

Research Article

Is ghost fishing in Banderas Bay, Mexico, a problem? (Perception, causes, consequences, and knowledge)

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ABSTRACT. Fishing is one of the most significant economic activities, providing food to communities worldwide. Its technological development has enabled the maximum exploitation of fish stocks, resulting in various environmental problems, including ghost fishing. The United Nations estimates that 640,000 t of ghost fishing gear can be found in the oceans, accounting for 85% of the plastic waste on the seabed. The study was conducted in Banderas Bay, where surveys were administered to individuals with a connection to the marine area. The surveys consisted of three sections: general population, issue perception, and a section to determine the effects and damages according to six groups of people related to activities at sea. The primary fishing gear that causes ghost fishing in Banderas Bay is gillnets, followed by longlines. Ninety-six percent of the population considers ghost fishing a problem with repercussions for the environment and the region's economy. The main causes of loss are current waves and snagging on the bottom. There are no programs or actions to clean up the bottoms or to avoid the loss. The issue in the bay needs to be addressed through an integrated program that includes environmental education, vigilance/reporting, and incentives to prevent the loss of fishing gear.

Keywords: ALDFG; bottom damages; sea life entangled; gill nets

INTRODUCTION

Fishing is one of the primary economic activities worldwide, providing a significant source of food for coastal communities and beyond. In 2020, global fish production reached an estimated 78.8 million tons (FAO 2022). Despite its importance in food provision, fishing is also a leading contributor to ocean plastic waste (Macfadyen et al. 2011). Among the most significant sources of this waste are abandoned, lost and discarded fishing gear (ALDFG). The United Nations estimates that approximately 640,000 t of ghost fishing gear are present in the oceans, constituting around 85% of the plastic waste found on the seabed. The FAO highlights a global lack of quantitative data on this issue

and inadequate legislation in most regions to address it effectively (Espino-Barr & Cruz-Romero 2006).

ALDFG poses a global threat not only due to the entanglement of endangered species but also because of its capture of commercially valuable species that are not regulated on a commercial scale. This situation impacts both global and local economies, reduces fish stocks, and degrades the marine environments that support thriving tourist industries. Many losses occur unintentionally, often resulting from negligence or adverse weather conditions (Reyna-González et al. 2019, Richardson et al. 2019). In addition to its ecological impact, plastic pollution has well-documented effects on both human and animal health, including disruptions to the endocrine system, certain

types of cancer, and developmental issues in children (Barragán & Navas 2018).

In Mexico, ghost fishing has had a significant impact on marine biodiversity. Mammals such as the vaquita in the Upper Gulf of California, sea lions in Baja California Sur, and manatees in the Caribbean, as well as rays and sea turtles in Banderas Bay, are among the species indirectly affected (Elorriaga-Verplancken 2004, Curiel-Godoy et al. 2018, Frisch-Jordán & López-Arzate 2024). Strong efforts to address ghost fishing began in the 2010s; however, these initiatives have not led to substantial regulation or mitigation of its effects along Mexico's coasts.

Since 2017, the Ministry of Environment and Natural Resources (SEMARNAT, by its Spanish acronym) and various stakeholders have collaborated to develop regulatory frameworks aimed at addressing ghost fishing in designated protected areas of the Upper Gulf of California (Rojo-Nieto & Montoto-Martínez 2017, SEMARNAT 2018). In 2018, legislative proposals were introduced to amend the Law for the Comprehensive Management and Prevention of Waste and the Law on Sustainable Aquaculture and Fishing, to regulate and penalize the disposal of fishing-related waste. However, these efforts have yet to yield significant results (Parlamentarios 2018).

Between 2016 and 2018, the International Committee for the Recovery of the Vaquita Marina (CIRVA, by its Spanish acronym) and the World Wildlife Fund (WWF) spearheaded a program to remove lost fishing gear from the Upper Gulf of California, the vaquita's habitat. This initiative successfully recovered 1,113 ghost fishing nets and rescued 863 live marine organisms with the support of the community, other non-governmental organizations (NGOs), and government entities (Curiel-Godoy et al. 2018). In 2019, further advocacy efforts prompted the National Human Rights Commission (CNDH, by its Spanish acronym) to issue recommendations to various Mexican government entities, including SEMARNAT, Comisión Nacional de Acuacultura y Pesca (CONA-PESCA), Secretaría de Agricultura y Desarrollo Rural (SADER), and Procuraduría Federal de Protección al Ambiente (PROFEPA), to ensure the protection of species in the region (CNDH 2019).

In 2022, Mexico's federal government published its Sustainable Ocean Economy Strategy for 2021- 2024, which included measures to prevent, mitigate, and address ghost fishing in national waters (Gobierno de Mexico 2021).

Fishing in Banderas Bay and ghost fishing

For over five decades, fishing in Banderas Bay has provided a livelihood for the region's families and has played a crucial role in Mexico's fishing economy, distributing seafood nationwide. Historically, this multi-species fishery has evolved in response to political, financial, and technological changes (Brown et al. 2005). The region relies on artisanal and recreational fishing, utilizing gear such as gillnets, trammel nets, longlines, ropes, hooks, and gaffs, which are operated by small motorboats called "pangas" (Espino-Barr & Cruz-Romero 2006). While this has fostered moderate economic growth, it has also led to environmental challenges, including pollution, overfishing, and the impacts of climate change (Brown & Macfadyen 2007, Castañeda et al. 2012).

Since the 1960s, Banderas Bay has shifted economically from agriculture, mining, and fishing to tourism, primarily driven by the filming of the famous movie "Night of the iguana" in Puerto Vallarta. This transformation has increased the demand for seafood and outdoor activities such as whale watching and diving (Ramírez-Cordero 2008, Virgen-Aguilar et al. 2016). Tourists frequently encounter marine species affected by ghost fishing gear, highlighting the environmental impact and its effect on tourist activities.

Whale entanglements are the most visible impact of ALDFG in Banderas Bay. Between 1996 and 2021, 32.8% of entanglement reports involved fishing gear or ghost nets (Frisch-Jordán & López-Arzate 2024). Although citizen participation and the efforts of organizations like Red Nacional de Asistencia a Ballenas Enmalladas (RABEN) have enhanced reporting and response, scientific data on the broader impacts of ghost fishing on local fisheries remain scarce. Nevertheless, fishers and stakeholders observe a noticeable decline in production, partially due to this issue (Antonio Pelayo *pers. comm.*).

Understanding the extent of ghost fishing in the region is crucial for proposing practical mitigation actions, raising awareness, and integrating abandoned fishing gear into circular economy projects. Thus, as a first step, it is important to diagnose the fishing practices, the structure of the fishermen population, the fishing gear products that are commercialized, the involvement in conservation, and the participation of various institutions that interact with the Banderas Bay marine zone, as well as the local population's perception of this issue. This study aims to investigate the ghost fishing problem, focusing on its causes and consequences in Banderas Bay.

