between the artisanal fleet and the bottlenose dolphins in the area have been reported for this area (Revuelta et al., 2018). Nonetheless, there are no studies that gather direct data during fishing operations to obtain accurate estimations of dolphin-fisheries interactions and to quantify fishing gear damage. This information is needed to provide management guidelines in order to reduce the potential conflicts among fisheries that might hamper conservation efforts.

The aim of this study was to assess the interaction between cetaceans and trammel net fisheries in the coastal waters of the Valencia's region. We focused our study on the southern part of the province of Valencia and the northern part of the province of Alicante, an area that includes one of the highest densities of bottlenose dolphin in the region (Revuelta et al., 2018). Economic loss due to interactions was evaluated using direct observation.

2. Methods

2.1. Study area

The study area is located in the Valencian Gulf (SE Spain) and covers an area of 347 km^2 between the towns of Cullera and Denia (Fig. 1). At the time, there were 62 artisanal vessels operating in the area (Valencian Regional Government, 2020) and 26 at the port of Gandia (provided by the Fishers' Guild), where the study was conducted. The maximum depth in the study area was 40 m; 82% of the area is mud beds and only 15% is coralligenous reefs (Fig. 1).

2.2. Trammel nets

The vessels used for artisanal fishing measure between 7 and 15 m in length overall. Although different *métiers* (Ulrich et al., 2001) can be used (using gear types such as trammel nets, gill nets, pots, or long-lines), it is prohibited to use more than one gear type at the same time. All of the vessels herein were considered during the period when they were using the same *métier* which includes trammel nets, cuttlefish as target species and at depths ranging from 5 to 40 m.

In this study, the trammel nets were made of white nylon monofilament. The inner-panel mesh size was 30 mm and the outer-panel mesh size was 180 mm (Fig. 2). Each vessel used between 80 and 100 net panels in each setting operation. The dimensions of each net panel were 1.2 m in height and 45 m in length (Fig. 2). On average, each fishing set involved around

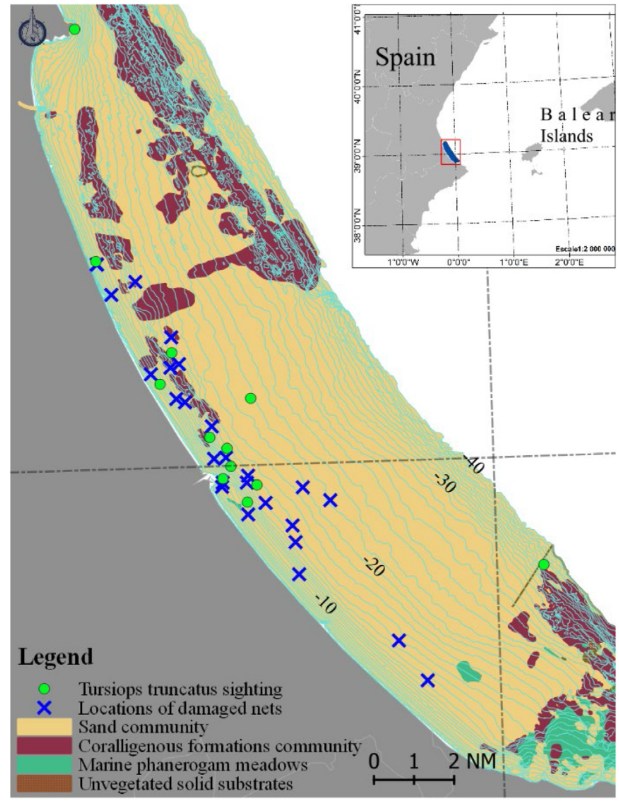

Fig. 1. Location of the study area. Artisanal fishing area. Marine communities present in the artisanal fishing area. Location of fishing operations with damaged nets (x) and dolphin sightings (o).

4,000 m of trammel net. The cost of each panel was €22.5. Therefore, the cost of the vessel gear ranged from €1,800 to €2,250.

The trammel nets were set around mid-day until about 6 or 7 am in the next morning (depending on the sunrise time). The setting duration lasted around 18–19 h. Most of the sets were done in areas with mud beds (Fig. 1).

