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RESEARCH NOTE

Testing low-cost mitigation devices to reduce dolphin depredation in artisanal trammel nets in the northern Alboran Sea

Evaluación de dispositivos de mitigación de bajo costo para reducir la depredación por delfines en redes de trasmallo de la pesca artesanal del norte del mar de Alborán

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Abstract.- Dolphin depredation is a significant problem for artisanal net fisheries worldwide. Interactions between dolphins and fishing nets can lead to entanglement, gear damage, and loss of catch. Although acoustic deterrents, such as dolphin anti-predation pingers, are widely used, they are costly. The objective of this study was to develop and assess the effectiveness of new low-cost devices to reduce depredation by common bottlenose dolphin (*Tursiops truncatus*) in artisanal fisheries in the Alboran Sea (Mediterranean). These innovative devices included recycled glass bottles and compact discs (CDs), based on the premise that they could impact the dolphins' echolocation sense. A total of 51 experimental fishing operations were conducted at depths ranging from 4 to 29 m off the coast of Malaga, Spain. Results indicate that the new low-cost bottle and CDs based devices had a deterrent effect on depredation by dolphins. A statistically significant logistic model was derived for the observed probability of depredation by dolphins in relation to the use of recycled glass bottles and CDs as acoustic mitigation devices. Limitations of these new low-cost devices are discussed, along with future research directions and their relationship to environmental and fisheries variables.

Key words: Dolphin depredation, artisanal fisheries, trammel nets, low-cost mitigation devices

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INTRODUCTION

Local small-scale fisheries play a fundamental role in supporting food security, sustaining coastal livelihoods, and contributing to local economies worldwide. Their ecological, social, and economic importance has been widely recognized, particularly in the Mediterranean region, where they are considered essential for sustainable fisheries management and community development (Griffiths *et al.* 2007, Teh & Pauly 2018, Lloret *et al.* 2018).

In the Alboran Sea, small-scale fisheries are predominantly artisanal and are characterized using a wide variety of fishing gears, with trammel nets representing the most common gear type (Camiñas 1990, Baro *et al.* 2021, Idrissi & Benziane 2021, Báez *et al.* 2023). In the northern Alboran Sea, the terms small-scale and artisanal fisheries are therefore used interchangeably (Baro *et al.* 2021). Beyond their economic relevance, these fisheries constitute an important component of the region's culture heritage, preserving traditional fishing practices that have been maintained for generations (Camiñas 1990, Baro *et al.* 2021, Báez *et al.* 2023). The artisanal fishing sector has been recognized as an essential component of the fishing industry in the northern Alboran Sea, accounting for a significant part of the total landed catch and economic profit (Camiñas 1990, Baro *et al.* 2021, Idrissi & Benziane 2021). Specifically, artisanal fisheries contribute 10% of the total weight landed by the fishing fleets operating in the area and generate around 21% of the total fish sales in the first-sale fish markets involved. The high value of sales achieved by these fresh products is due to their exceptional quality and the minimum time required to get them from landing points to final consumers (Camiñas 1990, Baro *et al.* 2021).

Local and small-scale fisheries in the Alboran Sea sub-region face a range of challenges that threaten their sustainability and economic viability, made worse by lack of juvenile replenishment in the fisheries. In addition to the issues of increasing costs, rising fuel prices, and the impact that the COVID-19 pandemic had on the fishing sector (Cousido-Rocha *et al.* 2023), one of the most significant daily challenges facing fishermen in the northern Alboran is the depredation of their catches by dolphins (Báez *et al*. 2023). This issue is particularly acute in the region and poses a significant threat to fishermen's economic well-being and livelihood (Aguilera *et al.* 2020, Báez *et al.* 2023, Cousido-Rocha *et al.* 2023).

Depredation by dolphins on fishing nets, particularly by the common bottlenose dolphins (*Tursiops truncatus*), is a widespread issue documented throughout the Mediterranean Sea (Brotons *et al.* 2008, Garagouni *et al.* 2022, Jog *et al.* 2022, Kaddouri *et al.* 2022, Pardalou *et al.* 2022, Li Veli *et al.* 2023) and adjacent waters (Marçalo *et al.* 2024, 2025). Depredation occurs when dolphins interact with fishing gear by removing or damaging fish caught in the nets, resulting in substantial economic losses for fishers and potential negative consequences for dolphin populations (Báez *et al.* 2023, Marçalo *et al.* 2025). Moreover, these interactions can create hazardous situations for both dolphins and fishers, as dolphins may become entangled in fishing gear and drown (Brotons *et al.* 2008, Garagouni *et al.* 2022, Jog *et al.* 2022, Kaddouri *et al.* 2022, Pardalou *et al.* 2022, Li Veli *et al.* 2023).

