Journal of Environmental Management 351 (2024) 119797



Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman



Research article



Towards a sustainable fisher-dolphin coexistence: Understanding depredation, assessing economic damage and evaluating management options

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ARTICLE INFO

Handling editor: Raf Dewil

Keywords:
Depredation
Economic damage
Human-wildlife conflict
Mediterranean sea
Participatory process

ABSTRACT

Finding solutions for a sustainable coexistence between wildlife and humans is considered among the most challenging environmental management issues for scientists, conservationists, managers, and stockholders world-wide. Depredation by the common bottlenose dolphin (*Tursiops truncatus*) on small scale fisheries has increased in the recent years, leading to a growing conflict in many areas of the Mediterranean Sea and pressing for urgent management solutions. This study aims at developing a management framework for a sustainable coexistence between fishers and dolphins in Sardinia (Mediterranean Sea). Relying on the combination of different approaches (field study, literature review and Multi Criteria Decision Analysis), the scientific evidence necessary for understanding dolphin depredation were updated and improved, the related economic damage was calculated, and different management options were identified and evaluated by several stakeholder groups to support the decision-making process. Averaging for all investigated net types (gillnet and trammel net), a depredation frequency of 53% was found, the highest values ever found in both Sardinia and many other Mediterranean sites. Depredation probability was influenced by different factors, such as net type, fishing operation duration, depth of the fishing site and period. The estimated economic damage due to depredation ranges on average between 6492 and 11,925 euro per year and depends on the type of fishing net. The results from the field study, the literature review and the stakeholder involvement allowed us to define the most plausible and shared management options, identifying a framework for assessing and managing the conflict between fishers and dolphins for the creation of a more sustainable vision for the future.

Credit author statement

La Manna Gabriella, Ceccherelli Giulia: Conceptualization; Data curation; Formal analysis; Writing - Reviewing and Editing. Arrostuto Nicola, Moro Morella Mariangela, Stipcich Patrizia: Investigation, Writing – original draft. Fois Nicola: Conceptualization; Resources; Supervision; Funding acquisition; Sarà; Gianluca: Conceptualization; Writing - Reviewing and Editing.

1. Introduction

Finding solutions for a sustainable coexistence between wildlife and humans is considered among the most challenging environmental management issues for scientists, conservationists, managers, and stockholders world-wide (Dickman, 2010). In fact, the high value attributed to wildlife, especially to large terrestrial and marine mammals, by an international audience composed of the general public, conservationists and management authorities, is rarely shared with local communities who suffer costs related to their presence (Dickman, 2010), in terms of attacks to humans or depredation (damages to livestock and

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https://doi.org/10.1016/j.jenvman.2023.119797
Received 20 April 2023; Received in revised form 6 November 2023; Accepted 3 December 2023
Available online 11 December 2023
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domestic animals in the terrestrial environment or fish catch loss and gear damages in the marine environment). This often leads to profound conflicts between local people who suffer the social and economic damage due to the animals' presence and depredation and those who aim to preserve species generally protected by national or international regulations (Young et al., 2010). To facilitate the coexistence of humans and wildlife in areas where people and wildlife frequently cooccur or compete for natural resources, interventions often promote environmental sustainability and wildlife conservation goals at the expense of the economic and social survival, leading to unbalanced and often counterproductive outcomes (Duffy et al., 2015). A sustainable coexistence should imply that humans and animals co-adapt to living in shared environments thanks to solutions that mitigate the interactions between them, to ensure the long-term wildlife population conservation, the social and economic survival of the local populations, and tolerable levels of risk for humans (Carter & Linnell, 2016a,b). Thus, even if the permanent removal of human-wildlife conflicts is unlikely, reducing the negative impacts on species and stakeholders through compromising can be feasible (Colyvan et al., 2011).

In the marine environment, one of the most challenging conflicts between wildlife and humans pertains to depredation on fishing gear by large predators (mainly marine mammals; Read, 2005), where depredation can be defined as the act of removing prey from fishing gear or foraging around fishing gear that may cause detrimental effects to human economy both due to catch loss and catch and gear damage (Bearzi and Reeves, 2022).

Although in decline, fishery sector is still highly relevant even in Europe. Particularly, artisanal (small scale, not industrial) fisheries comprise 84% of all fishing vessels in the EU Mediterranean countries and provide around 150,000 direct jobs in the EU alone (FAO, 2018). In the Mediterranean Sea, conflicts between small scale fisheries and dolphins have been documented for a long time and the negative impacts on both conservation of predators (due to accidental bycatch and revenge measures by fishers) and socio-economic survival of fishing activities have been stressed (Bearzi and Reeves, 2022; Tixier et al., 2021). Depredation by the most involved species, the common bottlenose dolphin (*Tursiops truncatus*), has increased in recent years leading to a growing conflict with fisheries in many areas of the Basin (Díaz Lopez, 2006; Lauriano et al., 2004, 2009; Rocklin et al., 2009; Pennino et al., 2015; Gonzalvo et al., 2015) and pressing for urgent management solutions.

In Sardinia, as in other Mediterranean areas, small scale fishing is conducted throughout the whole year (but mainly between spring and autumn) and in coastal areas (within 12 nautical miles) that can be reached in a short time (Raicevich et al., 2018). The activity often involves the family members (fishing practices are strongly traditional) and the income of fishers is often on the edge of the poverty threshold. For many years, fishers in Sardinia have suffered and complained about the frequent depredation of dolphins on trammel and gill nets, perceiving dolphins as the main cause of damages to their activities (Lauriano et al., 2004; Pennino et al., 2015; La Manna et al., 2022) and the decline of fish stocks. Some attempts to compensate fishers for dolphin depredation have been made in recent years, but they failed to resolve the conflict (and further deteriorated the relationship between fishers and the management body, the Autonomous Region of Sardinia – RAS; La Manna *pers. comm.*), likely due to the lack of the quantitative data and rigorous methodological approaches needed to develop strategies for coexistence (Kelkar et al., 2010). To effectively manage depredation, understanding depredation mechanisms and the related economic results, which in turn may depend on the interaction between predator and prey ecological traits (Amirian et al., 2020), on features of the marine environment where prey and predators live (Pennino et al., 2015), and on fishery features (fishery types and hot spots, fisher behavior, profitability, regulations, and management; Anais et al., 2021), seems pivotal. Within this context, this study aims to develop a management framework for a sustainable coexistence between fishers and dolphins thanks to the combination of different approaches: i) updating the scientific evidence necessary for understanding dolphin depredation and the quantification of the related economic damage and ii) identifying and evaluating the management options and their related acceptability by several stakeholder groups to support the decision-making process (Esmail and Geneletti, 2017). Decision-making processes concerning the management of human-wildlife conflicts may easily fail if run without methodology, for example by distorting stakeholder opinions and focusing on insufficient information or wrong objectives (Lahdelma et al., 2000). Thus, we used a Multi Criteria Decision Analysis (MCDA) approach, in which different stakeholders were involved in a participatory process to examine their attitudes and preferences toward the identified management options. MCDA is one of the methods that can support decision process, through a framework for collecting, storing and processing relevant information and stakeholder opinions, that has already been applied in the context of terrestrial carnivore depredation (Marino et al., 2021), wildlife conservation and resources management (Redpath et al., 2004; Huang et al., 2011; Mustajoki et al., 2011; Zia et al., 2011; Esmail and Geneletti, 2017). To our knowledge, this is the first time that a structured path going from the understanding of the ecological factors that influence depredation, to the assessment of the economic damage, up to the identification of different management options and their evaluation by different stakeholder groups, has been proposed to address a sustainable coexistence between fishers and dolphins in the Mediterranean Sea.

2. Methods

2.1. Logical framework

The logical framework consisted of two interrelated steps, performed between May 2021 and March 2023 (Fig. 1):

Step 1) Understanding depredation and measuring economic damage: a field study was performed to measure the frequency of depredation and identify the factors influencing depredation and catch amount; then, based on the results obtained in the field study, the economic damage due to the loss of catch was calculated.

Step 2) Multi Criteria Decision Analysis: the MCDA approach was applied to identify stakeholders and objectives (criteria) and define and evaluate management options (Fig. 1).