This *métier* is relatively indiscriminate. In the study area, it is used mainly to target cuttlefish (*Sepia officinalis*), although many other species are also found in the catches. These include: common pandora (*Pagellus erytrinus*), gilthead seabream (*Sparus aurata*), white seabream (*Diplodus sargus*), striped seabream (*Lithognathus mormyrus*), Klein's sole (*Synapturichthys kleinii*), hake (*Merluccius merluccius smiridus*), sole (*Solea solea*), and large-scaled scorpionfish (*Scorpaena scrofa*).

2.3. Damage to trammel nets caused by dolphins

In order to study the damage caused by dolphins to trammel nets, we made direct visual inspections at-port of nets from April 2018 to March 2019. Fourteen different vessels were open to participate in this study, 1,849 fishing operations were performed during the study period. The statistical values such as average, standard deviation, maximum and minimum have been calculated for the fishing days per vessel, number of interactions suffered by vessel and cost in euros per vessel for the 14 participating vessels. These statistical values have also been calculated for the 32 interactions recorded during the study period. Whenever any fishers reported damages, the nets were inspected by observers. We recorded the number of panels of nets with holes, the number and diameter of the holes, their vertical location, the presence of partially depredated fish, and whether dolphins

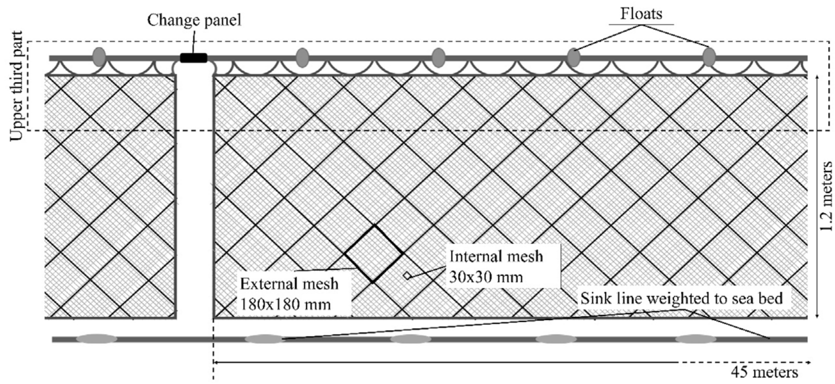

Fig. 2. Schematic representation of the trammel nets used in the fishing area.

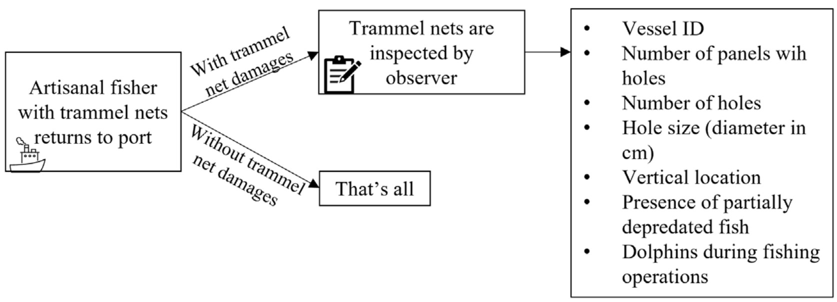

Fig. 3. Scheme of the methodology followed to obtain the data by direct observations.

Fig. 4. Photo of a hole in a trammel net with partially depredated fish.

were observed during fishing operations (Fig. 3). The observers supervised 1,246 panels from the 14 artisanal fishing vessels. If the holes were <20 cm and on the upper or lower third parts of the net (view Fig. 2), they were not considered. This is because in the study area there are other species that can make holes in the nets too. The small holes in the lower part of the net can be caused by depredation from octopus (*Octopus vulgaris*), moray eel (*Muraena helena*), other small fish (Brotons et al., 2008a), or blue crab (*Callinectes sapidus*), whose presence is increasing in the area (Mancinelli et al., 2017). By the way, the seabed in the study area was mainly mud (Fig. 1); therefore, it was unlikely for the holes to be caused by the nets coming into contact with rocks (Gazo et al., 2008). On the other hand, the small holes in the upper third part could be caused by contact being made with floats when the nets are hauled (Brotons et al., 2008a). In addition, we sometimes found remains of fish hanging from the nets, which helped us to identify the origin of the hole (Fig. 4). Photographs of dolphins for species determination, time, and location were provided by the fishers. Only the observations documented by the photographs or videos were taken into account to study the occurrence of dolphins. The percentage (% frequency) of total interactions and total dolphin sightings that have occurred in each month have been calculated.

