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Fisher-based assessments of sea turtle bycatch in small-scale fisheries in Pacific Mexico

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ABSTRACT: Reducing bycatch of sea turtles and other protected species in artisanal fisheries depends on first understanding where, how, and to what extent bycatch is occurring. We implemented rapid bycatch assessments (RBAs) — i.e. port-based surveys with fishers — along the Pacific coast of Mexico and combined results with those from a previous RBA effort. Results obtained from 1357 respondents across 99 communities in 11 states provided valuable insights about fishing gear and operations as well as bycatch of 5 different sea turtle species. Fishing gears varied geographically, but gillnets, followed by hook and line gears, were most commonly used. Species-specific and seasonal patterns of sea turtle bycatch also varied geographically, with olive ridleys *Lepidochelys olivacea*, followed by green turtles *Chelonia mydas*, being the most commonly reported bycatch species, especially in known feeding and breeding areas and periods. Loggerhead *Caretta caretta* bycatch was reported only in northwest Mexico, an area known to support foraging and developmental areas for juvenile and subadult North Pacific loggerheads. Leatherback *Dermochelys coriacea* bycatch was most frequently reported in the Gulf of California (Sea of Cortez), a documented feeding area, and southern Mexico, off nesting beaches. Most respondents indicated that turtles captured incidentally were released alive, but mortality, as well as consumption and sale, were also reported fates of bycaught turtles. Our results provide a robust baseline of valuable information about characteristics of small-scale fishing and turtle bycatch in Pacific Mexico and highlight ample opportunities for informing strategies to promote sustainable fishing and bycatch reduction.

KEY WORDS: Sustainable fishing · Artisanal fishing · Bycatch reduction · Rapid bycatch assessments · Gillnets · Handlines

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1. INTRODUCTION

Negative effects of incidental capture in fisheries, or fisheries bycatch, significantly impede the recovery of sea turtle populations across the globe (Lewison et al. 2013, 2014, Wallace et al. 2013a, 2025). This is especially true where overlapping aggregations of turtles and fishing gear occur, which, in many cases, are in small-scale or artisanal fisheries in national waters relatively close to shore (Peckham et al. 2007, Alfaro-Shigueto et al. 2011, Lewison et al. 2013, Wallace et al. 2013a). Bycatch not only affects endangered, threatened, or protected species including sea turtles, marine mammals, and seabirds, but it also negatively impacts fishers and their communities through damaged gear, lost catch, increased costs, reduced time fishing, and safety concerns related to handling and releasing large animals that are not target species (Hall & Roman 2013). While there are many approaches to reducing bycatch, fishers and communities must be engaged in a meaningful way from the start of the development through the implementation of bycatch reduction strategies to ensure long-term success (Cox et al. 2007, Jenkins 2023).

Reducing bycatch in artisanal fisheries and its impacts on protected marine species depends on first understanding where, how, and to what extent bycatch is occurring. Unfortunately, such understanding of bycatch in artisanal fisheries tends to be hindered by inconsistent and insufficient data collection and reporting (Moore et al. 2010, Hall & Roman 2013, Ortiz-Alvarez et al. 2020). For example, carrying onboard observers, which is the preferred method to obtain objective information about bycatch interactions, can be infeasible practically and potentially dangerous in the small, open, and low-draft vessels used by most small-scale fishers (Salas et al. 2007). Electronic monitoring has been promoted as an alternative to onboard observer programs and has shown some promise in small-scale fishery settings (Bartholomew et al. 2018), but is in preliminary stages and has only been tested in a few settings.

Alternatively, researchers have used rapid bycatch assessments (RBAs) — i.e. direct, shore-based surveys with fishers — to obtain large amounts of information directly from fishers via focused survey formats (Moore et al. 2010, Alfaro-Shigueto et al. 2011, 2018, Mangel et al. 2011, Ortiz-Alvarez et al. 2020). RBAs have been used in several small-scale fishery systems to gather fishers' knowledge about fishery characteristics and interactions with protected species (e.g. Moore et al. 2010, Alfaro-Shigueto et al. 2018, Ortiz-Alvarez et al. 2020). This information has improved understanding of potential high-bycatch areas in Central and South America and has facilitated more focused concentration of conservation resources. For example, the Red Laúd OPO (Eastern Pacific Leatherback Network) has used results of RBAs conducted at a regional scale to highlight communities and areas to target focused conservation efforts (Ortiz-Alvarez et al. 2020, Red Laúd OPO 2023). Compared to conventional methods like on-board observers, RBAs represent a relatively fast, cost-effective methodology for establishing a geographically broad baseline of critical information about small-scale fisheries and bycatch (Lucchetti et al. 2017, Ortiz-Alvarez et al. 2020). Further, information collected using RBAs can also be used to identify fisher perceptions about causes and potential solutions to the bycatch challenge.