MATERIALS AND METHODS

Study area

Banderas Bay is in the northern part of the central Mexican Pacific, between the geographical coordinates 20°47'52"N, 105°32'27"W (in the northern area, near Punta de Mita) and 20°24'46"N, 105°41'51"W (in the southern area, near Corrales). The bay covers an area of approximately 1,000 km² (Fig. 1). Its depth varies from 0 to 1,436 m, with an average depth of 273 m. The northern section is the shallowest, with slopes of 0.012 and depths reaching up to 25 m, while the southern section attains greater depths, with slopes of up to 0.08 m. An east-west-oriented canyon runs through the central part of the continent to a location known as Los Arcos (Plata & Filonov 2007). The bay features a diverse range of seabed types, including rocky, oyster, coral reefs, and sandy bottoms.

Three major oceanic currents converge in the bay. The California Current, characterized by cold, low-density water, flows from Baja California to Costa Rica, where it transitions into the North Equatorial Current, which carries warm, medium-density water northward along the southwestern coast of Mexico. The Mexican Coast Current also flows from southeast to northwest, influencing the bay's conditions. The warm California Gulf Current, with low salinity, also contributes. This dynamic interplay creates significant variations in temperature, salinity, and seasonal patterns (Mireles-Loera et al. 2019). Two main circulation patterns are identified: the first, from February to July, involves inflow from the northern side of the bay; the second flows southward from the bay's mouth in the reverse direction (Salas-Pérez & Cupúl-Magaña 2005).

The bay receives substantial inputs of brackish water, primarily from five main rivers in the southern region: Ameca, Pitillal, Cuale, Horcones, and Tuito, along with several intermittent streams. These water sources provide a constant flow of brackish water throughout the year, with added contributions during the rainy season, which typically lasts from June to October.

Identification of key stakeholders

Key stakeholders were identified with assistance from the Puerto Vallarta fishing office. In Banderas Bay, this process was supported by the Regional Center for Aquaculture and Fisheries Research (CRIAP, by its Spanish acronym) in La Cruz de Huanacastle. Additional collaboration was sought from operators of sport fishing and tourist diving activities. Interviews

were conducted with researchers from the Centro Universitario de la Costa at the University of Guadalajara, who are involved in fisheries and marine projects, to pinpoint areas where ghost nets have been observed and to identify other key stakeholders.

Survey design

To design the surveys, consultations were held with fishermen, government employees, and other stakeholders involved in maritime activities in Banderas Bay. This collaborative process aims to develop questions tailored to the region's specific activities.

The survey was structured in a closed-question format and divided into three sections. The first section gathered general information about participants and their perceptions of ghost gear, including its prevalence, the types of issues it causes, affected species, and impacted locations. The second section featured specialized questions tailored to specific maritime activities, resulting in six distinct survey types: for fishermen, divers, government employees, NGOs, fishing supply providers, and researchers. The third section concentrated on participants' willingness to engage in cleanup campaigns and initiatives aimed at removing ghost gear.

To ensure representativeness, the sample comprised 10% of a simple random sample (Bostley-Muyembe & Anselemo 2023) of the active population of fishing boats with commercial permits (CONAPESCA) and whale-watching vessels (SEMARNAT) in the municipalities of Jalisco and Nayarit. Since not all fishers and tourism operators are active, this proportion was considered appropriate. For researchers, NGOs, and government agencies working in Banderas Bay, all relevant entities, suppliers, and dive shops were included.

The study employed a non-experimental, descriptive design, with no variable manipulation. Data collection took place within a specific time frame.

Survey administration

Surveys were administered between June 14 and June 30, 2021, in both states. Due to COVID-19 safety protocols, surveys were conducted through home visits and small group meetings (with fewer than 10 participants) in locations such as Punta de Mita, La Cruz de Huanacastle, Bucerías, and Jarretaderas in Nayarit, as well as Puerto Vallarta, Las Ánimas, Quimixto, Yelapa, and Pisota in Jalisco. Fishermen, divers, and tour operators were contacted in each location. Visits were also made to government offices and research centers. Surveys were distributed via email

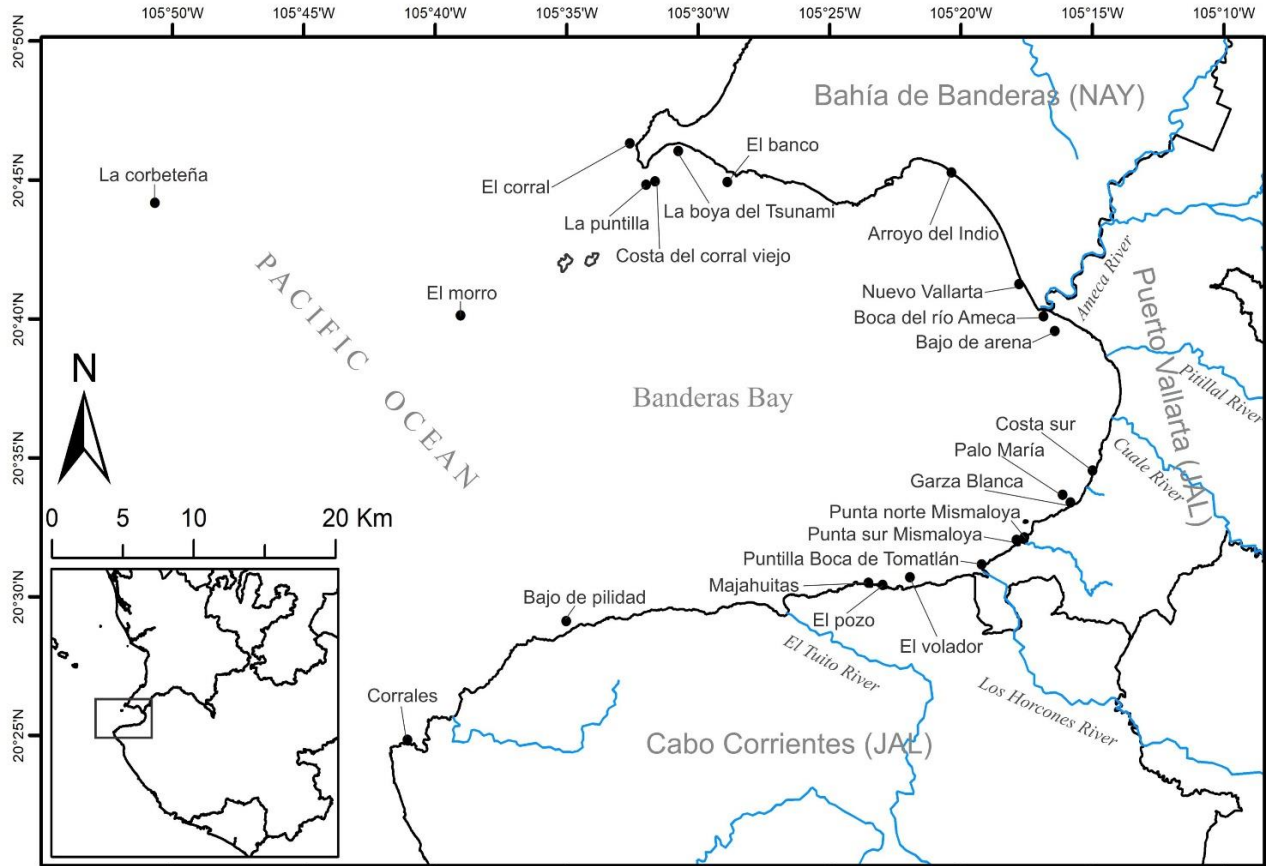


Figure 1. Area of study.

and completed in person or through focus groups when feasible.