2.2. Step 1: Understand depredation and measure economic damage

2.2.1. Frequency of depredation and factors related to depredation

In Sardinia depredation by dolphins on small scale fisheries concerns mainly static gillnets and trammel nets (La Manna et al., 2022), which represent the majority of fishing licenses in the whole island (Agris, 2023). As reported by fishers, the common bottlenose dolphin (*Tursiops truncatus*) is the only species responsible for depredation on this type of fishery. Depredation was measured from May to October 2021 and from June to November 2022 in three areas of Sardinia (West, North, East) (Suppl. Mat. 1) by using passive acoustic monitoring devices (La Manna et al., 2022). Particularly, during commercial (not experimental) fishing activities, acoustic data were collected by means of autonomous acoustic recorders attached by a line to the net float file of the monofilament gillnet or trammel net. The recorders were set to acquire data continuously for the entire duration of the fishing operation (setting up the fishing net, soaking and hauling). For each area, two to six fishers engaged in artisanal fishing by trammel net with stretched mesh size between 71 and 82 mm (TN78) and between 45 and 55 mm (TN10) and monofilament gillnet with stretched mesh size of 50 mm (MN11) were involved (Suppl. Mat. 1). Thus, we identified a depredation attempt based on the acoustic detection of dolphins (ADD: the occurrence of dolphins in proximity to the net as revealed by the recording of one or

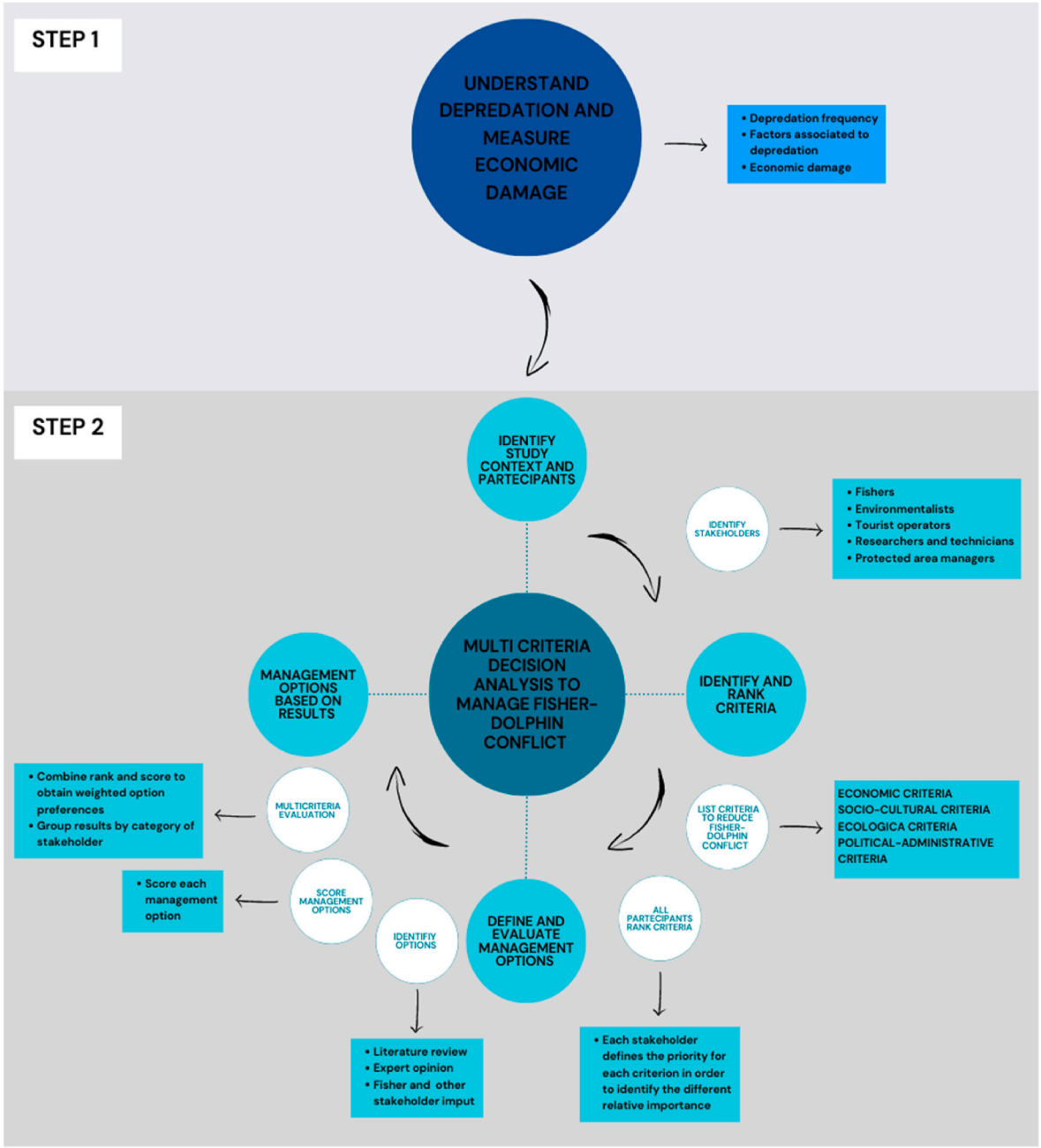


Fig. 1. The logical framework with the two steps and relative phases.

more sound bouts) (La Manna et al., 2022; see Suppl. Mat. 2 for methodological details). At the end of each fishing operation, the species and weight of each fish caught were noted together with data related to the type of fishing net used (trammel net or monofilament gillnet), the mesh size, the net length, the coordinates, and bottom depth of the fishing site. The CPUE (Catch per Unit Effort) per fishing operation was calculated as the weight (in kg) per 1000 m of net in total and for each species present. Both acoustic and fishery data were collected on the same day but at different sites, or at the same site but on different days, to avoid temporal correlations between fishing operations.

To test the differences in acoustic dolphin detection (ADD) among areas and fishing net types, Fisher's exact test was applied. Then, to investigate the factors associated with ADD (response variable as: 0 = no dolphins in proximity to the net; 1 = dolphins in proximity to the net), a binomial GLM (Generalized Linear Model) was run using the following predictors: area (West, North, East), period (May–June, July–August, September–November), fishing net type (TN78, TN10, MN11), fishing operation duration (FOD), set up time (morning, afternoon, night), depth of the fishing site and distance to the harbor. Before running the analysis, collinearity between predictors was assessed visually and tested with generalized variance inflation factors (GVIF, calculated using the "car" package; Fox and Weisberg, 2019). Fishing net type and set up time were excluded due to the correlation with fishing operation duration, and area was excluded due to the correlation with distance to the harbor ($GVIF^{(1/(2 \times Df))} > 2$). Further, to disentangle some of the factors which may influence catch amount, a second GLM (with gamma distribution, since CPUE data were continuous, only positive, and right skewed) was run on total CPUE using area, depth, fishing operation duration, fishing net type, net length, and ADD as predictors. Before running the analysis, collinearity between predictors was assessed visually and tested with generalized variance inflation factors (GVIF). Fishing net type and area were excluded due to the correlation with

fishing operation duration and net length, respectively ($GVIF^{(1/(2 \times Df))} > 2$). The GLMs were fitted in R (R Foundation for Statistical Computing, Vienna, Austria) using the "mass" package (Venables and Ripley, 2002). The Akaike Information Criterion with second-order correction for small sample size (AICc; Burnham and Anderson, 2002) was used for model ranking. A graphical model validation was applied to check patterns and spatial correlation in the residuals (Suppl. Mat. 3). Further, we applied a k-fold cross validation (k = 5) to evaluate model performance using the package "caret" in R (Kuhn, 2008).

2.2.2. Measurement of economic damage

Since both the type of fishing net and depredation influenced the CPUE, the economic damage per fishing operation for each fishing net type was calculated separately. First, the mean CPUE *per species* in presence of depredation (ADD = 1) and the mean CPUE *per species* in absence of depredation (ADD = 0) were calculated, by averaging the CPUE *per species* of all fishing operations in presence and absence of dolphin depredation, respectively. The percentage of loss per species per fishing operation (PLFO) was calculated as:

$$PLFO_{species} = \left(\frac{mean\ CPUE\ per\ species_{ADD=1}}{\text{mean CPUE per species}_{ADD=0}} \times 100\right)\text{-}100$$

Then, the economic damage per fishing operation EDFO was calculated as:

$$EDFO = \sum PLFO_{species} \times local\ price_{species}$$

where the local prices ranged between a minimum (wholesale prices) and a maximum (retail prices).