In the Alboran Sea, depredation may be particular concern because the region constitutes an important habitat for the common bottlenose dolphins and supports a substantial resident population (Karamitros *et al.* 2020). Consequently, this issue has received increasing scientific attention in recent years (Aguilera *et al.* 2020, Báez *et al.* 2023, Cousido-Rocha *et al.* 2023). Aguilera *et al.* (2020) reported that, according to local fishers, the frequency of depredation events has increased in recent years. Similarly, Báez *et al.* (2023) estimated that approximately 20% of trammel net sets deployed by the artisanal fleet operating off the Málaga coast were affected by dolphin depredation. Their study also identified fishing operation characteristics, particularly net deployment depth and soak time, as the main factors influencing the occurrence of these interactions, reflecting differences in fishing strategies among vessels.

To mitigate dolphin depredation on fishing gear, several deterrent strategies have been developed, including acoustic devices such as Dolphin Anti-Depredation Pingers (DADPs) and Dolphin Deterrent Devices (DDDs) (Brotons *et al.* 2008, Gazo *et al.* 2008, Ayadi *et al.* 2013, Dawson *et al.* 2013, Waples *et al.* 2013, Maccarrone *et al.* 2014, Bruno *et al.* 2021, Marçalo *et al.* 2025). These devices emit acoustic signals intended to discourage dolphins from approaching fishing nets, either by generating aversive sounds or by producing high-frequency signals that interfere with their behaviour around fishing gear. Although acoustic deterrents have shown potential for reducing interactions, their application in artisanal fisheries remain limited because they are relatively costly, unfamiliar to many fishers, difficult to deploy, and contribute to underwater anthropogenic noise (Wisniewska *et al.* 2016). Consequently, their effectiveness and long-term suitability have been questioned (Kremers *et al.* 2016, Findlay *et al.* 2018, Fouda *et al.* 2018, Omeyer *et al.* 2020). Furthermore, because of common bottlenose dolphins primarily detect fishing nets using echolocation (Bielli *et al.* 2020), alternative mitigation approaches should either interfere with this sensory mechanism or employ novel deterrents that reduce depredation without compromising fishing operations.

More recently, bycatch reduction technologies (BRTs) have incorporated sensory cues to increase the detectability of fishing gear by non-target species, including the use of light-emitting diodes (LEDs) (Bruno *et al.* 2021). However, these technologies also involve substantial implementation costs, limiting their adoption by small-scale fisheries. Recognizing this limitation, Read (2008) emphasized the need to develop low-cost mitigation measures suitable for developing countries. Following this approach, Berggren *et al.* (2020)[1] evaluated recycled plastic bottles as an inexpensive method to reduce cetacean bycatch in gillnet fisheries. This low-cost approach may also provide an alternative for reducing dolphin depredation in artisanal fisheries, although its effectiveness for this purpose has received little scientific attention.

Building on these previous approaches, we developed two inexpensive mitigation devices intended to reduce depredation by common bottlenose dolphins. The first consisted of unmodified compact discs (CDs), whereas the second consisted of recycled glass bottles containing an internal screw suspended by a thread, designed to strike the inner wall of the bottle during movement and generate additional acoustic stimuli. CDs were selected because of their reflective properties, which could potentially interfere with dolphins' perception of fishing gear, whereas the glass bottles were inspired by the low-cost mitigation approach proposed by Berggren *et al.* (2020)[1].

It was hypothesized that the recycled CDs and modified glass bottles would reduce dolphin depredation by modifying the sensory cues perceived by dolphins during interactions with fishing gear. Accordingly, the aim of this study was to develop and experimentally evaluate the effectiveness of these low-cost mitigation devices in reducing depredation by common bottlenose dolphins (*Tursiops truncatus*) on artisanal trammel nets in the Alboran Sea (Mediterranean Sea). Finally, the potential

[1]Berggren P, AJ Temple, J Alfaro-Shigueto & JC Mangel. 2020. Low-cost solutions to cetacean bycatch in global gillnet fisheries. In: IWC SC68. International Whaling Commission, Electronic Meeting, pp. 1-4. <https://archive.iwc.int/pages/download.php?direct=1&noattach=true&ref=17553&ext=pdf&k=a1199ab647>

applicability, limitations, and future improvements of these devices as practical mitigation tools for small-scale fisheries were analyzed.

Materials and methods

Field trials were conducted between 9 February and 14 June 2022 along the coast of Málaga Province in southern Spain, an area that supports the largest concentration of artisanal fishing vessels in the country, accounting for approximately 52% of the national fleet (Baro *et al*. 2021). Three volunteer vessels operating from the ports of Caleta de Vélez (Vélez, Málaga) and Fuengirola were selected for this study (Fig. 1). These ports were chosen because they had previously been subject to extensive daily port-based monitoring of dolphin fishery interactions. The participating vessels ranged from 5 to 7 m in length overall and operated trammel nets at depths between 4 and 29 m.