Data analysis

The data were organized in a double-entry matrix in Excel, with the response to each survey item captured in the column and the identification of each respondent in the rows.

For each item, the responses were summed, and the corresponding percentage was calculated. The responses were then represented in bar graphs. Questions with multiple responses were counted separately to obtain individual frequencies (Agresti 2019).

RESULTS

General information

A total of 180 surveys were obtained, comprising 123 from fishermen, 34 from tourist divers, 12 from researchers, 4 from fishing input suppliers, 6 from government employees, and 1 from an ONG member

(Table 1). The surveys were administered to a total of 154 men (86%), 24 women (13%), and 2 individuals who chose not to disclose their gender (1%). The age range was from 21 to 86 years. Eight age groups were identified, with the 49- to 55-year group being the most representative, while the 21- to 27- and 77- to 83-year groups were the least represented. Most respondents live in Puerto Vallarta, followed by Bahía de Banderas, Cabo Corrientes, and Zapopan (Table 1).

Respondents in Banderas Bay engage in a diverse range of activities, which they combine according to the time of year and their work availability. Thus, 64% engage in commercial fishing, 18% dedicate themselves solely to recreational diving, 6% work for research or educational institutions, 6% work for tour operators, 3% work for government agencies, 2% work as fishing equipment suppliers, and 1% work for NGOs (Fig. 2a).

Perception of the ghost gear issue

From the total number of respondents, it was found that 72% of the individuals had heard about the issue, while

Table 1. Respondent's demographic information regarding the perception of the problem of ghost fishing in Banderas Bay.

Place	Gender			
	Female	Age range (yr)	Male	Age range (yr)
Bahía de Banderas	7	28 a 60	68	21-73
Puerto Vallarta	17	28 a 60	74	23-76
Cabo Corrientes	0	0	12	24-70
Zapopan	0	0	1	47

28% had not, although they were aware of the problem. An important 96% consider ghost fishing a problem, whereas 4% do not perceive it as such (Table 2). For 58% of respondents, the issue is primarily environmental, 23% believe it involves economic, social, and environmental factors, 14% see it as a combination of economic and environmental factors, 3% consider it a combination of environmental and social factors, and 2% did not respond (Fig. 2b).

A substantial 92% of the surveyed population affirm that they have seen ghost fishing gear, while 7% have not encountered it, and 1% did not respond (Table 2). The lost fishing gear reported by those active in the marine area includes gillnets (39%), long lines (29%), lines and hooks (20%), and fishing gear for lobster and octopus (Fig. 2c).

Regarding incidents, 36% did not respond; however, it is expressed that vessels become entangled with such gear, 17% have experienced damage to their ships, 15% to their fishing gear, 14% have suffered personal harm, 11% have only experienced damage to their fishing gear, 4% have had adverse effects in all three categories, and 3% have had a combination of vessel and fishing gear damage (Fig. 2d).

In terms of encounters with wildlife damaged by ghost fishing gear, 29% reported had seen sea turtles, 20% fish, 15% manta rays, followed by 10% pelicans, 8% whales, 6% dolphins, 6% other organisms, 5% seagulls, and 1% crocodiles (Fig. 2e). The impacts on the marine fauna of Banderas Bay due to the presence of ghost gear include death and injuries caused by these materials. Specifically, 34% indicated having found dead animals trapped in the nets, 29% have located animals entangled either alive or dead, 25% have found animals injured by fishing gear, and 12% reported animals with hooks in their beaks or snouts (Fig. 2f).

Respondents reported being aware of two cleanup efforts focused on ghost gear: one in La Cruz de Huanacastle, Banderas Bay, Nayarit, reportedly conducted over 10 years ago, and another more recently in Yelapa, Cabo Corrientes, Jalisco. Of these activities,

53% of respondents were aware of their occurrence, 44% were not, and 3% did not respond (Table 2).

Moreover, approximately 55% of respondents indicated that they had participated in beach or underwater cleanups, although not specifically targeting the debris mentioned above; 43% had not attended, and 1% did not respond (Table 2). The surveyed population participated in the cleanups in various capacities: 79% did not respond, 15% participated by collecting debris, 3% initiated cleanups on their own, 2% were involved in organizing the efforts, 0.5% provided training, and 0.5% removed ghost nets (Fig. 3a).

Commercial and sport fishers

A total of 123 surveys were obtained from artisanal and recreational fishers. Of these, 88% have been engaged in fishing for over 10 years, 7% for 5 to 10 years, 4% have dedicated themselves to fishing for less than 5 years, 1% are just starting (Fig. 3b). Fishing activities varied among respondents: 43% commercial fishing, 21% sport fishing; 18% octopus/lobster hook (OLH), 6% diving fishing, 4% commercial and sports fishing, 3% did not respond, 15% oyster bar, 3% no answer (Fig. 3c).

Regarding the organization of the fishing sector, approximately 12 fishing cooperatives operate in Banderas Bay. Representatives from cooperatives in both states were surveyed. Among the respondents, 54% belong to a fishing cooperative, 42% are independent or licensed fishers, and 4% did not respond (Table 2). Additionally, 55% of respondents have fishing permits, 42% do not, and 3% did not respond. Of those with permits, 41% admit to having exceeded the number of fishing gear they are authorized to use (Table 2).

The frequency of commercial fishing activities varies and depends on sea conditions; most fishers engage in daily activities (52%), 20% fish irregularly, 15% fish once a week, 5% fish once a month, 5% did not respond, and 3% have retired (Fig. 3d).