2.4. Catch loss estimation

The data of catches per day, species, and vessel in 2018 and 2019 were provided by the Fishers' Guild, which in Spain is an association made up of fishers from the same fishing port, which is responsible for managing the sale of fish, payments and interests of the local fishing sector. The catch per Unit Effort (CPUE) was estimated for biomass as kg caught per 50 m of trammel net. In order to assess the impact of dolphins on the fishery, we compared the CPUE between vessels with and without

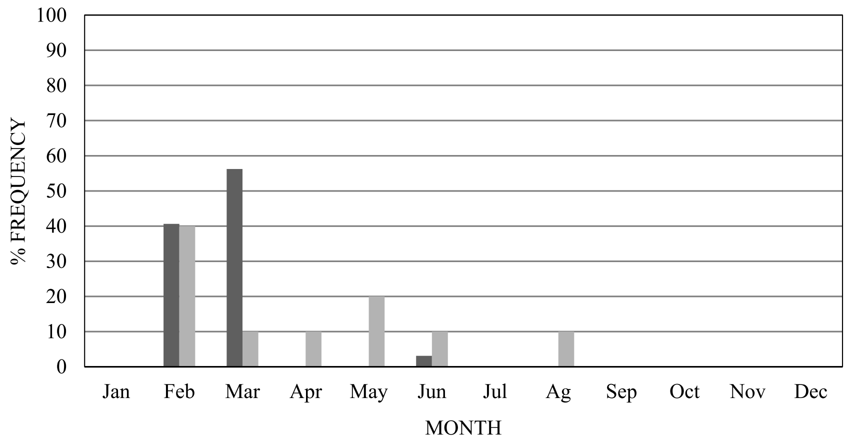

Fig. 5. Dark bars: temporal distribution of the interactions reported between April 2018 and March 2019 ($n = 32$ interactions). Clear bars: temporal distribution of bottlenose dolphin sightings ($n = 10$ sightings).

interaction. For that analysis, we used only the data of the days when at least one vessel experienced interaction with dolphins. We compared for both total CPUE, and the CPUE for each main species targeted by the fishery in the area to determine any significant differences in total CPUE. As the distribution of data was not statistically normal according to the *Shapiro–Wilk* test, the *Mann–Whitney–Wilcoxon* non-parametric test was performed. Statistical analyses were done using RStudio software (R Core Team, 2021).

For the comparisons, nine species that were present in the catches were chosen based on their importance in the catch by weight: cuttlefish represented 32% of the catch by weight, common pandora (15%), gilthead seabream (4%), white seabream (4%), striped seabream (3%), Klein's sole (3%), hake (2%), sole (1%), and large-scaled scorpionfish (1%). These species accounted for 65% of the total recorded catch weight. The other species (120 species) were not fished with enough frequency to be able to compare the catches with and without interactions with trammel net fisheries.

2.5. Economic loss estimation

We tried to calculate the economic loss whether it was due to damage to fishing nets or loss of catch. On the one hand, we quantified the damage to the nets as the total number of metres of affected mesh. The cost to repair one square metre of trammel net was €8.80, as reported by the Fishers' Guild. In some cases, when a panel was too damaged, the entire panel was changed at a cost of €22.5. On the other hand, on the basis of available catch data, it has not been possible to calculate the economic losses in catch value that may result from dolphin interactions.

3. Results

3.1. Dolphins and trammel net interactions

When the observers monitored nets from April 2018 to March 2019, the damage attributed to dolphins was recorded in 32 out of 1,849 fishing operations (1.7%). The average number of times that each vessel gets interaction in one year was 2.3 (SD $= \pm 1.5$, $n = 14$ fishing vessels).

During the period monitored by the observers, 50% ($n = 11$) of the total dolphin observations in the study area occurred between February and March, and 97% of the interactions took place during the same period (Fig. 5). Nonetheless, no significant relation was found between the dolphin observations by fishers in the study area and the number of interactions with trammel nets (Spearman rank correlation $z = 122.99$, p = 0.05; Fig. 5). Out of 11 dolphin sightings, 10 were bottlenose dolphins and the other was not determined. The mean number of school size was three individuals, ranging from one to eight individuals. Most of the observations of bottlenose dolphins were above 20 m in depth. All of the dolphins and trammel net interactions occurred in the sets located between 4.8–19.8 m in depth. The locations of these interactions is shown in Fig. 1.