Together, these two ports account for nearly half of the registered small-scale fishing fleet in Málaga Province, which is characterized by its operational flexibility and the use of a wide variety of fishing gears (Camiñas 1990, Baro *et al.* 2021). The present study focused exclusively on the artisanal trammel-net fishery during the season when target species are abundant and market demand is high. This fishery is particularly vulnerable to gear damage caused by invasive algae and by depredation from common bottlenose dolphins (*Tursiops truncatus*) (Báez *et al.* 2023).

The principal target species include common cuttlefish (*Sepia officinalis*), striped red mullet (*Mullus surmuletus*), slender rockfish (*Scorpaena elongata*), common seabream (*Pagrus pagrus*), common pandora (*Pagellus erythrinus*), common dentex (*Dentex dentex*), redbanded seabream (*Pagrus auriga*), and greater amberjack (*Seriola dumerili*), among others (Báez *et al.* 2023).

Low-cost mitigation devices

Two low-cost mitigation devices were evaluated in this study: modified recycled glass bottles and compact discs (CDs).

The bottle devices were constructed from empty 330-mL green glass beer bottles. Prior to use, the bottles were thoroughly cleaned and dried. A metal bolt was suspended inside each bottle using monofilament fishing line attached to a screw fixed to the cork stopper, allowing the bolt to swing freely and strike the inner wall of the bottle as the device moved with wave action. An additional small metal piece was incorporated to increase sound production. The bottles were then sealed with cork stoppers, waterproofed with silicone sealant, and wrapped with vulcanized insulating tape (Fig. 2a). The devices were attached to the headrope of the trammel net every 25 m using thread commonly employed for net repair. They were designed to generate intermittent acoustic stimuli through the movement of the suspended bolt inside the bottle.

The second mitigation device consisted of new compact discs (CDs), selected because of their reflective properties and low cost. CDs were attached to the headrope of the trammel net at 25-m intervals (Fig. 2b).

Bottle and CD experiments were conducted independently; the two devices were never deployed simultaneously on the same net.

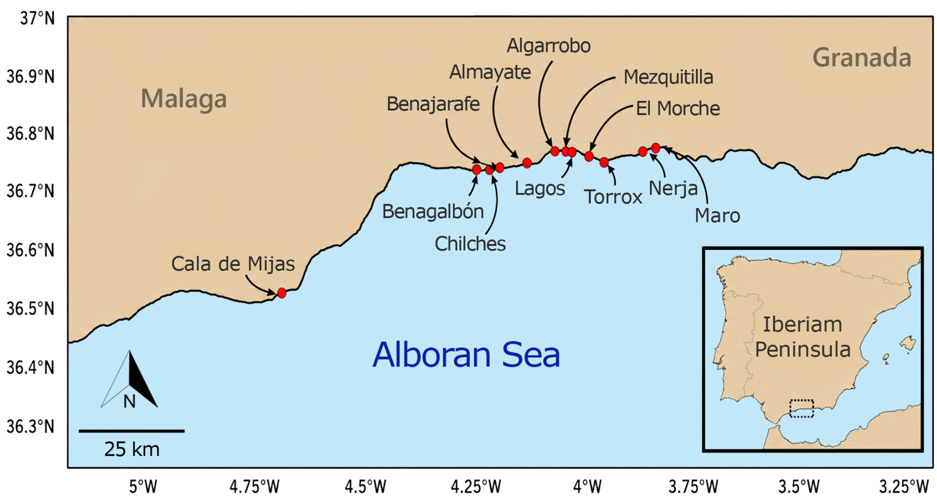

Figure 1. Map of the study area showing the twelve fishing sites where collaborating fishers conducted the experiments. Geographic coordinates (latitude and longitude) are expressed in decimal degrees / Mapa del área de estudio que muestra los doce sitios de pesca donde los pescadores colaboradores realizaron los experimentos. Las coordenadas geográficas se presentan en grados decimales (latitud y longitud)

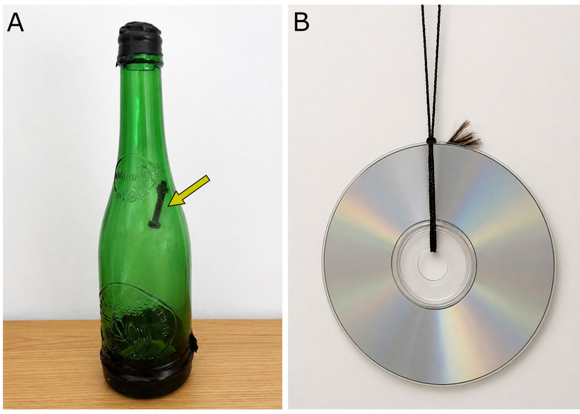

Figure 2. Low-cost mitigation devices evaluated in this study: A) recycled glass bottle (330 mL; approximately 23 cm in height and 6.5 cm in diameter) containing a metal bolt suspended by a string (arrow); and B) standard compact disc (CD) (12 cm in diameter and 1.2 mm thick) / Dispositivos de mitigación de bajo costo evaluados en este estudio: A) botella de vidrio reciclada de 330 mL (aproximadamente 23 cm de altura y 6,5 cm de diámetro) que contiene un perno metálico suspendido mediante un hilo (flecha); y B) disco compacto (CD) estándar (12 cm de diámetro y 1,2 mm de espesor)