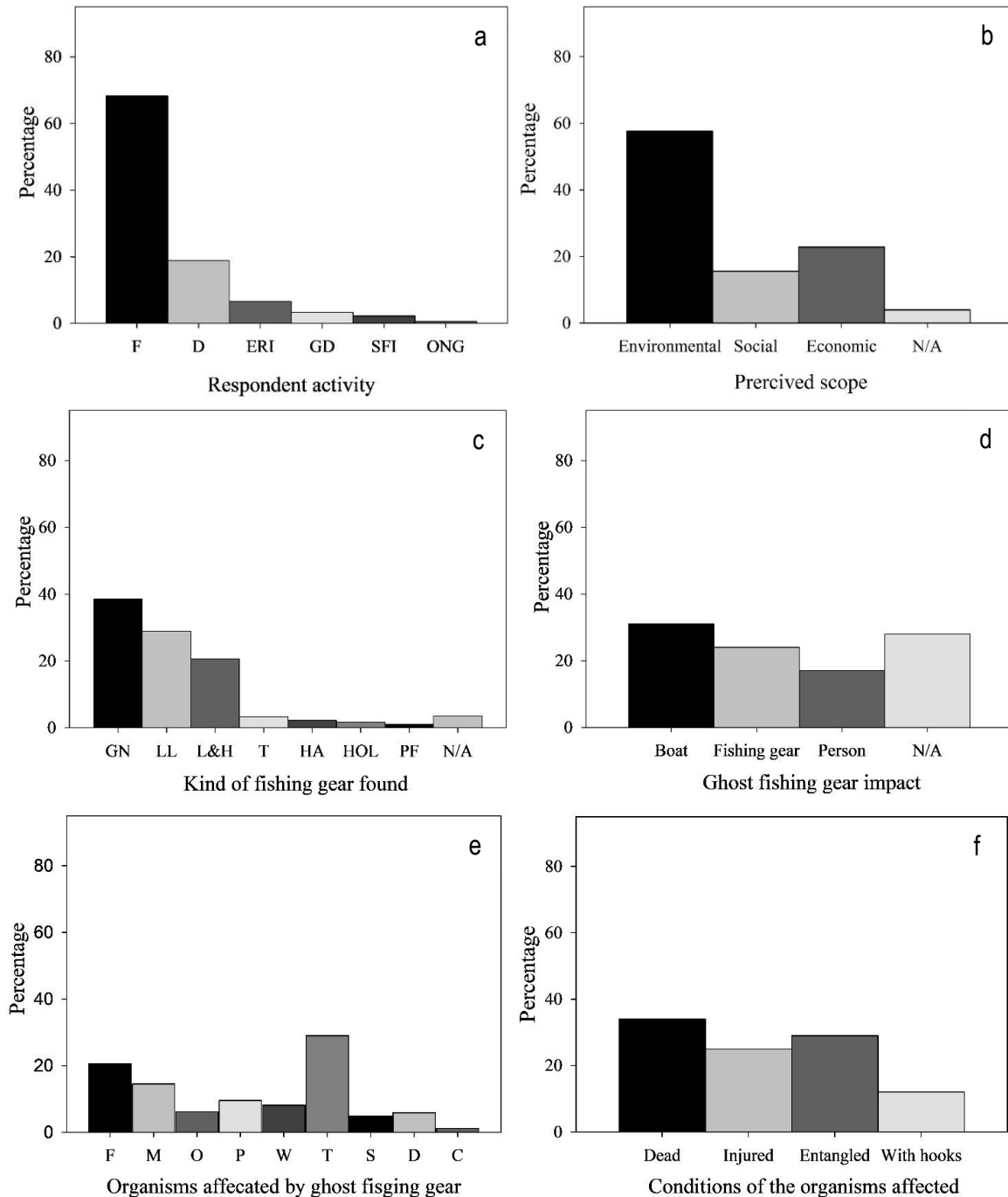


Figure 2. a) Activities of the actors in the maritime area of Banderas Bay; F: fisher, D: diver, ERI: educational or research institution, TO: tour operator, GD: government dependence, SFI: supplier of fishing inputs, ONG: non-governmental organization. b) Perceived scope of the ghost fishing net problem, N/A: no answer. c) Fisheries crafts that have been observed in Banderas Bay; GN: gill net, LL: longline, L&H: ropes and hooks, T: traps, octopuses/lobster hooks, HA: harpoons, PF: Purkait fishnet, N/A: no answer. d) Affectations reported by fishing activity in the marine problem, N/A: no answer. e) Proportion of wild marine life that users of the Banderas Bay marine area report having found affected by ghost nets; F: fishes, M: manta rays, O: other, P: pelicans, W: whales, T: turtles, S: seagulls, D: dolphins, C: crocodiles. f) Ways in which Banderas Bay wildlife is affected by ghost fishing nets.

Table 2. Respondent's perception about the ghost gear fishing problem, its fisheries practices, and actions taken to resolve the issue. N/A: no answer.

Question	Yes	No	N/A
Respondents who have heard about the problem of ghost fishing	72	28	-
Respondents who consider it a problem	96	4	-
Respondents who have observed ghost fishing gear	92	7	1
Respondents who have participated in cleanups	53	44	3
Respondents who have participated in cleanups of all kinds	55	43	1
The respondent who has been seeing ghost nest	72	28	-
Respondent fishers belonging to a cooperative	55	42	3
Fisher with permission	55	42	3
Fishers who have exceeded the fishing gears allowed	41	44	15
Fishers who identify sites of lost fishing nets	42	54	4
Fishers who have at least lost their fishing gear	59	37	4
Fishers trying to recover lost fishing gear	38	45	17
Fishers who conduct maintenance activities on their fishing gear	86	8	6
Fishers who use original materials in their fishing gear	55	38	7
Fishers who conduct preventive activities against the loss of fishing gear	67	28	8
Knowledge about collection and recycling centers for fishing nets in the region	14	84	2
Knowledge about the existence of a management and discard plan for fishing gear	15	84	1
Perception about the beneficial effects of preventive maintenance on the loss of fishing gear	72	25	3
Socialization of the topic among fishers	71	25	4

Concerning the knowledge of lost fishing gear in the bay, 54% of fishers have identified sites where lost fishing gear exists or has been sighted, 41% are unaware, and 5% did not respond (Table 2). During fishing activities, the loss of fishing gear is common; 59% of respondents confirmed having lost nets or other fishing gear at some point, 37% reported not having lost any, and 4% did not respond (Table 2). Respondents attributed the loss of fishing gear to 25% due to waves and currents, 25% did not respond, 19% to vandalism or theft, 19% to animal damage, 6% to meteorological phenomena, and 6% to the type of seabed (Fig. 3e).

The frequency of lost fishing gear in Banderas Bay, as reported, indicates that 30% of fishers have never lost their gear, 28% experience two incidents of loss per year, 6% lose their gear more than three times a year, and 36% fall into other frequency categories (Fig. 3f).

The attempt to recover lost fishing gear amongst fishers is observed as follows: 38% of fishers responded negatively, 45% affirmatively, and 17% did not respond (Table 2). The primary reasons cited for not attempting to recover the gear are that it sinks quickly, currents transport it to deeper areas, and the recovery cost exceeds the value of the lost gear.

Maintenance, repair, and waste management

When fishing gear is recovered, 62% of respondents dedicate time to repairs, 32% discard it, and 6% do not respond (Fig. 4a). Eighty-six percent of the fisher population engages in maintenance activities for their fishing gear to prevent deterioration and loss, 8% do not, and 6% do not respond (Table 2). The useful life of fishing gear depends on its intensity of use and the fishing season. To systematize the information, it was classified into three categories: 51% stated that the gear's useful life is more than one year, 21% said it lasts up to six months, 20% said one year, and 8% did not respond (Fig. 4b).