Finally, to estimate the yearly economic damage (ED_{year}) per fishing net type, the following formula was applied:

$$ED_{year} = [\text{EDFO} \times \text{Frequency of depredation x number of fishing days}]$$

where the frequency of depredation per fishing net type was obtained from the field study and the number of fishing days per year was declared by the fishers involved in the study.

2.3. Step 2: Multi criteria decision analysis

2.3.1. Identify stakeholders and criteria

The MCDA involves several, interrelated phases (Figs. 1 and 2).

First, the study context and the stakeholders have been identified. In our case, stakeholders include groups of people who see the issue as critical or important for their economic survival or for the conservation of wildlife (Lahdelma et al., 2000), namely: fishers, MPA (Marine Protected Area) managers, tourist operators, researchers, and environmentalists. Particularly, the following participants were involved: i) 17 fishers, selected among those who had already joined previous projects related to fishing and depredation, known for having good comprehension and participation skills; ii) the environmental managers of three Sardinian MPAs; iii) five representatives of the regional environmental associations directly involved in the conservation of cetaceans in Sardinia; iv) three representatives of the main tourist operators offering dolphin and whale watching tours along the island. We have also included five researchers from the University of Sassari (UNISS) and AGRIS (Regional Agency for the research in agriculture and fishery). Secondly, a list of preliminary criteria (objective to achieve or questions to address) divided into four sectors (economic, socio-cultural, ecological, and political-administrative) were identified and discussed with the representatives of each stakeholder group by using face-to-face and online meetings and e-mails (Lahdelma et al., 2000) (Fig. 2).

2.3.2. Definition and evaluation of the management options

To define the possible management options, a systematic literature review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). Particularly, to answer the question "which management options are suggested on the basis of the factors influencing depredation or the related economic damage?", the following research strings ("bottlenose dolphin" OR "*Tursiops truncatus*") AND ("interaction" OR "depredation") AND "fishery" AND "Mediterranean Sea" AND "management" were used to include only studies conducted in the Mediterranean Sea and related to bottlenose dolphin depredation. Academic online databases (Web of Science and Scopus), Google Scholar, ResearchGate, published reviews, international agencies (ACCOBAMS, IWC) and the database of the European Life Projects were investigated to collect data from peer reviewed papers, technical reports, and gray literature. The reference lists of the documents found were also cross-checked to find relevant additional studies. Case studies were selected if addressing depredation (defined as the removal of prey from the net and/or foraging around the nets) of bottlenose dolphin in static net fisheries (gill net or trammel net) and assessing the depredation occurrence and/or the related economic

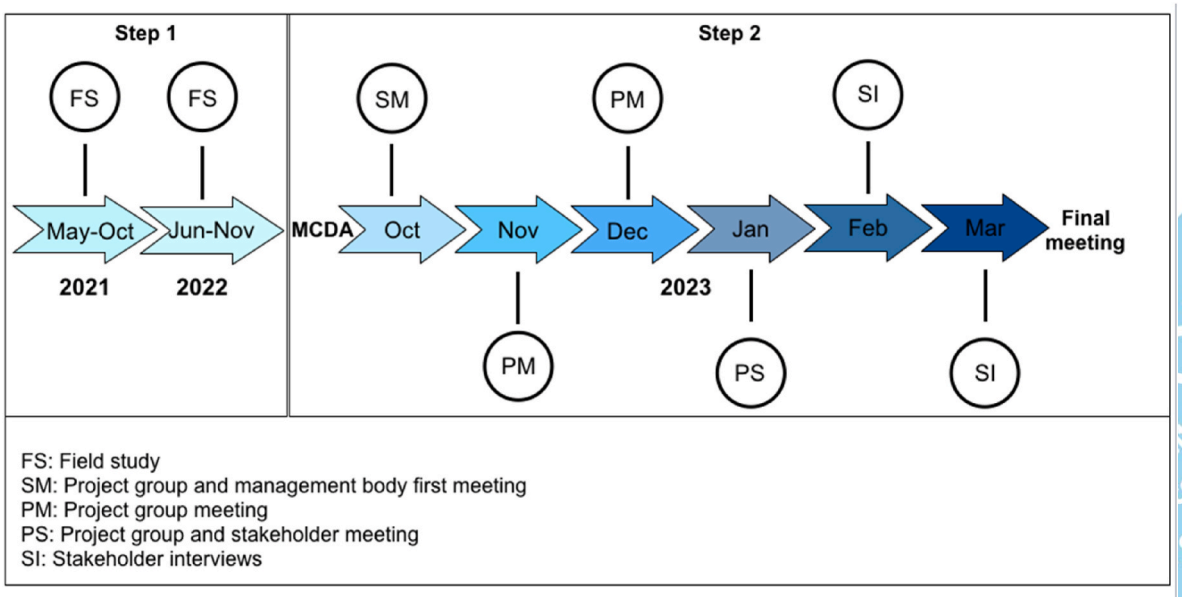


Fig. 2. Timeline of the step 1 and 2, with details on the phases of the MCDA process.

damage and/or the factors influencing depredation and/or the ways to manage this issue. From each selected case study, information was extracted, and a matrix was created including the following data: i) document type, title, author, year of publication; ii) region and country; iii) depredation frequency and method used to estimate it; iv) factors associated to depredation (area and depth of the fishing sites, fishing period, fishing target, type of net or mesh size, fishing operation duration) and economic damage; v) method used to estimate economic damage; vi) suggested management. Management actions were categorized in the four following strategies:

- Adaptation: a strategy that includes actions aimed to prevent or minimize the damage caused by depredation (spatial and temporal avoidance practices).
- Mitigation: a strategy that includes actions aimed to prevent or minimize depredation success (change of gear or use of deterrent device).
- Compensation: a strategy based on the restoration of economic impact (economic compensation based on catch and/or gear damage or on the abundance of predators).
- Alternative: a strategy not directly involved in reducing depredation success/damage or in economic compensation.

When a study contained more than one element or type of information, it was split into different case studies. To synthesize the collected data, a semi-quantitative description was performed in R (R Foundation for Statistical Computing, Vienna, Austria), presenting the outcomes as percentage frequency. The decision-making process should investigate all relevant knowledge, not only the science-based ones, but also those coming from local communities and stakeholders (Lahdelma et al., 2000). Thus, the results of the field study and the literature review were discussed with representatives of fishers, tourist operators, researchers and environmentalists during face-to-face and online meetings and the management options initially suggested were integrated and modified (Fig. 2).

Lastly, the evaluation of the management options against the ranked criteria was obtained by face-to-face or online interviews between one or two decision analysts and single stakeholder or small group of stakeholders (Mustajoki et al., 2011). This approach was preferred, even if more time-consuming than participatory meetings with all the stakeholders, due to the need to communicate in a personal and interactive way with each stakeholder, to highlight eventual inconsistencies in the answers but without directing or influencing the responses of the interviewees (Mustajoki et al., 2011). Before the interview, an information package (consisting of two videos) was sent to the interviewee to provide the fundamental information related to the outputs of the field study and the MCDA approach. Following a procedure already used in similar contexts, interviewees were asked to rank each criterion on the basis of their importance and priority (in a scale from 1 to 5; Redpath et al., 2004; Mustajoki et al., 2011; Marino et al., 2021) and evaluate management options against each criterion as follows: 1) a score of "100" to the management options that best satisfy the criterion; ii) a score of "0" to the management options that satisfy the criterion the least; iii) a score between 1 and 99 to the other management options. Management option evaluations were done by applying a technique known as weighted linear combination (Esmail and Geneletti, 2017), already applied in similar contexts (Redpath et al., 2004; Mustajoki et al., 2011; Marino et al., 2021). First, the criteria scores were transformed into weight, so as the sum of all criteria equaled one (Steele et al., 2009). Then, the criteria weights were multiplied to the management option scores and the resulting scores were summed across each management option and normalized so that their sum equals 100. In the end, the results were aggregated by stakeholder groups and presented to all the stakeholders to guarantee the transparency of the decision-making support approach.