Experimental design

Separate fishing trials were conducted to evaluate each mitigation device. In each trial, a commercial trammel net was divided into two equal sections: (1) a treatment section equipped with mitigation devices placed every 25 m, and (2) an untreated control section without mitigation devices (Fig. 3). This paired design allowed direct comparison between protected and unprotected sections of the same net while minimizing variability associated with fishing location, environmental conditions, and fishing operations.

The mitigation devices were installed along approximately half of the net in each fishing operation. The fishermen agreed to evaluate the devices only over part of the gear until evidence of their effectiveness became available. This design also enabled comparisons between treatment and control sections under identical fishing conditions. Reducing fishing vessels' reluctance to participate in the proposed new experiments, the project compensated each captain or vessel for each experimental fishing operation.

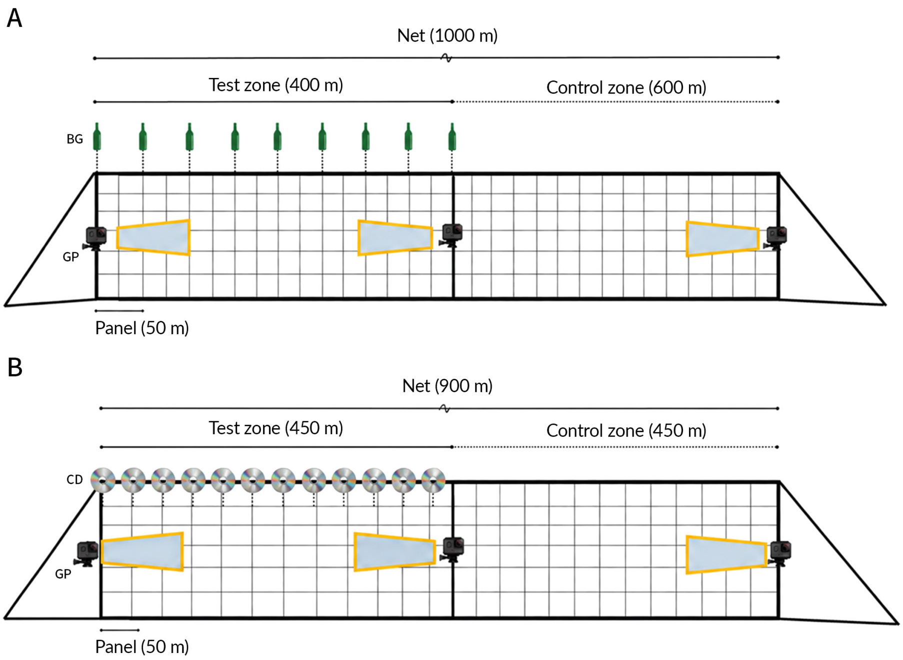

Figure 3. Experimental design of the fishing trials: (A) experiment using recycled glass bottles (BG) attached to the headrope at 25 m intervals; and (B) experiment using compact discs (CDs) attached to the headrope at 25 m intervals. In both experiments, the treatment and control sections of the net are indicated. The location and orientation of the GoPro cameras (GP) are also shown (yellow shaded boxes) / Diseño experimental de los lances de pesca: A) experimento con botellas de vidrio (BG) instaladas cada 25 m en el cabo superior de la red; y B) experimento con discos compactos (CD) fijados cada 25 m al cabo superior de la red. En ambos casos se indican la sección de tratamiento y la sección de control. Asimismo, se muestra la ubicación y orientación de las cámaras GoPro (GP), representadas mediante un recuadro amarillo sombreado

Monitoring fishing operations

Fishing operations were monitored using GoPro™ cameras (GoPro Inc., USA) attached to the headrope close to the mitigation devices to record dolphin activity and interactions with the fishing gear. Owing to the small size of the participating artisanal vessels (5-7 m length overall), onboard scientific observers could not be accommodated. Therefore, fishing activities were additionally monitored through daily port-based surveys.

Dolphin interactions were assessed following the criteria of Báez *et al.* (2023), who defined an interaction as any break in the trammel net larger than the palm of a hand that was associated with the removal or partial consumption of fish captured in the net.