Generally, 55% of respondents use substitute materials to repair or assemble the gear, typically domestic waste or materials such as jerrycans, buoys, PET bottles, vehicle spark plugs as lead weights, or pieces of rebar; 38% do not use these materials, and 7% did not respond (Table 2). Sixty-seven percent of fishers engage in activities to prevent the loss of fishing gear, such as labeling them, marking the points where they are set, placing flags, securing the gear firmly, placing intermittent lights, continuous inspection, and maintenance, among others; 25% of respondents indi-

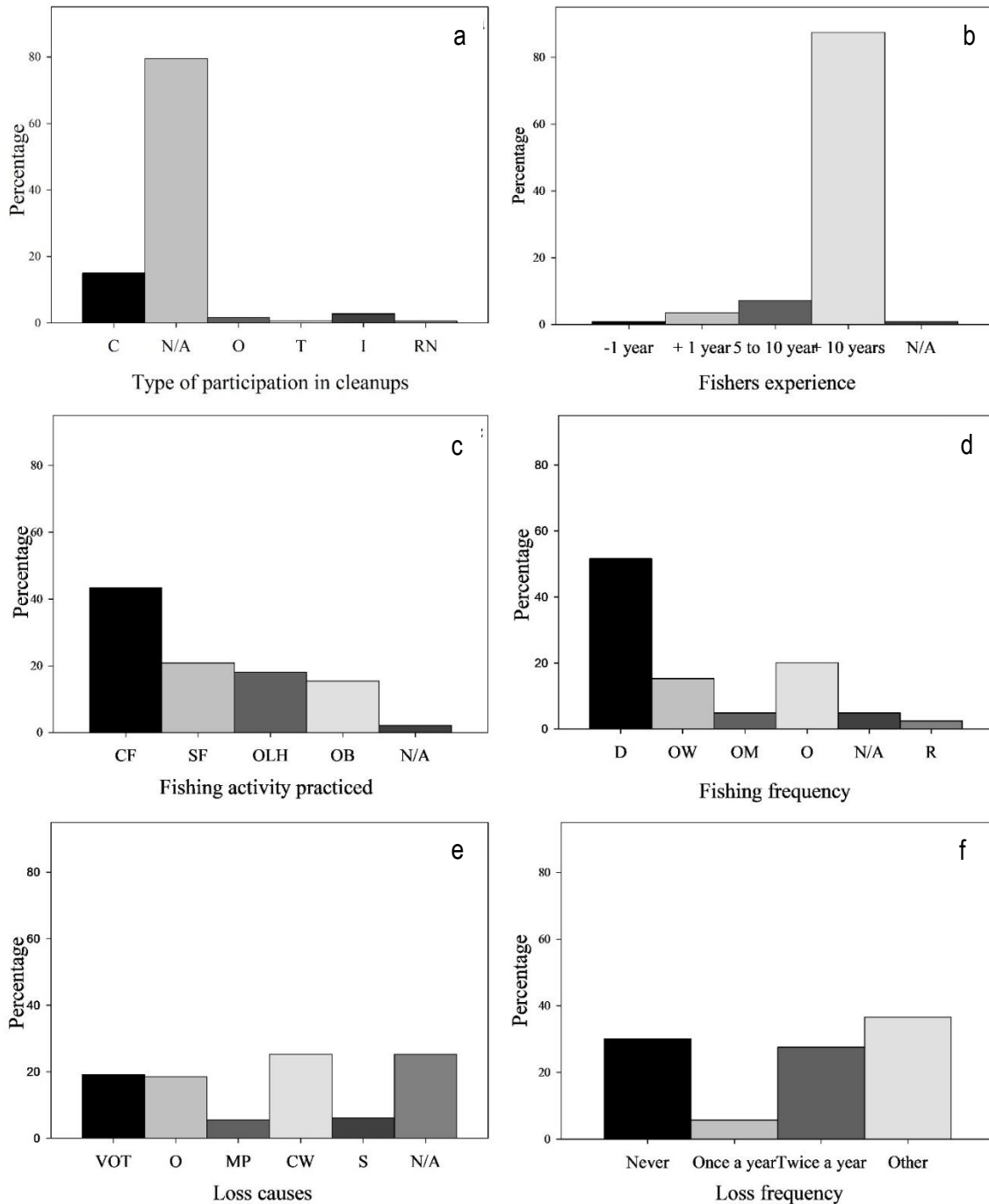


Figure 3. a) Type of participation in cleanups in the area; C: cleaning, N/A: no answer, O: organizing, T: training, I: independent, RN: removing nets. b) Years of experience; -1 year: less than a year of experience, +1 year: more than a year of experience, 5-10 years: between 5 and 10 years of experience, +10 years: more than 10 years of experience, N/A: no answer. c) Fishing practiced; CF: commercial fishing, SF: sport fishing, O/LH: lobster/octopus hook, OB oyster bar, N/A no answer. d) Fishing frequency; D: daily, OW: once a week, OM: once a month, O: other, N/A: no answer, R: retired. e) Lost causes of fishing gear in Banderas Bay; VOT: vandalism or theft, O: organisms, MP: meteorological phenomena, CW: currents and waves, S: sabotage, N/A: no answer. f) Lost frequency never: never lost their fishing gear; Once a year: they lost the fishing gear once a year, twice a year: they lost their fishing gear twice a year, other: they lost their fishing gear whit different frequencies.