3. Results

3.1. Understanding depredation and assessing economic damage

3.1.1. Factors related to depredation

A total of 987 h of acoustic recordings and catch data from 103 fishing operations (Supp. Mat. 1) were collected, namely: 46 operations from the West (24 by TN78 and 22 by TN10), 43 from the North (11 by TN78, 12 by TN10, 20 by MN11) and 14 from the East (2 by TN78 and 12 by MN11). A significant difference was found in ADD among fishing net types (Fisher exact test, $p = 0.00015$), while no difference was found among areas (Fisher exact test, $p = 0.244$). The depredation frequency (ADD/total number of fishing operations) was 59% per MN11, 25% per TN10 and 73% per TN78. ADD was related to FOD, depth and period (Table 1 part a). Particularly, the probability of ADD increased with longer fishing operation duration and deeper fishing sites, and it was higher in Sept–Nov compared to the other two periods (Fig. 3). The CPUE was related to ADD only (Table 1 part b), being lower in the case of depredation (Fig. 3).

3.1.2. Economic damage

The mean catch of TN78 had an economic value ranging between 106 and 150 euro per fishing operation. The mean catch in presence of depredation was reduced by 49%, mainly due to the loss of *Scorpaena scrofa, Phycis phycis,* and *Dentex dentex*. The annual economic damage (ED_{year}), considering a depredation frequency of 73% and 120 fishing operations per year was estimated in the range between 4621 and 6693 euro (Table 2). The mean catch of TN10 in absence of depredation had an economic value ranging between 65 and 113 euro per fishing operation. The mean catch in presence of depredation was reduced by 43%, mainly due to the loss of *Mullus surmuletus* and *Symphodus tinca.* The annual economic damage (ED_{year}), considering a depredation frequency of 25% and 90 fishing operations per year was estimated in the range between 565 and 1080 euro (Table 2). The mean catch of MN11 in absence of depredation had an economic value ranging between 102 and 210 euro per fishing operation. The mean catch in presence of depredation was reduced by 70%, mainly due to the loss of *Mullus surmuletus* and *Pagellus erythrinus*. The annual economic damage (ED_{year}), considering a depredation frequency of 59% and 40 fishing operations per year was estimated in the range between 2440 and 3455 euro (Table 2).

Finally, by averaging the depredation frequencies and the EDFO and adding the number of fishing operations per year for the three net types, the average economic damage suffered by fishers ranged between 6,492 and 11,925 euro.

Table 1
a) Output of the binomial GLM testing the influence of fishing operation duration (FOD), period, and depth on ADD (acoustic dolphin detection). Model accuracy obtained by k-fold cross validation: 0.70 (95% CI: 0.61–0.85); b) Output of the gamma GLM testing the influence of ADD (acoustic dolphin detection) on CPUE (Catch per Unit Effort) Model performance obtained by k-fold cross validation: Root Mean Squared Error = 4.38; Mean Absolute Error = 3.31.

a)	Estimate	Std. Error	z value	P
Intercept	−3.97758	1.07516	−3.700	<0.001
FOD	0.12379	0.03541	3.496	<0.001
Period-[May–June]	−1.04108	0.70746	−1.472	0.14113
Period-[Sept–Nov]	1.83265	0.72734	2.520	0.01175
Depth	0.0870	0.02823	3.302	<0.001
b)	**Estimate**	**Std. Error**	**z value**	**P**
Intercept	2.1184	0.1051	20.17	<0.0001
ADD	−0.8047	0.1493	−5.39	<0.0001

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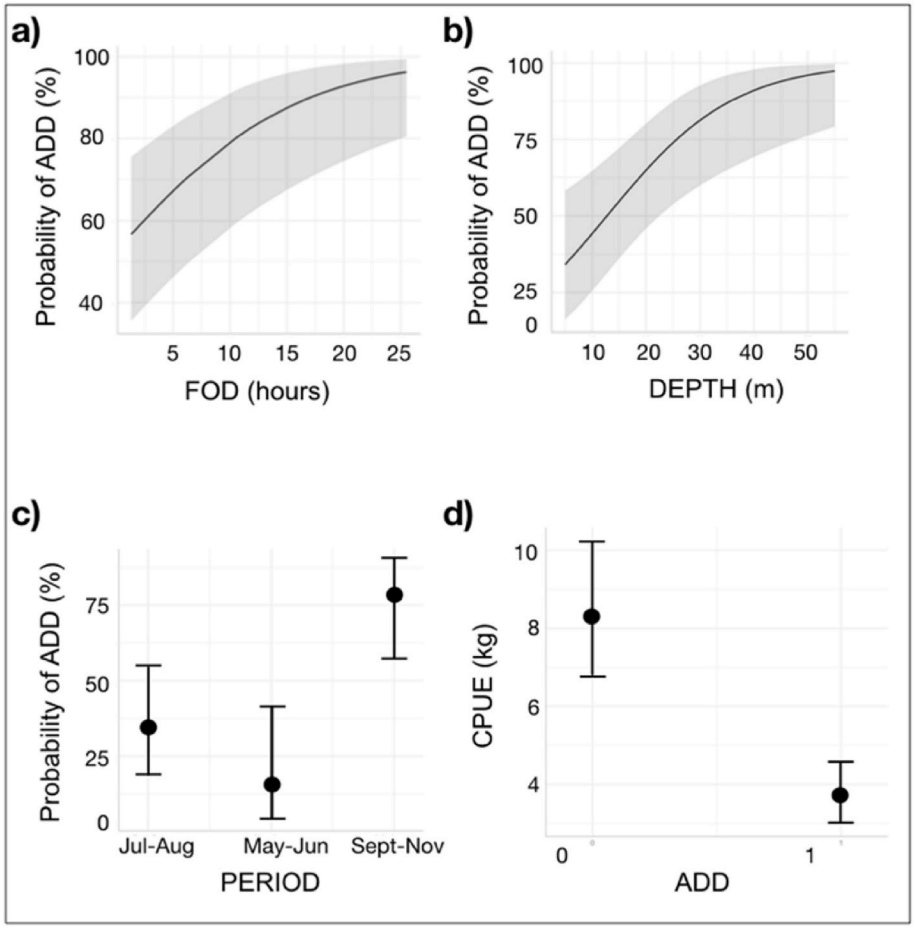


Fig. 3. GLMs outputs on the influence of FOD (fishing operation duration) (plot a), depth (plot b) and period (plot c) on ADD (acoustic detection of dolphins) and on the influence of ADD on CPUE (catch per unit effort) (plot d).

Table 2
Mean catch in absence (ADD = 0) and in presence of depredation (ADD = 1), percentage of catch loss, economic damage per fishing operation (EDFO) and economic damage per year (ED_{year}) for each type of fishing net.

Fishing net type	Mean catch (kg) ADD = 0	Mean catch (kg) ADD = 1	Catch loss (%)	EDFO range (euro)	ED_{year} range (euro)
TN78	7.0	3.6	49	53–76	4621–6693
TN10	7.1	4.0	43	25–48	565–1080
MN11	11.1	3.3	70	69–146	2440–3455

3.2. Multi criteria decision analysis

3.2.1. Identification and ranking of criteria

The final list of criteria was composed of 27 concise, operational, independent, and understandable criteria (Gregory et al., 2012; Esmail and Geneletti, 2017) (Table 3).

The criteria were ranked for their importance and priority by 33 stakeholders, together with the desired directions of change. All criteria were ranked as more than important enough (criteria score >0.75) by all the stakeholder groups, especially those related to the socio-cultural sector, with few exceptions (Suppl. Mat. 4). For example, some ecological criteria were found less important by fishers than by other stakeholders, namely those related to the environmental capacity to sustain dolphin populations, dolphin bycatch and injuries and dolphin population conservation. The directions of change were consistent between all stakeholder groups, with few exceptions: i) all stakeholders agreed with the "development of new economic opportunities for fishers" (criterion 4), except for the tourist operators; ii) all stakeholders agreed to increase the "role of dolphins as regulators of biodiversity" (criterion 14) and "dolphin population conservation" (criterion 18), except for fishers (Suppl. Mat. 4).