Statistical analysis

A series of stepwise binary logistic regression models were performed to assess whether the probability of dolphin depredation observed in trammel nets could be explained by different independent variables. These variables included the fishing area (Area), net material (nylon or monofilament), depth of the fishing ground (Depth), the month in which the experimental fishing operation was conducted (Month), the presence or absence of interaction in the experimental half of the net, and the type of deterrent device deployed (Device) either glass bottles (BG), compact disc (CD), or no device (WD).

The study included 19 half-net sets equipped with glass bottles, 32 half-net sets using CDs, and 51 half-net sets without any device serving as control treatments.

To examine the effects of these devices on depredation by common bottlenose dolphins, different models were fitted to compare: (1) the combined effect of both deterrent devices (glass bottles and CDs) against the control condition, (2) the specific effect of only CDs relative to the control, and (3) the specific effect of only glass bottles relative to the control. These comparisons assessed the extent to which each mitigation device influenced the likelihood of dolphin interactions with the fishing nets. Model coefficients were assessed using an Omnibus test (Hosmer & Lemeshow 2000), which is used to determine if there are significant differences between the -2LL (less than twice the natural logarithm of the likelihood) of the initial step and the -2LL of the model, using a Chi-squared test with one degree of freedom. In the case of logistic regression, the Wald test was used to compare the models according to the best-fit criterion. This technique is used to determine 'significant' variables of the set of predictors used in a varied model with binary variables or models with continuous variables (Peng *et al*. 2002). In addition, discriminatory ability of the model (trade-off between sensitivity and specificity) was evaluated with the area under the ROC (Receiver Operating Characteristic) curve (AUC), which provides a scalar value representing the expected discriminatory ability of the model (Lobo *et al*. 2008).

Ultimately, the model with the lowest Akaike Information Criterion (AIC) value (Akaike 1973) was selected. The AIC is a model selection criterion that balances goodness of fit and model complexity. Specifically, it rewarded models that best explain the observed data, as assessed by the likelihood function, while imposing a penalty that increases with the number of estimated parameters. This penalty is crucial to avoid overfitting, since adding more parameters to a model generally improves its fit to the data, but may reduce its generalizability to new observations. By incorporating this trade-off, the AIC facilitates the selection of models that achieve an optimal balance between explanatory power and parsimony.

Results and discussion

A total of 102 half-net deployments were analyzed. Dolphin depredation was recorded in 53 (52.0%) of the deployments, occurring in 30 of the 51 control half-nets (58.8%), 18 of the 32 half-nets equipped with compact discs (56.3%), and 5 of the 19 half-nets equipped with glass bottles (26.3%). A summary of the characteristics of each half-net deployment and the corresponding fishing outcomes is presented in Table 1.

During the experiments with compact discs, dolphin's depredation was recorded only in the control section in four deployments, in both the control and treatment sections in 18 deployments, and in neither section in 10 deployments (Table 1). No deployments showed depredation exclusively in the treatment section.

Logistic regression models were fitted using Area, Month, Depth, Net Type, and deterrent device as explanatory variables. Of the candidate models evaluated, two models showed statistically significant overall fits (Table 2). Both models showed a statistically significant overall fit according to the Omnibus test. The model including both glass bottles and CDs received slightly greater support than the model including glass bottles alone, as indicated by its lower Akaike Information Criterion (AIC) value and higher Area Under the Receiver Operating Characteristic Curve (AUC) (Table 2). The fitted logistic regression model was:

$$y = 0.357 + [\mathrm{Device(BG)} \times (-1.386)] + [\mathrm{Device(CD)} \times -(0.105)] + [\mathrm{Device(WD)} \times 0]$$

where WD represents the reference category, corresponding to the control treatment without a deterrent device.

Thus, the use of glass bottles (BG) and CDs showed a significant effect compared with the control treatment without a deterrent device (WD)

A summary video of the experimental fishing operations was uploaded to YouTube (of 66 min and 17 s long), in which it was possible to observe a dolphin swimming around the net at minute 17:08 (@jairocastrogutierrez)[2].

[2] Low-cost dolphin mitigation devices experiments <https://youtu.be/mSjEq2BtaO8>

Table 1. Characteristics of each half-net deployment for all experimental fishing sets, including set code (Code), fishing area (Area), fishing depth (Depth), net material (nylon or monofilament), sampling month (Month), occurrence of dolphin depredation (Interaction), and deterrent device deployed (Device) / Características de cada mitad de la red en todos los lances experimentales, incluyendo el código del lance (Código), área de pesca (Área), profundidad del caladero (Profundidad), material de la red (nylon o monofilamento), mes de la operación de pesca (Mes), ocurrencia de depredación por delfines en cada mitad de la red (Interacción) y el tipo de dispositivo de mitigación utilizado (Dispositivo)