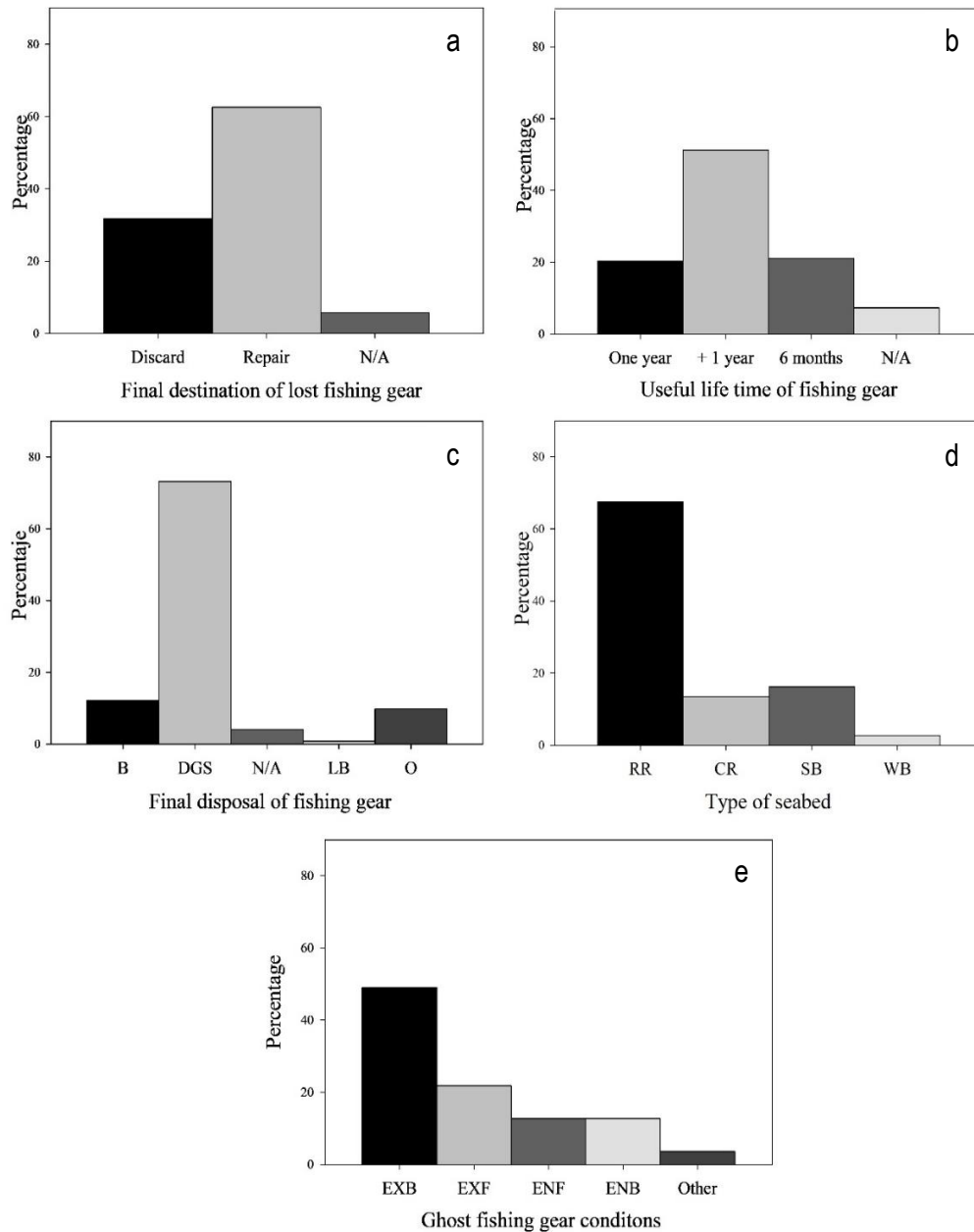


Figure 4. a) Recovery of end-of-life ghost nets; Discard: they throw it away in the trash, Repair: they repair them to be used again, N/A: no answer. b) Useful life of fishing crafts; One year, +1 year: more than a year, 6 month: used six months, N/A: no answer. c) End-of-life fishing gear; B: burns it, DGS: delivers it to the garbage service, N/A: no answer, LB: leaves it on the beach, O: other. d) Types of seabeds where ghost nets have been observed; RR: rocky reef, CR: coral or oyster reef, SB: sandy bottom, WB: woody bottom. e) Conditions of the fishing gear found on the seabed of Banderas Bay; EXB: extended on the bottom, EXF: extended floating, ENF: tangled floating, ENB: entangled on the bottom.

cated they do not perform any activities, and 8% did not respond (Table 2).

Seventy-three percent of the population stated that they deliver waste to public cleaning services, a significant number that bodes well for waste management efforts. Twelve percent burn it, 10% do

other things with it, 4% do not respond, and 1% leave it on the beach (Fig. 4c).

In the region, the proper management for the final disposal of fishing waste is practically nonexistent. Among the total interviewed by the fishing sector, 84% are unaware of any collection center where they can

deliver the waste, 14% claim to know of a center, and 2% did not respond. Similarly, regarding the existence of a management plan for the final disposal of fishing waste, 84% expressed ignorance of its existence, 15% did not know, and 1% did not respond (Table 2).

Seventy-two percent of fishers believe that better care of fishing equipment will reduce investment costs, while 25% said no, and 3% did not respond. Additionally, 72% discuss the issue with their colleagues, 25% do not, and 3% do not respond (Table 2).

Recreational divers

Divers reported that ghost gear are generally observed in 68% of rocky reefs, 13% in coral or oyster reefs, 16% in sandy bottoms, and 3% in woody bottoms (Fig. 4d). Forty-nine percent stated that they are usually spread out on the bottom, 22% spread floating, 13% tangled floating, 13% on the bottom attached to a weight, and 3% in other conditions (Fig. 4e). From the 33 surveys conducted with divers in Banderas Bay, a list of 25 dive sites where lost fishing gear has been sighted within the bay was compiled (Table 3).

Government institutions

Of the government institutions mentioned, applying the survey was only possible at the CONAPESCA representation in Nayarit and the Comisión Nacional de Áreas Naturales Protegidas (CONANP) in Jalisco. From the surveys conducted in both institutions, it was found that there are no specific programs in place for recovering lost fishing gear or raising awareness about the problem of ghost nets; however, CONANP routinely carries out bottom cleaning activities and removes fishing nets in the vicinity of the protected natural area.

Suppliers of fishing supplies

Four fishing supplies were surveyed in the region. Recreational fishing supplies dominate sales, with commercial fisheries being less significant. Leading suppliers are located in Mazatlán, Guadalajara, and Ciudad Obregón, where artisanal fishers frequently operate with government support. Suppliers exhibit negligible involvement in cleanup initiatives and lack awareness of net recycling programs. Local suppliers report seasonal sales variability, leading to inconsistent consumption tracking. Conversely, larger entities maintain sales records, reporting approximately 100 net sales for Jalisco's coast. Suppliers' limited engagement in marine activities hinders their understanding of related issues, including the issue of abandoned nets. Additionally, knowledge of recyclable fishing products

is scarce, with Berkley being the sole brand mentioned for marketing monofilament.

Non-governmental organizations (NGOs)

In the marine area of Banderas Bay, four local NGOs were identified that work in the marine and coastal zones. Among their objectives are raising awareness, educating the public, and researching topics related to humpback whales, sea turtles, and the importance of plastic waste discharged into the sea from terrestrial areas. Only one of these NGOs responded to the survey and indicated that it does not have a specific program for removing and cleaning ghost gear. However, its environmental education activities include awareness campaigns to reduce the damage caused by ghost gear, participation in beach cleanups, and the recovery of lost fishing gear, which is then handed over to government agencies involved in maritime surveillance. This recovery is carried out depending on the size and location of the ghost nets.

Research and educational institutions

The analysis of research and educational institutions in the three municipalities encompassing Banderas Bay revealed that three institutions conduct work in the marine area of the bay. These institutions are CRIAP in La Cruz de Huanacastle, the Mexican Institute for Sustainable Fisheries and Aquaculture Research (INAPESCA, by its Spanish acronym), the Technological Institute of Banderas Bay (ITBB, by its Spanish acronym), and the Coastal Research Center of the University Center of the Coast, University of Guadalajara.

Generally, these institutions do not have research, awareness, or environmental education programs related to ghost gear. However, unofficially, awareness actions regarding the issue are carried out by researchers and educators who are in contact with fishers. For instance, CRIAP researchers offer informative talks on good fishing practices and have recently joined the ghost gear program operated by WWF Mexico.

Researchers in the area report that they have not encountered problems or impacts on their research due to ghost gear. However, they have observed them during their work. Only the team from the Coastal Research Center at the University Center of the Coast, University of Guadalajara, mentioned that ghost gear directly affects their coral restoration program, which they have been conducting for years. Regarding participation in cleanup campaigns, members of the research teams from the various institutions surveyed

Table 3. Sites where ghost nets have been found during their activities.

Norte	Centro	Sur
Boca de Tomates	Cerca del río Pitillal	El Faro
Punta de Mita	Costa Sur	La Ventanilla
Bajo de la arena	Garza Blanca	Boca de Tomatlán
Boya del tsunami	Gran Fiesta	Majahuitas
Cárcamo en el tubo	Marina	Mismaloya
Corbeteña	Palo María	El Pozo
Costa del corral viejo		El Volador
Desembocadura del arroyo del indio		
El Arco		
El Banco		
El Morro		
Nuevo Vallarta		

reported having participated in cleanup campaigns in the bay.

DISCUSSION

General information

Ghost fishing has been a globally recognized issue since the 1960s, stemming from the abrupt transition from natural fishing gear to less expensive and more durable materials, such as monofilament (plastics) (Gunn et al. 2010). In Banderas Bay, synthetic fishing gear was first introduced in the 1980s, twenty years later, when materials used for fishing gear were sourced from natural fibers (A. Güereña-Garibaldo, *pers. comm.*).