3.2.2. Definition and evaluation of the management options

The preliminary list of the management options was formulated thanks to the literature review. From the literature search, 147 records were identified (133 in academic database and 14 from other sources). After the selection by title and by abstract/text the records have dropped to 44 and 22, respectively, consisting of 77 case studies from 2002 to 2022 (Suppl. Mat. 5). Most of the studies were conducted in Italy (41%) and Greece (27%), while the remaining were from Spain (14%), France (9%), Algeria (4.5%) and Malta (4.5%). To evaluate depredation, different methods were used: interviews with fishers alone (36.4%) or in association with other methods (22.7%), visual observation and catch measurement (31.8%), overlap analysis between fishing and dolphin areas (4.5%) and acoustic methods (4.5%). Economic damage was estimated in 12 case studies (55%) and concerned both net damage and catch loss. Fishing net type (50%) and area (27%) were the factors most frequently associated with depredation, followed by depth (23%), period (23%), target (18%) and fishing operation duration (9%). Only in four case studies no factor associated with depredation was investigated. In 59% of cases some management actions were suggested, divided into adaptation, mitigation, compensation, or alternative strategies (Fig. 4). Particularly, the most suggested strategies were mitigation (30%), adaptation (18%) and alternative (15%), while compensation was suggested in only 6% of cases. The relationships between the factors related

Table 3
List of criteria clustered per sector (economic, socio-cultural, ecological, and administrative) and the expressed direction of change.

Code	Sector	Criterion	Direction of change
1	Economic	Fishers' income from catch	increase
2	Economic	Time and money for the bureaucracy related to depredation	decrease
3	Economic	Time and money spent due to depredation	decrease
4	Economic	Development of new economic opportunities for fishers	increase
5	Economic	Economic damage due to depredations	decrease
6	Economic	Working opportunities for researchers and technicians	increase
7	Economic	Economic value of dolphins for the nature-based tourist activities	increase
8	Socio-cultural	Protection of traditional and artisanal fishing practices	increase
9	Socio-cultural	Social cohesion among stakeholder groups	increase
10	Socio-cultural	Knowledge on dolphins	increase
11	Socio-cultural	Availability of scientific data	increase
12	Socio-cultural	Intrinsic value of wildlife and marine ecosystems	increase
13	Ecological	Influence of fishing on the feeding ecology of dolphins	increase
14	Ecological	Role of dolphins as regulator of biodiversity	increase
15	Ecological	Environmental capacity to sustain fish populations	increase
16	Ecological	Environmental capacity to sustain dolphin populations	increase
17	Ecological	Dolphin bycatch and injuries	increase
18	Ecological	Dolphin population conservation	increase
19	Administrative	Efficiency of the management option	increase
20	Administrative	Cost/benefit ratio	increase
21	Administrative	New laws & regulations	increase
22	Administrative	Compliance with actual legal limitations	increase
23	Administrative	Acceptability for fishers	increase
24	Administrative	Acceptability for MPA managers	increase
25	Administrative	Acceptability for environmentalist	increase
26	Administrative	Acceptability for researchers	increase
27	Administrative	Acceptability for tourist operators	increase

to depredation and the suggested management strategies and actions were identified (Fig. 5). Economic compensation was suggested in 27% of cases where the damage was measured, being preferred by alternative strategies (40%), such as the development of tourism activities as measure to implement fishing profitability. Mitigation, particularly the fishing gear change, was suggested when the influence of gear was found but also when other factors were related to depredation, such as fishing site, depth, and period. In the end, some cases suggesting adaptation were not supported by factor-depredation relationships (Fig. 4).

Based on the outputs of the field study and the review, the management options were defined and discussed with the stakeholder groups. The final list contained eight management options (MOs), relative to adaptation, mitigation, compensation, and alternative strategies, and three MOs, defined as supplementary, aimed to reinforcing the effectiveness of the process to reduce fisher-dolphin conflict (Table 4).

The management options that obtained the highest scores were the economic compensation based on damage, the development of fishers' business and the performing of monitoring and research activities, while the least appreciated one was the use of deterrent devices (Fig. 6). Some disagreements among stakeholders were also found. Fishers favored the economic compensation based on catch/net damage and disagreed with the other stakeholder groups concerning fishing gear change and temporal and spatial avoidance practices, considering these options the least suitable for reducing the fisher-dolphin conflict. Researchers, environmentalists, MPAs and tourist operators favored training and education activities for fishers. The development of fishers' business was less appreciated by MPA managers, while the development of alternative (tourism-related) economic activities was less appreciated by tourist operators. The supplementary options (MO9, MO10, MO11) were those obtaining the largest consent among all stakeholders (Fig. 7).

4. Discussion

4.1. Dolphin depredation and related economic damage

The field study allowed updating the information related to depredation frequency, highlighting some of the factors which influence its occurrence. Averaging for all net types, the depredation frequency was 53%, the highest values ever found in both Sardinia (Lauriano et al., 2004; Díaz Lopez, 2006; Pennino et al., 2015) and many other Mediterranean sites (Brotons et al., 2008; Rocklin et al., 2009; Snape et al., 2018). The cause of the increased depredation frequency over the years may concern both the new methodology used in this study (dolphin acoustic detection) respect to previous efforts (Lauriano et al., 2004; Díaz Lopez, 2006; Pennino et al., 2015), depletion of fish stocks in the last decade (Tixier et al., 2021) and/or even a larger spread of this opportunistic feeding strategy in the bottlenose dolphins in Sardinia (La Manna et al., 2022). Nevertheless, the most relevant result from a management point of view is that the estimated depredation frequency was noticeably higher than what was considered by the Autonomous Region of Sardinia to compensate fishers for the economic damage due to dolphins (33%, decided in 2018 based on knowledges dated back to 15 years ago). This result stresses the need to periodically measure the actual depredation to avoid the risk of negatively swaying fisher opinions on monitoring and research outcome, erode trust in management bodies, reduce social cohesion and, consequently, implement ineffective management strategies.

In Sardinia depredation probability was influenced by different factors, and these results have been useful in defining the management options. Particularly, depredation was influenced by net type, fishing operation duration, depth of the fishing site and period. The highest depredation probability concerned TN78, the fishing net type with the longest fishing operation duration (≅ 24 h), followed by MN11, gillnet having *Mullus surmuletus* as main target species, similarly with other Mediterranean studies (Lauriano et al., 2004; Brotons et al., 2008; Garagouni et al., 2022). The influence of sea bottom depth (namely, the increase in depredation probability as the seabed was deeper) was found elsewhere in the Mediterranean Sea (Garagouni et al., 2022), although in other Sardinian areas, some inconsistent evidence was gained as a higher dolphin depredation was found in shallower water (Pennino et al., 2015). This conflicting evidence corresponds with the contrasting empirical knowledge found among fishers, regarding the probability of depredation in more (or less) deep areas (La Manna, *pers. comm.*) The same incoherent pattern was found with respect to the period: even if fishing period influences depredation in different parts of the Basin (Brotons et al., 2008; Pennino et al., 2015; Garagouni et al., 2022), the periods with the highest depredation are not always consistent among areas. These results, as well as the limited amount of variation explained by our models (see Supp. Mat. 3), suggest the high variability of dolphin depredation strategies in relation to both local environmental conditions and dolphin behavioral and social context (Pennino et al., 2015), which makes defining the management options based on spatial or temporal avoidance even more challenging.

Depredation strongly impacts catch amount: the related economic damage ranges on average between 6,492 and 11,925 euro per year and depends on the type of fishing net, with the highest damage concerning TN78 and MN11. However, it is important to highlight that the damage measurements included neither gear damage nor the additional costs due to time spent repairing or changing the nets, even if this latter aspect is perceived by fishers as less impacting on profitability than the loss of catches (Agris, 2023).