1.1. Mexican small-scale fisheries and associated bycatch

Among many areas where assessment of bycatch is warranted, Mexico is a high priority because it hosts several biodiverse and productive marine ecosystems that support many commercially valuable species as well as protected megafauna species. As of 2022, Mexico's capture fisheries produced approximately 1.6 million tonnes of seafood, representing 2.1% of global production and ranking the country 11th in the world (FAO 2024). The sector directly employs an estimated 292 584 individuals across both small-scale and industrial fisheries, supported by a fleet of 76 131 vessels, 97% of which belong to the small-scale fishery (SSF) sector (CONAPESCA 2023, 2024). Within Mexico, the Pacific coast accounts for 63% of the national fishing fleet and accounts for approximately 88% of the country's total fishery production (CONAPESCA 2023). The northern Pacific states (Sonora, Sinaloa, Baja California, and Baja California Sur) account for around 70% of national production, while the southern Pacific states (Nayarit, Jalisco, Colima, Michoacán, Guerrero, Oaxaca, and Chiapas) contribute only about 18% (CONAPESCA 2023).

Despite their importance, SSFs remain understudied in Mexico, particularly regarding their social-ecological impacts and challenges (Cisneros-Montemayor et al. 2013); among other factors, overexploitation of marine resources, increasing fuel prices, pollution, and climate change have exacerbated the economic and social instability of artisanal fishers from coastal communities. Mexican SSFs are typically multi-species and multi-gear, with most catches sold locally and a portion retained for household consumption (Schuhbauer et al. 2019).

1.2. Sea turtle biology, distribution, and bycatch in Mexico

In addition to the challenges faced by small-scale Mexican fishers, reducing sea turtle bycatch has been a recognized conservation priority for years (Peckham et al. 2017, Senko et al. 2017). Bycatch in SSFs has been documented to include sea turtles (Peckham et al. 2007, Cuevas et al. 2018) and other protected species like small cetaceans (Taylor et al. 2017, Romero-Tenorio et al. 2022) and sharks (Zea-de la Cruz et al. 2021). However, such research has been sporadic and geographically limited, with few comprehensive or regional assessments. A notable exception is the rapid bycatch assessment led by Ortiz-Alvarez et al. (2020), which identified potential bycatch hotspots for leatherback turtles among surveyed sites along the Mexican Pacific coast.

Pacific Mexico hosts 5 of the world's 7 sea turtle species, all of which use the region for feeding and/or nesting and are protected by Mexican law (NOM-059-SEMARNAT-2010). The olive ridley *Lepidochelys olivacea* is the most abundant species, nesting along the entire coast of Pacific Mexico, with major 'arribada' (synchronized mass nesting) sites in Oaxaca and Michoacán. Estimates suggest that approximately 1.39 million individuals inhabit Pacific waters (Eguchi et al. 2007), with a mean of over 1 million females nesting annually at La Escobilla beach between 2001 and 2005 (Abreu-Grobois & Plotkin 2008, Ocana et al. 2012). The green turtle *Chelonia mydas* (East Pacific subpopulation, hereafter referred to as 'green turtle') is the second most abundant species, with roughly 20 000 nesting females primarily in Colola and Maruata in Michoacán state (Delgado Trejo & Alvarado Díaz 2012), and the overall population foraging extensively in northwestern Mexico, especially in the Gulf of California and adjacent waters (Seminoff et al. 2021). Hawksbill turtles *Eretmochelys imbricata*, critically endangered in the eastern Pacific region (Gaos et al. 2010), occur sparsely in Mexico, with fewer than 50 nests yr^{-1} reported mainly in Guerrero, Nayarit, Jalisco, and Oaxaca (SEMARNAT 2020). Their feeding grounds, used mostly by juveniles, are associated with coral reefs and mangrove estuaries, and the population is considered at high risk (Martínez-Estévez et al. 2022) and under high threat (Wallace et al. 2025). North Pacific loggerhead turtles *Caretta caretta* do not nest in Mexico but migrate from nesting beaches in Japan to important foraging areas off the Baja California Peninsula, especially the Gulf of Ulloa and Gulf of California, with sightings extending south to Sinaloa and Nayarit (Zavala-Norzagaray et al. 2017). Aerial surveys have estimated approximately 43 000 individuals in the region (Seminoff et al. 2014). Finally, the Critically Endangered eastern Pacific leatherback turtle *Dermochelys coriacea* population (Wallace et al. 2013b, 2025) depends heavily on Mexico for reproduction, with nearly 90% of nesting activity occurring along its Pacific coast (Sarti Martínez et al. 2007, Laúd OPO Network 2020). Characterization of sea turtle bycatch in the eastern Pacific Ocean region using RBAs has increased in recent years (e.g. Alfaro-Shigueto et al. 2018, Ortiz-Alvarez et al. 2020), though important knowledge gaps remain, especially in Mexico.