N° half-net deploy	Code	Area	Depth (m)	Net material	Month	Interaction (*)	Device
1	BG01	Cala de Mijas	4.57	Nylon	February	0	BG
2	BG02	Nerja	6.69	Nylon	May	0	BG
3	BG03	Maro	6.69	Nylon	May	1	BG
4	BG04	Algarrobo	21.94	Monofilament	May	1	BG
5	BG05	Lagos	8.23	Nylon	May	1	BG
6	BG06	Nerja	8.23	Nylon	May	0	BG
7	BG07	Nerja	8.23	Nylon	May	0	BG
8	BG08	Nerja	9.14	Nylon	May	0	BG
9	BG09	Nerja	9.14	Nylon	June	0	BG
10	BG10	Lagos	5.49	Nylon	May	0	BG
11	BG11	Nerja	9.14	Nylon	May	0	BG
12	BG12	Nerja	9.14	Nylon	June	0	BG
13	BG13	Nerja	9.14	Nylon	June	0	BG
14	BG14	Nerja	9.14	Nylon	June	0	BG
15	BG15	Nerja	9.14	Nylon	June	0	BG
16	BG16	Nerja	9.14	Nylon	June	0	BG
17	BG17	Nerja	8.23	Nylon	June	0	BG
18	BG18	Torrox	8.23	Nylon	June	1	BG
19	BG19	Nerja	10.05	Nylon	June	1	BG
20	CD01	Maro	6.4	Nylon	February	0	CD
21	CD02	Maro	6.4	Nylon	March	1	CD
22	CD03	Lagos	23.77	Monofilament	March	0	CD
23	CD04	Lagos	22.86	Monofilament	March	0	CD
24	CD05	El Morche	21.94	Monofilament	March	1	CD
25	CD06	Lagos	17.37	Nylon	April	1	CD
26	CD07	Chilches	21.94	Monofilament	April	0	CD
27	CD08	Benagalbón	13.72	Monofilament	April	1	CD
28	CD09	Nerja	8.23	Nylon	April	0	CD
29	CD10	Benajarafe	19.2	Monofilament	April	1	CD
30	CD11	Maro	10.05	Nylon	April	0	CD
31	CD12	Maro	9.14	Nylon	April	1	CD
32	CD13	Maro	8.23	Nylon	April	1	CD
33	CD14	Nerja	9.14	Nylon	May	0	CD
34	CD15	Almayate	29.3	Monofilament	April	1	CD
35	CD16	Lagos	6.4	Monofilament	May	1	CD
36	CD17	Maro	10.97	Nylon	May	1	CD
37	CD18	Nerja	8.23	Nylon	May	1	CD
38	CD19	Nerja	8.23	Nylon	May	0	CD
39	CD20	Maro	7.31	Nylon	May	0	CD
40	CD21	Nerja	5.49	Nylon	May	0	CD
41	CD22	Nerja	9.14	Nylon	May	1	CD
42	CD23	Nerja	6.69	Nylon	May	0	CD
43	CD26	Mezquitilla	20.12	Monofilament	May	0	CD
44	CD27	El Morche	8.23	Nylon	June	1	CD
45	CD28	Mezquitilla	10.97	Nylon	June	1	CD
46	CD29	Benajarafe	10.97	Nylon	June	0	CD
47	CD30	Benajarafe	10.97	Nylon	June	1	CD
48	CD31	Benajarafe	10.97	Nylon	June	1	CD
49	CD32	Benajarafe	25.6	Monofilament	June	1	CD
50	CD33	Chilches	7.32	Nylon	June	1	CD
51	CD34	Benajarafe	8.23	Nylon	June	0	CD

(*): 0= no interaction with dolphins; 1= interaction with dolphins. BG: glass bottles, CD: compact disk