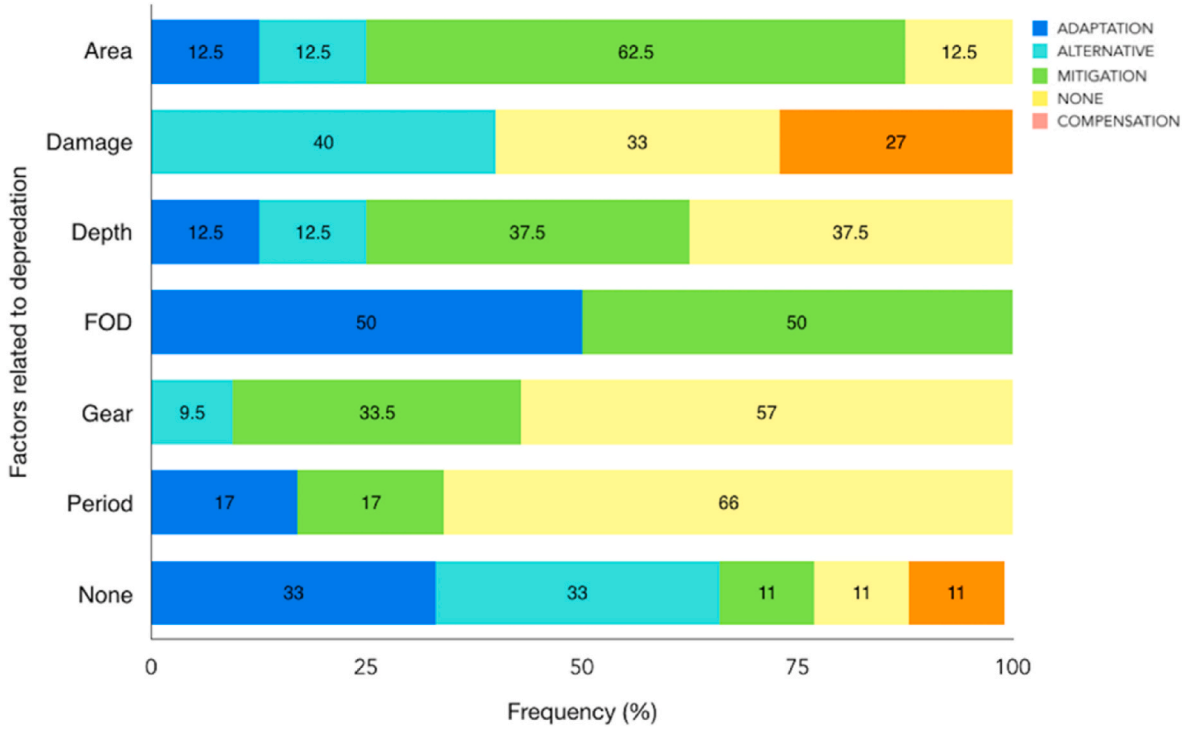


Fig. 4. Relative frequency (%) of strategies suggested per type of factor related to depredation (obtained from the 22 studies found by the systematic literature review). FOD: fishing operation duration.

The comparison of economic damage with other Mediterranean areas is hampered by the local contexts, types of fishing gear and targets, and by the methods used to estimate the damage. However, the damage found for MN11 was more than twofold the one measured by Lauriano et al., in 2004 (in northern Sardinia), due to both the higher depredation frequency found here and the raised local fish prices. Instead, in La Maddalena Archipelago (north-eastern Sardinia), Pennino et al. (2015) found that depredation did not affect catch profitability of trammel net, since the loss of some species is compensated by the catch of other higher priced species, an aspect not detected in our study. Nevertheless, the economic costs of depredation we have estimated can be considered quite substantial, both at national and regional scale and at the level of affected fisher families.

4.2. *Multi criteria decision analysis*

The definition of the criteria required an effort of synthesis and clarity to balance completeness and conciseness, which proved to be effective during the evaluation process. In fact, almost all criteria were rated as important for the decision-making process. Most of the directions of change expressed by the various stakeholders were consistent across different groups, even though some divergent opinions, highly relevant from a management point of view, emerged. For example, fishers disagreed to increase the role of dolphins as a regulator of biodiversity and to improve dolphin population conservation. Likely, fishers believed that an improvement in the conservation status of dolphins will lead to an increase in their abundance and, consequently, in the likelihood of depredation. This pattern was already observed in other human-wildlife conflicts (Redpath et al., 2004; Marino et al., 2021). Further, tourist operators disagreed to increase the development of new tourism-related economic opportunities for fishers, because the latter would become direct competitors in the tourism sector.

In the literature review some management options, already suggested in the contexts of bottlenose dolphin depredation in the Mediterranean Sea, have been identified and related to the factors influencing depredation. Further, the review allowed us to define the most plausible management options that increase acceptability to stakeholders. Some relevant issues were particularly useful in the definition of the management options. To refund the economic damage due to depredation, the economic compensation was suggested in a few cases where the damage was measured, while alternative strategies, such as the development of tourist activities, were preferred. Further, when depredation was related to fishing-related factors the most suggested strategy was mitigation by fishing gear change, while temporal and spatial avoidance practice were less suggested. At the end, the need of training and education activities for fishers also emerged as an important potential management option. In this regard, this option was the most preferred by environmentalists, researchers and MPA managers. These stakeholder groups had a higher agreement level than fishers and tourist operators, which instead diverged the most in their relative evaluations. For example, fishing gear change and temporal and spatial avoidance were the two most and least favored management options for tourist operators and fishers, respectively, while they were among the most preferred options by environmentalists, researchers, and MPA managers. Surely, the use of pots or traps instead of nets would be an efficient and relatively low-cost means to avoid dolphin bycatch (Hamilton and Baker, 2019). Further, field study as the present one and oceanographic and species distribution models could provide insights into habitat use by marine predators involved in depredation (Thorne et al., 2017; Anderson et al., 2020), improving the efficiency of the adaptation strategy based on spatial and temporal avoidance. However, the implementation of such management options would be hindered by reluctant fishers, who are afraid of modifying their fishing practice (Fader et al., 2021). In fact, since dolphins and fishing activities may target similar oceanographic features in terms of habitat type and sea surface temperature patterns, changing fishing site or period while maintaining catch rate of target species and profitability, may be difficult to achieve. This is especially true considering the limits of small-scale fishing: moving over wider or more distant areas may be hampered by the small size of vessels and the need to comply with fishing regulations (Fader et al., 2021).

The use of deterrent devices was the option which received the least

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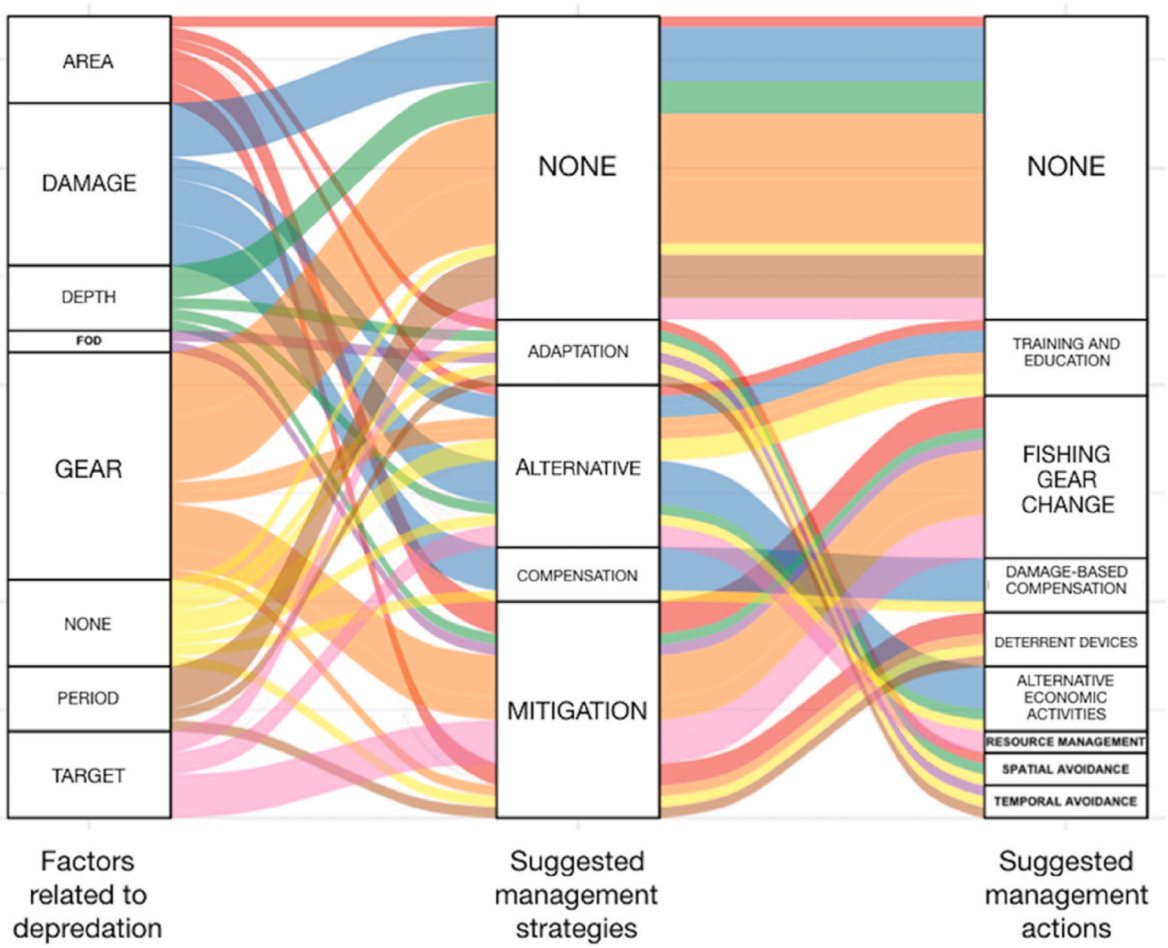