Its effects in Mexico have been measured in a fragmented manner, as they are confined to certain regions of the country, such as the Upper Gulf of California, Banderas Bay, and some areas of the Caribbean (Curiel-Gody et al. 2018, Pelatmatti 2019). These have been observed in charismatic or large animals, including whales, sea lions, sea turtles, and manta rays (Frisch-Jordán & López-Arzate 2024), which is consistent with Tatsuro & Naoki (1995).

To understand the problem of ghost fishing in the region, it is essential to comprehend the structure and functioning of the local fishing population. Thus, in the present study, it was found that the fisheries on the bay are mainly composed of artisanal fishermen using small boats with outboard motors, free-diving fishers, and sport fishermen.

It is mainly composed of men, with a smaller proportion of women, in contrast to the findings of Blázquez & Palacios (2016), who reported women's

cooperative societies in San Felipe, Yucatán, with members ranging in age from 19 to 50 years. Uc-Espadas et al. (2017) found that the increased presence of women in fishing is due to the transfer of permits to obtain more subsidies and economic benefits.

The fishing sector comprises adults aged between 21 and 78, with a few young and elderly members, indicating that the activity is declining due to the lack of new fishers under the age of 20. Moreover, the fishers express that the youngest fisher prefers realized activities related to the tourist as the recreative fisheries. This observation supports the assertions of some fishing leaders in the bay and contrasts with other regions, such as western Venezuela, where 66% of fishers are between 15 and 34 years old, followed by those aged 35 to 64 years (Yanes & Primera 2006). This trend has already been evidenced by the work of Malcolm et al. (2021), who analyzed its probable causes and concluded that tourism pressure is the most significant factor.

These situations appear to indicate a shift in fishing activities from commercial to recreational fishing. It may be suggested that monitoring the effects of this change on the ecosystem related to ghost fishing could be required.

Perception of the ghost gear issue

More than half of the population views it as a problem, primarily perceiving it as an environmental issue, and secondarily as a socio-economic issue, which aligns with Barbosa-Fhilo et al. (2020), who mention that fishers in Brazil also view it as an ecological and social concern. Brazilian fishers report that some trawlers from other localities are drifting, which affects the local

environment and causes issues between fisher groups. Despite this, only a few fishers have acted to prevent or mitigate this problem.

Encounters with ghost fishing gear in Banderas Bay are constant, as evidenced by the results. The situation is similar on the Basilian coast, where 90% of fishers have encountered ghost fishing gear (Barbosa-Filho et al. 2020).

The most impactful fishing gear in Banderas Bay includes fixed gear, such as gillnets and trammel nets, which can remain active for long periods even when lost (Lively & Good 2018, Thomas & Sandhya 2019). These nets pose a significant threat to protected species (Royer et al. 2023). Surveys reveal that gillnets and trammel nets are the predominant gear in the region, highlighting the issue of ghost fishing. Gunasekaran et al. (2024) found that nets are the most commonly discarded gear, followed by lines, traps, and hooks. Divers frequently encounter these abandoned nets. Longlines have been found in the bay, and according to NOM-064-SAG/PESC/SEMARNAT-2013 (DOF 2013), using longlines in bays is prohibited, indicating their illegal usage, which can cause the cinders to be the second most damaging fishing art in the bay. According to Angiolillo & Fortibuoni (2020), the most common incidents caused by fishing gear include damage to vessels and fishing equipment, as well as environmental harm to marine fauna and the seabed.

Over time, these issues lead to habitat degradation and the presence of environmental microplastics (Gilman et al. 2021, Mejia-Estrella et al. 2023). These problems have been observed in Banderas Bay; however, to date, no existing research has addressed the damage caused (Pelamatti et al. 2019). Furthermore, although there are no studies indicating that microplastics originating from fishing gear are present in the bay, it cannot be ruled out that they are indeed present.

Divers have reported several mantarray turtles and other species. Similar reports have been found in the marine reserve Galapagos, where the mortality of fishing sharks has increased, attributed to bycatch and ghost fishing (Castrejon & Defeo 2024).

On Banderas Bay, more than half of the respondents have encountered organisms that have been harmed by fishing gear. The most affected species include turtles, fish, manta rays, mammals, crocodiles, and birds. Our results align with those reported by Mghili et al. (2023), which indicated that the most affected species in Morocco are fish, birds, turtles, and whales. These species become more vulnerable to predation, physical injuries, exhaustion, and even death.

Commercial and sport fishers

It is observed that artisanal fishers also engage in tourist diving, or divers who participate in both sport and artisanal fishing activities (Castañeda et al. 2012), as is the case in Banderas Bay. This situation is similar to other regions in Mexico, such as Yucatán, where fishers also engage in diving or alternative activities, allowing them to earn extra income (Hucim-Lara et al. 2015).

Additionally, this enables tourists to become more familiar with the activity and benefits local commerce, which is why many fishers are also involved in tourism activities (González & Piñeiro 2020). The fact that the population engages in more than one activity increases the probability of incidents involving the loss of fishing gear. Still, this could be an opportunity to improve the monitoring of lost fishing gear.

Regarding the organization, most Banderas Bay fishers belong to a cooperative in either state, followed by independent or licensed fishers. In contrast, in the case of Veracruz, 48% of fishers are licensed, followed by cooperatives and social societies (Reyna-González et al. 2019). It could be a key point for communication and education about the issues, applied preventive measures, and curative activities. Additionally, being organized and licensed allows for better control and understanding of the number of active fishing gears, thereby reducing illegal fishing.

Fishing frequency is related to the loss of fishing gear, as demonstrated by the results. A significant group of fishermen engage in daily activities at sea, and a similar group reported having lost their fishing gear at least once in their lives. These results are higher than those reported in the Gulf of Gabès, where 40% of fishermen report losing their fishing gear (Ghaouar et al. 2024).

The lost fishing gear in Banderas Bay is less common than reported by Riyanto et al. (2022) in West Java, where 98% of fishers stated that they have lost their fishing gear. Even with the low loss rate in the bay, it does not mean that there is no damage to the marine ecosystem. On the other hand, the authors report that the primary cause of lost fishing gear is the currents, while conflicts (19%) are less frequent than in Banderas Bay, in contrast to our study.

Over the last 10 years, there have been no scientific reports on how often fishers lose their fishing gear in a year. However, some research has calculated the amount in linear meters, the percentage of fishing gear, the impact of tramps, and the risk of loss per year in several localities around the world. Which is why it could not contrast with our answer regarding this

characteristic. Nevertheless, fishers in Banderas Bay report that more than half lose their gear at least once a year; this is a topic that warrants further analysis in future research, as it will provide specific information about the amount of fishing gear lost in the bay.

On the bay, the lost causes are most attributed to waves and currents by the fishers, and to a lesser extent, vandalism or other causes. Ninety-six percent of the population considers ghost fishing a problem with repercussions for the environment and the region's economy. This result is similar to studies conducted in Australian and Indonesian communities, although entanglements on the seabed are also an important cause (Do & Armstrong 2023).