N° half-net deploy	Code	Area	Depth (m)	Net material	Month	Interaction (*)	Device
1	BG01	Cala de Mijas	4.57	Nylon	February	0	WD
2	BG02	Nerja	6.69	Nylon	May	0	WD
3	BG03	Maro	6.69	Nylon	May	1	WD
4	BG04	Algarrobo	21.94	Monofilament	May	1	WD
5	BG05	Lagos	8.23	Nylon	May	1	WD
6	BG06	Nerja	8.23	Nylon	May	0	WD
7	BG07	Nerja	8.23	Nylon	May	0	WD
8	BG08	Nerja	9.14	Nylon	May	0	WD
9	BG09	Nerja	9.14	Nylon	June	0	WD
10	BG10	Lagos	5.49	Nylon	May	0	WD
11	BG11	Nerja	9.14	Nylon	May	0	WD
12	BG12	Nerja	9.14	Nylon	June	1	WD
13	BG13	Nerja	9.14	Nylon	June	0	WD
14	BG14	Nerja	9.14	Nylon	June	1	WD
15	BG15	Nerja	9.14	Nylon	June	0	WD
16	BG16	Nerja	9.14	Nylon	June	1	WD
17	BG17	Nerja	8.23	Nylon	June	0	WD
18	BG18	Torrox	8.23	Nylon	June	1	WD
19	BG19	Nerja	10.05	Nylon	June	1	WD
20	CD01	Maro	6.4	Nylon	February	0	WD
21	CD02	Maro	6.4	Nylon	March	1	WD
22	CD03	Lagos	23.77	Monofilament	March	0	WD
23	CD04	Lagos	22.86	Monofilament	March	0	WD
24	CD05	El Morche	21.94	Monofilament	March	1	WD
25	CD06	Lagos	17.37	Nylon	April	1	WD
26	CD07	Chilches	21.94	Monofilament	April	0	WD
27	CD08	BeCAgalbón	13.72	Monofilament	April	1	WD
28	CD09	Nerja	8.23	Nylon	April	1	WD
29	CD10	BeCAjarafe	19.2	Monofilament	April	1	WD
30	CD11	Maro	10.05	Nylon	April	1	WD
31	CD12	Maro	9.14	Nylon	April	1	WD
32	CD13	Maro	8.23	Nylon	April	1	WD
33	CD14	Nerja	9.14	Nylon	May	1	WD
34	CD15	Almayate	29.3	Monofilament	April	1	WD
35	CD16	Lagos	6.4	Monofilament	May	1	WD
36	CD17	Maro	10.97	Nylon	May	1	WD
37	CD18	Nerja	8.23	Nylon	May	1	WD
38	CD19	Nerja	8.23	Nylon	May	0	WD
39	CD20	Maro	7.31	Nylon	May	0	WD
40	CD21	Nerja	5.49	Nylon	May	0	WD
41	CD22	Nerja	9.14	Nylon	May	1	WD
42	CD23	Nerja	6.69	Nylon	May	1	WD
43	CD26	Mezquitilla	20.12	Monofilament	May	0	WD
44	CD27	El Morche	8.23	Nylon	June	1	WD
45	CD28	Mezquitilla	10.97	Nylon	June	1	WD
46	CD29	BeCAjarafe	10.97	Nylon	June	0	WD
47	CD30	BeCAjarafe	10.97	Nylon	June	1	WD
48	CD31	BeCAjarafe	10.97	Nylon	June	1	WD
49	CD32	BeCAjarafe	25.6	Monofilament	June	1	WD
50	CD33	Chilches	7.32	Nylon	June	1	WD
51	CD34	Benajarafe	8.23	Nylon	June	0	WD

(*): 0= no interaction with dolphins; 1= interaction with dolphins: WD: without a deterrent device

Table 2. Summary of goodness-of-fit statistics for the logistic regression models fitted to evaluate glass bottles (BG), compact discs (CDs), and their combined use (BG + CDs) as mitigation devices. Abbreviations: AUC, area under the receiver operating characteristic curve; AIC, Akaike Information Criterion / Tabla resumen de las estadísticas de bondad de ajuste de los modelos de regresión logística utilizados para evaluar las botellas de vidrio (BG), los discos compactos (CDs) y su uso combinado (BG + CDs) como dispositivos de mitigación. Abreviaturas: AUC, área bajo la curva característica operativa del receptor; AIC, criterio de información de Akaike

Independent variable	Omnibus test signification	R^2 Nagelkerke	AUC	AIC
CDs+BG	0.041 (df: 2)	0.081	0.604	136.865
BG	0.012 (df: 1)	0.080	0.596	136.919
CDs	NF	NF	NF	NF

NF: Model not fitted.

Previous studies by Báez *et al.* (2023) identified spatial and temporal factors as significant in explaining dolphin depredation in fishing nets, suggesting a potential correlation with the abundance of bottlenose dolphins in the area. Similarly, studies conducted in Algarve waters have also reported seasonal effects on depredation patterns (Marçalo *et al.* 2024). However, no significant spatial or temporal effects were observed in our experiments. Additionally, no significant models were obtained for net material (nylon or monofilament) or fishing ground depth. The lack of significance of fishing ground depth can be attributed to the fact that the study focused on shallow areas, between 4 and 29 m, which had previously been identified as zones with the greatest impact of depredation by dolphin (Báez *et al.* 2023).

In contrast, the use of low-cost deterrent devices, such as recycled glass bottles and CDs, had a significant effect on reducing depredation by dolphins on fishing nets. Notably, glass bottles proved to be significantly more effective than CDs. However, due to the fragility of glass, fishermen were reluctant to use them, fearing that they would break during retrieval with the automatic trawl machine and had to manually retrieve the section of the net containing the glass bottles, which increased the duration of the fishing operation and complicated overall handling. Additionally, they expressed concern that the glass bottles might scare away from the target fish species. One of the volunteer fishermen refused to continue participating in the experiments with glass bottles despite the incentives offered. These practical limitations demonstrated that glass bottles were not the most accepted option among fishermen, but rather CDs, which were preferred by fishermen due to their ease of deployment and retrieval, as they did not interfere with normal fishing operations. CDs have been widely used as scarecrow devices due to their affordability and accessibility. However, a major drawback of CDs is their rapid degradation. The plastic coating on CDs peels off after several fishing operations, raising concerns about potential environmental pollution. Consequently, although the experimental results suggest that CDs could serve as a deterrent, their long-term use is not recommended due to the risk of contributing to marine plastic pollution. Furthermore, the rapid deterioration of CDs could reduce their effectiveness over time, leading to inconsistency deterrent effects. A comprehensive economic analysis of the impact of these devices on fleet revenues is necessary before considering their large-scale implementation in other fleets using trammel nets for similar target species.