Fig. 5. Alluvial plot showing the relationships between the factors related to depredation or the evaluation of the economic damage and the strategies and actions suggested by the authors (obtained from the 22 studies found by the systematic literature review).

Table 4
List of the management options submitted for stakeholder evaluation.

Code	Management strategy	Management options
MO1	Adaptation	Changes of fishing area (spatial avoidance) and/or fishing period and/or fishing operation duration (temporal avoidance) on the basis of updated scientific evidence on depredation
MO2	Mitigation	Fishing gear change (e.g., pot instead of net, or different mesh size) on the basis of updated scientific evidence on depredation
MO3	Mitigation	Use of new deterrent devices (preliminarily tested with fishers)
MO4	Compensation	Economic compensation based on catch and/or net damage
MO5	Compensation	Economic compensation based on bottlenose dolphin abundance
MO6	Alternative	Development of fishers' business (through incentives or European funding)
MO7	Alternative	Development of alternative economic activities (such as fishing tourism or dolphin watching)
MO8	Alternative	Training and education activities for fishers (to improve knowledge on sustainable fishing and dolphin depredation)
MO9	Supplementary	Surveillance to counteract illegal fishing and killing of dolphins
MO10	Supplementary	Research and monitoring (to increase knowledge on fish resource status and dolphin depredation)
MO11	Supplementary	Participatory process: development of ways to choose management options in partnership with all the stakeholders

appreciation by all stakeholder groups. In the last decades, deterrent devices, mainly acoustic alarms known as "pinger", have raised interest by both fishers and environmentalists, as they are non-lethal methods to deter depredation on fishing gear and dolphin entanglement. However, after years of experimentations and use, their long-term efficiency is still controversial (Hamilton and Baker, 2019) In fact, depredating dolphins have shown to quickly habituate to the acoustic signals emitted by the deterrent devices, even being attracted to the net after a time lag (Cox et al., 2003).

The economic compensation, which is the most favored management options for fishers, was less appreciated by the other stakeholder groups. Implementing compensation programs is mainly aimed at taking away the resentment of humans against wildlife: compensated losses should mitigate the incentive to kill wild animals for economic reasons or for revenge and should also help in building support for pro-environment initiatives. However, worldwide compensation programs have obtained only partial evidence of success (Ravenelle and Nyhus, 2017) due to the lack of permanent funding, bureaucratic obstacles, and fraudulent claims. Moreover, the introduction of compensation may remove the impetus for implementing mitigation or adaptation actions, which may be worthwhile investments for fishers and a useful initiative to reduce accidental dolphin bycatch. These issues may explain why economic compensation has not achieved a broad level of consent among stakeholder groups, especially those with higher knowledge on biological conservation and environmental management. However, for improving compensation programs, payments may be linked to prevention measures. For example, making compensation conditional on the adoption of adaptation or mitigation activities would encourage fishers in

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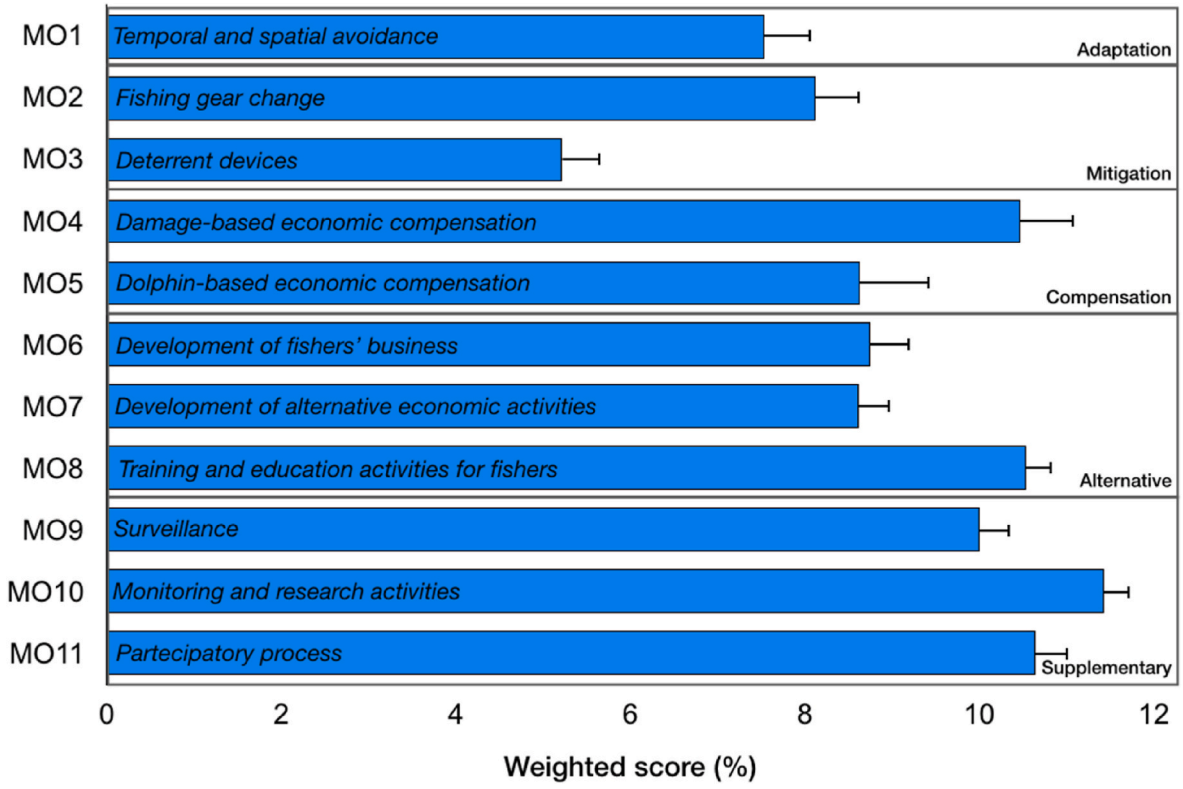


Fig. 6. Weighted standardized scores (mean ± SE) for each management option. MO1: Temporal and spatial avoidance; MO2: Fishing gear change; MO3: Deterrent devices; MO4: Damage-based compensation; MO5: Dolphin-based economic compensation; MO6: Development of fishers' business; MO7: Development of alternative economic activities; MO8: Training and education activities for fishers; MO9: Surveillance; MO10: Monitoring and research activities; MO11: Participatory process.

reducing the risk of future conflict (Ravenelle and Nyhus, 2017). Further, to increase fishers' profitability and compensate them for catch loss, the development of fishers' business and alternative economic activities obtained large consent, except among MPA managers and tourist operators, respectively. At the end, a strong consent emerged for the supplementary options, particularly the increase of surveillance, the performing of monitoring and research activities and the development of participatory processes, consistently with other studies on human-wildlife conflict management (Marino et al., 2021).