Bycatch in artisanal fishing gear continues to affect sea turtle populations that use Mexican waters for feeding, breeding, and recruitment (Peckham et al. 2007, Mancini et al. 2012, Senko et al. 2014, Gaona Pineda & Barragán Rocha 2016, Ortiz-Alvarez et al. 2020). Fisheries impacts to loggerhead turtles offshore of the Baja California Peninsula have been well documented (e.g. Peckham et al. 2007, 2008), resulting in high-stakes international management to achieve bycatch reduction (Koch et al. 2006, Peckham et al. 2017, Senko et al. 2017). Further, efforts are urgently needed to address bycatch in nearshore areas adjacent to priority leatherback nesting beaches in southern Mexico, where adult females and males congregate annually (Ortiz-Alvarez et al. 2020), and in northwestern Mexico, where some of the eastern Pacific's most important foraging areas for multiple sea turtle species are found (Seminoff et al. 2014, Hart et al. 2015, Wallace et al. 2023). For these reasons, a focused assessment of small-scale fisheries in Pacific Mexico and associated sea turtle bycatch is needed.

1.3. Context for this study

In 2020, a new free-trade agreement, the USA, Mexico, and Canada (USMCA) Trade Agreement, was ratified, effectively replacing the North American Free Trade Agreement (NAFTA). This new accord includes several environmental goals, one of which is to develop a comprehensive program to reduce fisheries bycatch of sea turtles, prioritizing loggerheads and leatherbacks, 2 species of high conservation priority that occur in Pacific Mexico. These sustainable fishing provisions in USMCA spurred the development of a holistic, community-centered bycatch reduction initiative called MARES Comunidad (www.marescomunidad.com). Since 2021, MARES Comunidad has involved numerous government, academic, and non-governmental partners in the USA and Mexico, as well as fishers and fishing communities in Mexico, who directly interact with turtles. The main goal of the MARES Comunidad initiative is to promote sustainable fishing practices and livelihood opportunities in coastal communities throughout Pacific Mexico and the Baja California Peninsula. The framework for these efforts begins with establishing a baseline of knowledge about small-scale fisheries bycatch of sea turtles using RBAs in coastal communities.

Here, we combine results of RBAs conducted by the MARES Comunidad project with results from previous RBAs in which several of this paper's co-authors were involved (Ortiz-Alvarez et al. 2020) to characterize the nature and frequency of fisheries interactions with sea turtle species along the Pacific coast of Mexico. Our goal was to describe sea turtle bycatch in terms of locations, gear types, fisher demographics, and catch rates through RBAs in ports and fishing communities throughout Pacific Mexico. We also sought to understand similarities and differences in fishing and bycatch experiences across age groups, by gear type used, and across regions. Our results can support identification of communities in which to conduct follow-up activities to develop bycatch reduction strategies.

2. MATERIALS AND METHODS

2.1. Study area

The Pacific coastline of Mexico spans more than 7300 km and contains 3 large marine ecosystems (LMEs): the California Current, Gulf of California, and Pacific Central American Coastal LMEs. The region is home to several of the world's most biodiverse and productive marine ecosystems, attracting numerous commercially valuable marine species as well as many protected taxa such as sea turtles.