The use of Acoustic Deterrent Devices (ADD) has been extensively studied, with results varying from significant reductions in depredation (Marçalo *et al.* 2025) to cases where ADD had no deterrent effect (Cox *et al.* 2004, McPherson *et al.* 2004, Erbe *et al.* 2016). Additionally, ADD raise welfare concerns, as they can cause habitat exclusion, leading cetaceans to avoid essential areas (Marçalo *et al.* 2025). In response to these concerns, and due to the variability in the effectiveness of ADDs and their high cost as technological devices, most fishermen do not invest in their use.

To date, few attempts have been made to develop low-cost deterrent devices. For example, Kiszka *et al.* (2021) tested low-cost modifications to fishing nets to reduce dolphin bycatch, while Berggren *et al.* (2020)[1] designed an accessible mitigation device costing no more than $0.50 per net section to minimize interactions between cetaceans and artisanal fishermen. This device was tested between 2019 and 2020 in Puerto Salaverry, Perú (8°12'S, 78°58'W) in artisanal driftnet fisheries primarily targeting elasmobranchs. However, the trial found that the glass bottle alarms did not significantly reduce the bycatch of dolphin or sea turtle in gillnets (Berggren *et al.* 2020)[1].

This study represents a first attempt to develop a low-cost deterrent device aimed at reducing depredation on fishing nets by dolphins. Although preliminary findings suggest that visual stimuli such as CDs or sound generated by marbles and screws inside glass bottles can deter dolphins, the results are not yet definitive. A viable, and cost-effective prototype that is practical for fishermen during their operations has not yet been developed.

This study has certain limitations. The deterrent devices were tested in a relatively small number of experimental sets (51 fishing operations), and no data is available on their long-term effectiveness. Several long-term studies have shown that dolphins can become habituated to deterrent devices that emit sounds, such as ultrasonic pingers (Cox *et al.* 2004, Carlström *et al.* 2009). In some cases, a "dinner bell effect" may even develop, where dolphins associate the devices with an easy source of food, ultimately reducing their deterrent effectiveness (Dawson *et al.* 2013). Although the CDs do not emit sound, any new object introduced into fishing nets may initially startle dolphins, but they may also become habituated over time, potentially leading to the same "dinner bell" phenomenon. Thus, the initial deterrent effect observed in this study may be due to the novelty of the devices, and their effectiveness could diminish over time. To maintain the deterrent effects, it may be necessary to modify the shape and appearance of the devices to prevent habituation.

Further research is needed to evaluate effectiveness of deploying both deterrent devices simultaneously and to assess their long-term performance under commercial fishing conditions. Building on the findings of this study, future low-cost deterrent devices should prioritize durability, high visibility or reflectivity, and unconventional shapes, while ensuring that they neither reduce catches of target species nor contribute to marine pollution. Such devices should provide an effective, environmentally responsible, and economically feasible option for mitigating dolphin depredation in artisanal fisheries.

Addressing dolphin depredation remains essential to maintaining long-term sustainability and economic viability of small-scale fisheries in the Alboran Sea (Báez *et al.* 2023). Achieving this objective will require an integrated management approach that combines the development and evaluation of effective mitigation measures with responsible fishing practices aimed at reducing interactions between dolphins and fishing gear. The implementation of these measures should be guided by the best available scientific evidence while balancing the conservation of marine biodiversity with the socioeconomic needs of local fishing communities.

Overall, the results of this study demonstrate that simple, inexpensive mitigation devices based on recycled materials have the potential to reduce dolphin depredation in artisanal trammel-net fisheries, providing a promising foundation for the development of practical mitigation strategies.

Statements

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Author contributions

J.C.B. and J.A.C. conceived the study and were responsible for its conceptualization and methodological design. J.C.G. conducted the field sampling and compiled the database. J.C.B. performed the statistical analyses, and J.C.G. prepared the figures. J.C.B. wrote the original draft of the manuscript. All authors contributed to the review and editing of the manuscript and approved the final version for publication. Funding acquisition was carried out by J.A.C.

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Data availability statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that they have no conflicts of interest.

AI statement

No artificial intelligence (AI) tools were used in writing of this manuscript or in the analysis of the data.

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