3.2. Catch loss

There were no significant differences in CPUE when comparing sets with depredation/damage to nets by dolphins and without depredation/damage to nets by dolphins (total CPUE: *Wilcoxon* test = 86, $p = 0.3013$).

We also compared the CPUE for the main commercially important species individually. In five (*cuttlefish*, *white seabream*, *klein's sole*, *hake* and *sole*) out of the nine species considered, the CPUE value was higher in sets with depredation or nets damaged by dolphins than in the sets with no damage to nets. For the other four species, the CPUE was higher in the sets without damage due to dolphins. Nevertheless, we did not find significant differences for any species when comparing sets with and without net damage due to depredation by dolphins (Fig. 6).

3.3. Damaged nets

The holes in the 32 observed interactions were measured. The hole diameter was between 0.50–3 m (mean = 1.18, σ = 0.42, 95%IC: 1.03–1.33, $n = 595$ holes). The number of square m of mesh affected by one interaction was between 0.39–1345 square m (mean = 17.8, σ = 16.9, 95%IC: 11.8–23.8, $n = 32$ interactions). The number of holes for one interaction was between 1–100 holes (mean = 19.1, σ = 20.0, 95%IC: 12.0–26.1, $n = 32$ interactions).

3.4. Economic loss estimation

We considered only the economic loss due to damages to the nets since we did not find any significant difference in CPUE. The costs to repair all the damage made per interaction was between €11–€1,100 (mean = 242, σ = 256, 95%IC: 157–320, $n = 32$ interactions; Table 1). The economic loss by vessel and year ranged between €82.5–€1,331 (mean = 556, σ = 438, 95%CI: €303–€809; $n = 14$ vessels; Table 1).

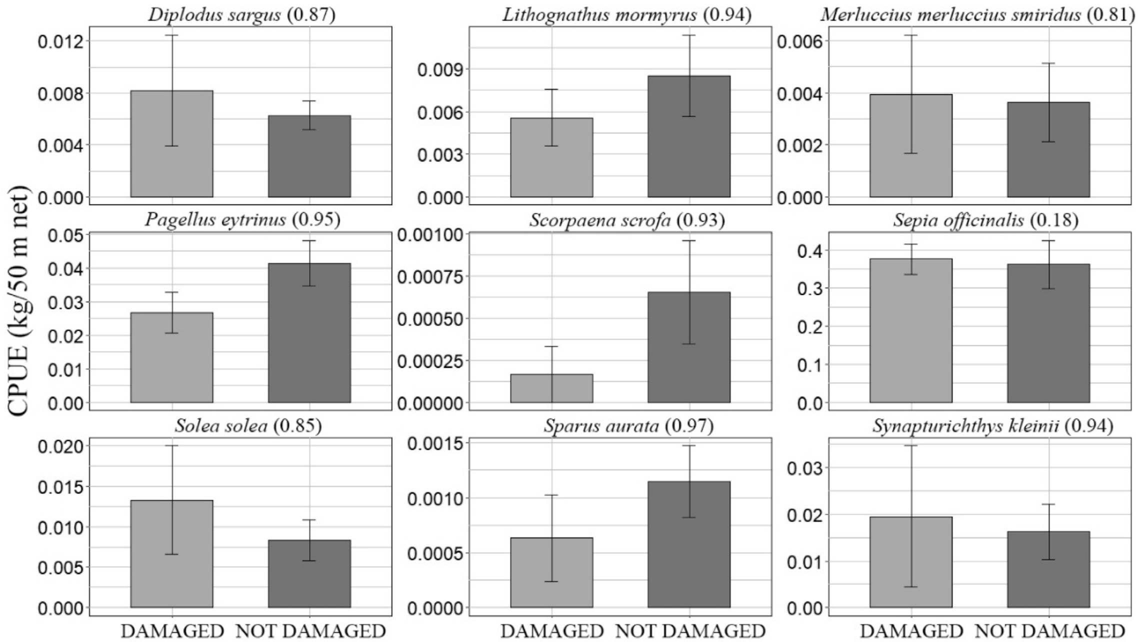

Fig. 6. CPUE of the nine main species caught with (clear bars) and without (dark bars) net damage due to an interaction with dolphins. The number in brackets is the *Mann–Whitney–Wilcoxon* test *P*-value. Bars represent means and error bars represent the standard deviation.