As described briefly in Section 1.2, the distribution of sea turtle species varies across the Pacific coast of Mexico. Northern regions serve as important feeding grounds, particularly for green, loggerhead, and hawksbill turtles, and include secondary nesting sites for olive ridley, green, and leatherback turtles. In contrast, the southern Pacific hosts the most significant nesting sites for green, olive ridley, and leatherback turtles.

For the purposes of this study, the Mexican Pacific coastline was divided into 7 regions (Table 1, Fig. 1), reflecting differences in dominant ecosystems, fisheries structures and techniques, and regional cultural identities.

2.2. Survey development and data collection

2.2.1. Survey development

To provide the most complete picture possible of operational characteristics and bycatch in artisanal fisheries in Pacific Mexico, we combined results from the 2 rapid bycatch assessment efforts conducted in Mexico (Fig. 1, Table 1). One occurred between May

Table 1. Communities per coastal region where the rapid bycatch assessments were conducted as shown in Fig. 1. BC: Baja California

Coastal region	Communities
BC Peninsula	Bahía de los Ángeles (Baja California), Laguna San Ignacio, Puerto Adolfo López Mateos, Todos Santos, San Juan de los Planes, La Ventana, El Sargento, La Paz, Las Pacas, El Pardito, Ensenada Blanca, Liguí, Juncalito, Loreto, San Juaniquito, San Nicolás, San Nilo, Las Ramaditas (Baja California Sur)
Alto Golfo	Golfo de Santa Clara, Puerto Peñasco, Puerto Lobos, Puerto Libertad, Desemboque, Punta Chueca, Bahía Kino (Sonora)
Zona Norte	La Manga, La Guásima, Bahía Lobos, Paredon Colorado, Paredoncito (Sonora), El Colorado, Topolobampo, Cerro Cabezón, Huitussi, Boca del Río, Costa Azul, La Reforma (Sinaloa)
Zona Centro Norte	Barras de Piaxtla, Isla de La Piedra, Playa Norte, Playa Sur, Chametla, Agua Verde, Teacapán (Sinaloa), La Puerta del Río, Novillero, Cuautla, Palmar de Cuautla, Boca de Camichín, Boca del Asadero (Nayarit)
Zona Centro	San Blas, Chacala, La Peñita de Jaltemba, Bahía de Jaltemba, Rincón de Guayabitos, Los Ayala, Punta de Mita (Nayarit), Puerto Vallarta, Nogalito, Mismaloya, Yelapa, Chimo, Corrales, Tehuamixtle, Chalacatepec, Punta Perula, Xametla, Careyes, Melaque, Barra de Navidad (Jalisco)
Zona Centro Sur	Manzanillo, Boca de Pascuales (Colima), Faro de Bucerias, Maruata, Caleta de Campos, Playa Azul, Lázaro Cárdenas (Michoacán), Zihuatanejo, Vicente Guerrero, Bahía de Acapulco (Guerrero)
Zona Sur	Barra de Tecoanapa, Punta Maldonado (Guerrero), Corralero, El Azufre, San Juan, Bahía de Chacahua, Zapotalito, Cerro Hermoso, Puerto Escondido, Huatulco, Mazunte, San Agustinillo, Puerto Ángel, Morro Ayuta, Chipehua, Ventosa (Oaxaca), Paredón, Puerto Arista (Chiapas)