Maintenance, repair, and waste management

Regarding attempts to recover lost gear, it is considered complicated due to the gear sinking quickly, usually due to climatic effects and currents that transport it elsewhere. Additionally, removing them without the proper equipment can be risky, as it is straightforward to become entangled. Some of the respondents indicated that it is within their capabilities to attempt to recover lost fishing gear. In Macedonia, attempts have been made to retrieve fishing gear; however, accidents have occurred due to rescuers lacking the necessary training and equipment (Mghili et al. 2023). Therefore, it is crucial to have a team of specialized divers to remove ALDFG.

Among the actions fishers take to prevent the loss of fishing gear are labeling it, marking the points where it is placed, and providing regular maintenance and inspection of their equipment. Other strategies proposed by Siles-Martínez & Abarca-Guerrero (2022) in Costa Rica include implementing a management plan for the proper disposal of this gear, maintaining a record of discarded waste, using biodegradable materials for fishing gear, and, if possible, ensuring that the gear has an escape mechanism for non-target species. Additionally, it is suggested to have storage space on boats, report incidents involving fishing gear, and provide economic incentives for recovered gear. Similarly, Jang (2023) in Taiwan proposes a licensing system for gillnets to reduce the amount of fishing gear.

Furthermore, fishing gear has a limited lifespan, typically ranging from six months to over a year, depending on usage frequency and the level of maintenance. Once this period ends, it must be disposed of. In Banderas Bay, most fishers hand over their fishing gear to public cleaning services, while the rest either burn it or leave it on the beach. In contrast, in India, most fishermen personally sell, store, or dispose

of their gear, while the remainder leave it on the beach, burn it, or dump it into the ocean (Daniel & Thomas 2023). Therefore, Macdayfen et al. (2011) mentioned that the adequate installation of onshore containers to dispose of unwanted fishing gear could help mitigate the problem of ALDFG.

The respondents mentioned that they perform maintenance on their equipment; however, they use materials such as domestic waste or plastics, which, although recycled, are unsuitable for fishing activities. These materials are more likely to be lost, as their characteristics do not provide sufficient resistance to the environmental conditions to which they are exposed. Nonetheless, fishing supplies are more expensive, making it difficult for fishermen to purchase them, leading them to opt for cheaper alternatives.

It is also observed that the General Law classifies fishing gear and general waste from this activity as handling waste for the Prevention and Integral Management of Waste. Therefore, fishers are required to have a management plan in place. Some of the respondents indicated that it is within their scope to attempt to recover lost fishing gear. In Macedonia, attempts have been made to retrieve fishing gear; however, accidents have occurred due to rescuers lacking the necessary training and equipment (Mghili 2023). Therefore, it is crucial to have a team of specialized divers to remove ALDFG.

Recreational divers

In Mexico, diving contributes to the economy and conservation efforts, as activities such as coral reef conservation and monitoring the status of marine ecosystems are involved (SEMARANT 2018). Thus, diving is a significant economic activity. Moreover, certified and trained divers must remove ghost gear to foster synergy amongst communities, tourism promoters, and fishermen in favor of ecosystem health.

An important activity that tourist diving groups have undertaken on their initiative is cleaning beaches and the seabed, as well as removing ghost gear. However, they argue that these activities decreased due to prevailing conditions in 2020 and 2021 and are awaiting the opportunity to resume them.

Causes of lost gear fishing in Banderas Bay

There have been very few attempts to prevent, control, and mitigate this problem in the bay regarding governmental, research, educational institutions, and NGOs. Although the fishing population is small and has low economic income, the tourism sector's impact on the activity during the region's economic development

period still represents a significant portion of the population throughout the bay. Due to poor fishing practices, this population contributes to the dumping of plastic waste into the sea.

The issue of ghost gear in Banderas Bay reflects various social and economic factors that the fishing community has experienced since the 1960s, when the region's development shifted towards tourism. The fishing population in Banderas Bay faces diverse economic conditions, with a marked tendency towards poverty (Espino-Barr & Cruz-Romero 2006, Chávez-Dagostino et al. 2018).

As a result, the level of formal education is low, as are incomes, especially in communities where access to land is difficult. Both factors hinder the guild members' ability to obtain fishing gear made entirely from fishing-specific materials, leading to a strong tendency to substitute these materials with others. They cannot choose recyclable materials, which are significantly costlier. This situation is exacerbated by indifference toward government initiatives, stemming from the neglect experienced in recent decades and the ongoing displacement processes driven by tourism infrastructure development.

There is a difference between fishermen in the involved states. In Jalisco, all fishermen are organized into fishing cooperatives, while in Nayarit, fishermen hold individual permits. Two cooperatives and numerous unlicensed fishermen work for the permit holders. This organizational disparity complicates the registration of the number of fishing gears used annually. Furthermore, fishermen, lacking business training, often fail to keep track of the gear they acquire, lose, or discard. The occurrence of illegal fishing, which does not adhere to the regulations established in the Sustainable Aquaculture and Fishing Law, disregards the number of fishing gear stipulated in the permits and increases the amount of ghost gear in the bay.

Federal institutions are authorized under the General Law on Ecological Balance and Environmental Protection (DOF 2021), the Law on Sustainable Aquaculture and Fisheries (DOF 2018), and their respective regulations to seize fishing gear in cases of violations of these statutes, including noncompliance with minimum mesh size regulations, the use of prohibited fishing implements, fishing in designated protected natural areas, and the capture of species protected by international legislation and NOM-ECOL-059 2010 (DOF 2010). However, these regulations do

not impose penalties for the abandonment or mishandling of fishing gear, particularly in situations of disposal or loss. Moreover, it has been observed that fishing gear and general waste from this activity are not classified by the General Law for the Prevention and Comprehensive Management of Waste (DOF 2015) as waste requiring special management, thereby necessitating that fishermen develop a management plan to ensure the proper final disposal of fishing gear. In this regard, there are areas where this norm could be implemented.

Additionally, it is necessary to seek cross-sectoral collaboration among the three levels of government to develop and implement new regulations on fishing waste management, encouraging the collection, handling, and adoption of best practices for the final disposal of these wastes (Abarca-Guerrero et al. 2015).

CONCLUSION

Ghost fishing in Banderas Bay is viewed as a significant issue that causes injuries to marine wildlife, damages vessels, and harms the local economy. The primary fishing gear lost at sea, contributing to the ghost fishing problem in Banderas Bay, Mexico, includes gillnets, longlines, lines, and hooks. There is no control over the number of fishing gear used, lost, and discarded, and there is inadequate management of fishing waste. There are no environmental education programs or information on the effects and repercussions of ghost fishing in the bay. Therefore, it is crucial to implement environmental education programs, raise awareness among the population and fishermen about proper fishing waste management, and establish an organization with the main stakeholders in the region.

Credit the author's contribution

D.G. Miranda-Peralta: writing-original draft, formal analysis, review, and editing; K.G. Ríos-González: conceptualization, validation, methodology, formal analysis, writing-original draft review, and editing; E.J. Marin-Perkins: methodology, validation, review, and editing English version; I. López-Olvera: funding acquisition, project administration, review. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare that there are no conflicts of interest.

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Received: October 11, 2024; Accepted: July 18, 2025