Table 1
Results of interactions recorded during the study period.

	Fishing days per vessel	Interactions/ vessel annually	€/vessel	€/interaction
AVERAGE	143.4	2.3	556.4	241.7
SD	40.8	1.5	438.1	255.7
N	14	14	14	32
Minimum	73	1	82.5	11.0
Maximum	196	5	1331.0	1100.3

4. Discussion

The results of the study represent the first direct evaluation made of the economic costs of interactions between the artisanal fleet in the Valencia region and the bottlenose dolphin (see Revuelta et al., 2018). Therefore, this study is an important contribution to obtain reliable data on damage and costs caused to fishers by dolphins. The evaluation of these financial losses is essential to establish the need for management conservation measures. The only dolphin species interacting with trammel nets was the common bottlenose dolphin identified in most cases by fishers, which is consistent with the results presented in other studies (Alexandre et al., 2022; Bearzi et al., 2009; Blasi et al., 2015; Brotons et al., 2008a; Gomercic et al., 2009; Lauriano et al., 2009; Lopez, 2006; Milani et al., 2019; Pennino et al., 2015; Revuelta et al., 2018).

The average financial loss caused by dolphins to artisanal vessels in our study area was estimated to be €556 per year/vessel. The reported economic loss per vessel in other studies ranges from €155 to €20,000 (Alexandre et al., 2022; Bearzi et al., 2011; Brotons et al., 2008a,b; Gonzalvo et al., 2015; Revuelta et al., 2018; Snape et al., 2018). Our results are similar to the results reported by Brotons et al. (2008a) and are slightly lower than those presented by Lauriano (2004) (€1,094 per trammel boat); and Gazo et al. (2008) (€1,168). There are 62 artisanal fishing vessels operating in the study area. We can estimate the total economic loss in the area due to interaction with dolphins to be about €5,115 – €82,522. If we assume a similar level of damages due to interaction with dolphins for the artisanal fleet in the Valencian region and extrapolate the costs, these will be at most around €244,000.

Given our results, the interaction with dolphins does not represent important economic damage to fishers. Bearzi et al. (2011) also suggest that the overall economic impact on artisanal fleets may be modest. However, in individual boat terms, it may be a problem, especially if the damage is concentrated at certain times of the year. Most of the interactions between dolphins and trammel nets occur in the winter months. Brotons et al. (2008a) also reported fewer interactions in summer in the Balearic Islands. In winter, when many working days are lost due to bad weather conditions, even small losses may be a reason for concern for fishers. Furthermore, fishers' perceptions as well as some studies (Bearzi et al., 2011; Brotons et al., 2008a; Revuelta et al., 2018) suggest that the number of depredation events by dolphins in trammel nets has increased in recent decades. Therefore, if this trend is confirmed, in the future, the costs to fishers may be higher, which may lead to illegal acts of retaliation by fishers, as has occurred in the past in the western Mediterranean Sea (Natoli et al., 2021).

Several authors suggest that the occurrence and abundance of the local dolphin population may have an effect on the magnitude of the economic impact of interactions with the artisanal fleet (Revuelta et al., 2018; Snape et al., 2018). The Balearic Islands are considered to be a hotspot for the bottlenose dolphin (Forcada et al., 2004; Gonzalvo et al., 2014); thus a stronger impact on the artisanal fleet is expected than in our study area. The abundance of the common bottlenose dolphin population in the Valencia region is not known. Gomez de Segura et al. (2006) estimated that the population for the Valencian region (32,270 km^2) was of the same order of magnitude as the population at the continental shelf of the Balearic Islands (12,315 km^2). Therefore, higher densities are found around the Balearic Islands and, consequently, a stronger impact of dolphins on fisheries may be expected. Revuelta et al. (2018) suggested that the intense interactions in the fishing ports in the southern part of the Valencian region was probably due to higher dolphin densities there. This could be an important factor to consider when evaluating the damage reported in other areas. It is also a factor to take into account when evaluating the need for management measures in order to reduce the damage caused to artisanal fleets.