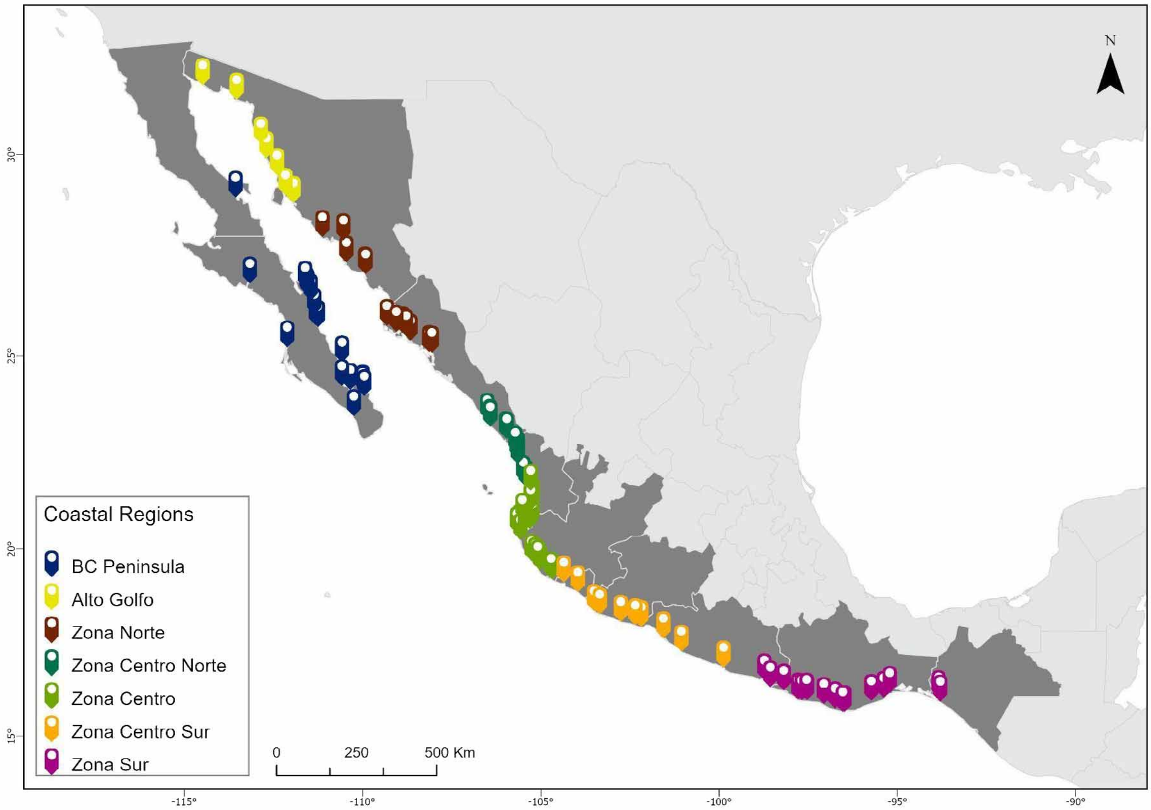

Fig. 1. Communities where rapid bycatch assessments (i.e. surveys) were conducted, shown by coastal region (identified by different colors). See Table 1 for list of participating communities in each region

2017 and May 2018 (Ortiz-Alvarez et al. 2020, hereafter 'Ortiz survey') and targeted the Mexican states of Baja California, Baja California Sur, Sonora, Sinaloa, Oaxaca, and Chiapas, as well as coastal fishing communities in Nicaragua, Costa Rica, Panama, and Colombia. The second survey was conducted under the MARES Comunidad project between February 2022 and January 2024 (hereafter 'MARES survey') targeting the Mexican states of Baja California, Baja California Sur, Sinaloa, Nayarit, Jalisco, Colima, Michoacan, and Guerrero. In addition, ~50 RBAs occurred before and sporadically during the COVID-19 pandemic from Feb 2020 to April 2021. The MARES survey targeted additional communities in southern Sinaloa, Nayarit, and central Guerrero that were not included in the Ortiz survey.

Both the MARES survey and the Ortiz survey were based on an existing RBA tool developed initially for Peru (Alfaro-Shigueto et al. 2018). The structure of the 2 survey instruments (Supplement 1 at www.int-res.com/articles/suppl/n058p205_supp1.pdf and Supplement 2 at www.int-res.com/articles/suppl/n058p205_supp2.pdf for the Ortiz and MARES surveys, respectively) was largely the same, except that the Ortiz survey focused on leatherbacks and up to 2 primary fishing gears per respondent, whereas the MARES survey allowed respondents to provide information about up to 4 fishing gears. Surveyors received training in sea turtle species identification and collaborated with fishers to accurately assign species based on physical descriptions and local names used. In this paper, we focus on multiple choice and open-ended questions that asked respondents about fisher demographics, fishing gear and techniques, sea turtle bycatch, and survival of caught sea turtles. The MARES survey also included several questions to understand fishers' perceptions about the causes of and potential solutions to bycatch; these results will be presented in a separate publication.

2.2.2. Data collection

Details about data collection methods for the Ortiz survey are described by Ortiz-Alvarez et al. (2020). For the MARES survey, fishing communities along the Pacific coast were selected based on *a priori* knowledge about the most active fishing communities (in terms of number of fishers and fishing activity) in each region. Additional survey sites were determined ad hoc based on information collected during early rounds of surveys. In all cases, a community was only visited if a member of the MARES Comunidad team had known contacts or had personal knowledge of the site. Surveyed fishers in each community were determined based on prior acquaintance with MARES team members, randomly intercepted, or were introduced during community visits.