4.3. Study limitations

The results provided are useful for understanding the stakeholders' points of view and preferences, forming a basis to further participatory process and negotiate solutions (Mustajoki et al., 2011). However, some study limitations must be highlighted. Firstly, the stakeholders involved, especially fishers and tourist operators, were only a limited representation of the relative economic sectors. The choice to limit the number of interviewees was due to the need of involving persons able to cooperate and willing to accept the need of considering different stakeholder groups with their different opinions and requirements (Marino et al., 2021). Thus, the opinions expressed by fishers and tourist operators cannot be considered a full representation of the relative stakeholder groups, and this may have influenced the outcome of the management evaluation (Marino et al., 2021). Further, individual interviews and separate meetings with each stakeholder group have led to a lack of interaction between different groups with competing interests. Even if this approach was useful in building trust and working relationships between project groups and stakeholders (Mustajoki et al., 2011), it prevents the opportunity for participants to shift positions and learn from the others' opinions. Another issue concerns the lack of quantitative analysis: since the criteria score derived from open discussions, which may have influenced stakeholder evaluations (Redpath et al., 2004), they cannot be considered independent. Further effort should be made to apply formal statistical analysis and evaluate within and between stakeholder group differences. Although the aggregation of our results by stakeholder groups was useful for summarizing their points of views (Redpath et al., 2004), no consensus for the management options can be inferred here without a further and collective deliberation.

5. Conclusion

Although a "silver bullet" management solution does not exist yet (Jog et al., 2022), our approach represents an initial framework for assessing and managing the conflict between fishers and dolphins by using ecological data and stakeholder involvement. Our participatory exercise provided stakeholders with a platform to include their perspectives and work with researchers and institutions for the creation of a shared, more sustainable vision for the future. However, other decision-model exercises should be planned, particularly with the aim to: i) reduce the tendency of stakeholders to maintain preconceived positions, despite research and monitoring outcomes; ii) focus on the most preferred alternatives and find compromise solutions in order to satisfy the mostly economically impacted stakeholder (fishers) without causing disagreement amongst the other stakeholders; iii) implement a participatory process in which stakeholders and management body were simultaneously involved to increase mutual understanding and acceptability and legitimize management decisions; iv) involve the individuals affected or worried about the local fisher-dolphin conflict but also professionals from other geographical areas and sectors (mainly sociology, anthropology and economics) in order to obtain the most complete picture of how people interact with this human-wildlife conflict in a much wider area (Dickman, 2010; Killion et al., 2020). Finally, research and monitoring activities over multiple years will be pivotal to assess additional factors that might influence depredation, identify the spatial overlap between small-scale fisheries and bottlenose dolphins, estimate

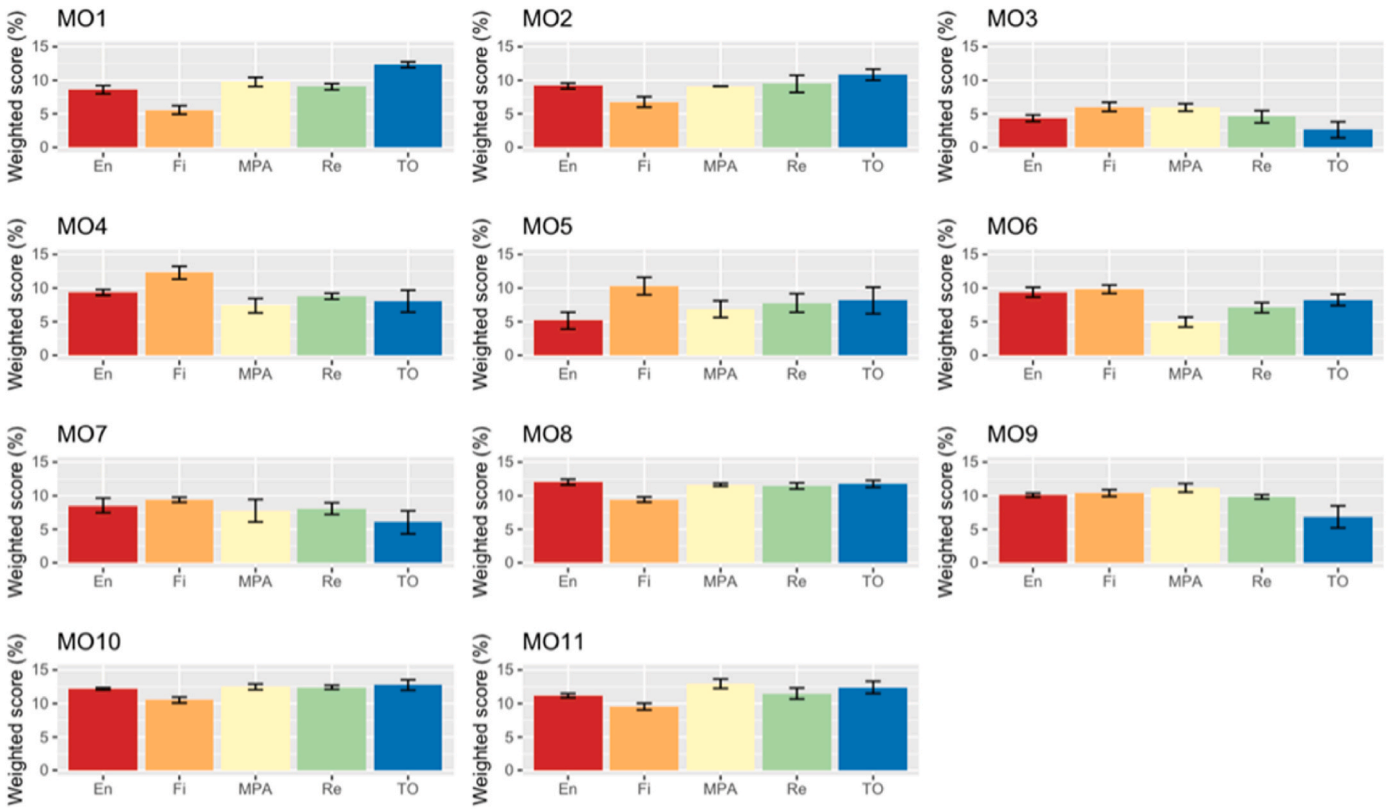


Fig. 7. Weighted standardized scores (mean ± SE) for each management option and stakeholder group. MO1: Temporal and spatial avoidance; MO2: Fishing gear change; MO3: Deterrent devices; MO4: Damage-based compensation; MO5: Dolphin-based economic compensation; MO6: Development of fishers' business; MO7: Development of alternative economic activities; MO8: Training and education activities for fishers; MO9: Surveillance; MO10: Monitoring and research activities; MO11: Participatory process. En: environmentalists; Fi: fishers; MPA: marine protected area menagers; Re: researcher; TO: tourist operators.

patterns of dolphin bycatch, and define conflict risks that remain to be unveiled (Karanth et al., 2012).

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Nicola Arrostuto, Nicola Fois reports financial support was provided by Autonomous Region of Sardinia.

Data availability

Data will be made available on request.

Acknowledgments

This work was supported by the Regione Autonoma della Sardegna through the project 'Realizzazione di uno studio sull'interazione dei cetacei con le attività di pesca per favorire una migliore attuazione della misura 1.40, paragrafo 1, lettera h) del Regolamento (UE) n. 508/2014, ai sensi dell'art. 5, comma 30, della L.R. n. 40/2018'. GC and GS acknowledge the support of NBFC to University of Sassari and University of Palermo, funded by the Italian Ministry of University and Research, PNRR, Missione 4, Componente 2, "Dalla ricerca all'impresa", Investimento 1.4 Project CN00000033. We would like to thank all the stakeholders involved in the field activities and Multi Criteria Decision Analysis. Special thanks to Lauren Polimeno for English editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.119797.

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