All of the studies on this subject agree that the main impact of dolphin depredation on trammel nets is the damage caused to the nets. Although this was the only clear cost detected in this study other authors have also reported a decrease in catch or catch value (Brotons et al., 2008a; Gazo et al., 2008; Lauriano, 2004; Revuelta et al., 2018; Snape et al., 2018). These differences with our results could be related to targeted species. Surprisingly, other studies have reported the opposite, i.e., higher catches in nets depredated by dolphins (Rocklin et al., 2009; Silva et al., 2002). This might be due either to dolphins being attracted by nets with high catches or dolphins actively driving fish into nets (Rocklin et al., 2009). These differences among studies and areas might also be related to differences in the abundance of bottlenose dolphins. Further studies to estimate the abundance of dolphin populations and their movements are required to be able to understand the impacts of interactions with artisanal fisheries.

Several studies have addressed mitigating measures to reduce the impact of dolphins on trammel net fisheries. The most widely applied measure is to use *pingers* (Brotons et al., 2008b; Buscaino et al., 2009; Carretta and Barlow, 2011; Carretta et al., 2008; Cox et al., 2004; Dawson et al., 2013; Gazo et al., 2008; Kraus, 1999; Maccarrone et al., 2014; Schakner and Blumstein, 2013; Snape et al., 2018). However, the results do not clearly support the use of *pingers*. While their short-term use may have some effect on reducing the number of interactions and damage, in the mid- to long-term, dolphins get adapted (Cox et al., 2004). Furthermore, in the long term, *pingers* may elicit a *dinner-bell* effect (Carretta and Barlow, 2011; Gazo et al., 2008; Richardson et al., 2013; Schakner and Blumstein, 2013). Although this technique has not been implemented in the concrete area of study of this work, we would not suggest the use of *pingers* as the first solution to the problem due to the high cost that can involve for the fishers and the low effectiveness that seems to have according to the other studies.

In many countries, the government administration covers the damage caused by large predators to shepherds and farmers (Dickman et al., 2011; Fernandez-Gil et al., 2016; Naughton-Treves et al., 2003). Similarly, we should consider implementing tools to economically compensate artisanal vessels for damage caused by dolphins. This falls in line with the EU maritime and fisheries policies (No. 508/2014). The first priority includes reducing the impact of fisheries on the marine environment as well as protecting and restoring aquatic biodiversity and ecosystems. Artisanal fisheries can be considered among the most sustainable fisheries (Herrera-Racionero et al., 2015), with a low impact on overfishing and habitat degradation. On the other side, although the economic loss caused by the dolphins in the case of study is not so high in absolute terms, there are cases where the individual costs for a boat are very high. In these cases, the fisher's discomfort could turn into injuries to the dolphin community in order to defend his livelihood, as observed in other areas (Milani et al., 2019). For all of these reasons, supporting artisanal fisheries is important for marine mammal conservation. To prevent taking advantage of the system, a management damage assessor would be required.

5. Conclusions

According to the results of this study, the interactions between the bottlenose dolphin and artisanal fishing in the study area represent a relatively low economic cost for the local fishing community. However, these interactions create discomfort and an expense (although not high) that today must be assumed by the fishers themselves.

The economic losses caused by the interactions are more due to the deterioration of the fishing material than to the losses in the catches.

In order to avoid further conflicts in the conservation of dolphin stocks in the future, and to conserve artisanal fishing gear, we believe that the costs of these interactions between artisanal fisheries and bottlenose dolphins should be borne by the entire community so that it does not fall solely on the fisher. That is why, in the not - too - distant future, a management plan and financial compensation should be defined.

CRediT authorship contribution statement

Blanca Feliu-Tena: Conceptualization, Mehodology, Software, Formal analysis, Data curation, Writing – original draft, Visualization. **M. Rodilla:** Conceptualization, Methodology, Investigation, Supervision. **J. Pastor:** Statistical analysis. **Sara Abalo-Morla:** Software, Formal analysis. **M. Bou-Cabo:** Review and editing, Supervision. **Eduardo J. Belda:** Conceptualization, Methodology, Formal analysis, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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