MARES surveys were conducted verbally in person and led by team members trained in proper and ethical survey techniques. Research protocols followed those used for the Ortiz survey, which were approved by an internal institutional review by ProDelphinus (https://www.prodelphinusperu.org), a Peruvian nongovernmental organization with experience on research and conservation of threatened and endangered marine species. These protocols required verbal consent from participants prior to answering survey questions. Before consenting, they were presented with the survey scope, as well as informed that their participation was voluntary and anonymous, they could skip any questions they did not want to answer, and that the survey was only for research purposes. Survey questions were designed and tested to ensure questions were framed correctly and not overly intrusive. Everyone who administered the survey was fluent in the language and colloquial terminology of the study area. Surveys were conducted using tablets, computers, or hard copy paper, depending on local conditions at the time. Validation questions (i.e. similar questions phrased differently) were included to measure the respondent's consistency. Surveys where answers seemed inconsistent or provided contradicting information were discarded. Each survey was typically completed within 45 min, although some took longer, as participants were allowed to elaborate beyond specific questions if they wished.

2.3. Analysis

With the complete data set, we first conducted data curation to facilitate analyses. We uploaded the completed data to SPSS, where several analyses were conducted. Data were analyzed by fisher age, primary occupation, and regions (Table 1), which were groupings of communities based on similarities in geography, as well as fishing areas and methods, both of which varied significantly across the Pacific Mexico region (Fig. 1; SEMARNAT 2009). Analyses primarily included relative frequencies and percentages of categorical answers and means of continuous variables (e.g. fisher age, number of years fishing). All graphs illustrate percentages except when (1) categories contained fewer than 30 individuals (as suggested by Sandelowski 2001) or (2) when a combined total number made sense for the analysis rather than a percentage (e.g. total number of turtles caught by each fishing gear type).

Fishers participating in the Ortiz survey could only list up to 2 types of fishing gear as the fishing gears they use, whereas those taking the MARES survey could report up to 4 gears. In addition, those taking the MARES survey could list the same fishing gear type more than once across multiple questions. Given these differences, we report only if the individual mentioned the gear type or not (e.g. 2 mentions of the same gear type by the same person were counted as 1 person using this method). We grouped respondent ages (years) into the following ranges: <35, 35–45, and >45 based on the midpoint of the overall sample. We calculated the number of years fishing (i.e. experience) by subtracting the age at which they started fishing from their age at the time of the survey.

2.4. Estimating turtle bycatch from survey data

To estimate minimum numbers of turtles reported as bycatch, we used responses to the question: 'How many turtles did you catch accidentally last year?' Because answers were provided either as exact numbers or ranges, we standardized all responses by converting them into numerical ranges. For each range, we extracted the minimum, maximum, and midpoint values. We then calculated the frequency of each range at 2 scales: individual region and entire Pacific coast. Using the summed minimum and midpoint values, we then estimated bycatch numbers at both scales. Finally, we estimated the number of bycatch interactions by species and fishing gear by weighting the bycatch estimates (minimum and midpoint) according to the reported frequency of each species and gear type involved in bycatch. See Text S1 in Supplement 3 at www.int-res.com/articles/suppl/n058p205_supp3.pdf for more details on how these calculations were performed.

3. RESULTS

The 2 surveys were completed by 1357 respondents across 99 communities in 11 different Mexican states. The Ortiz survey collected information from 779 fishers in 37 communities in 5 states, whereas the MARES survey collected information from 578 fishers in 62 communities in 8 states. The number of participants varied among regions due to the size of various communities and states. The regional breakdown of survey respondents was: Baja California (BC) Peninsula (n = 120), Alto Golfo (n = 214), Zona Norte (n = 325), Zona Centro Norte (n = 196), Zona Centro (n = 136), Zona Centro Sur (n = 126), and Zona Sur (n = 240) (Table 2). The number of respondents replying to each question varied and is indicated when reporting those specific findings.

3.1. Overall fisher characteristics

Fishers' ages ranged from 14 to 94 yr, with an average age of 45.8 yr at the time of surveys and 15.5 yr when they started fishing. Among respondents, 88.2% said fishing was their primary occupation, and 55.8% owned a boat. The average age of fishers in most regions was in the mid-40s (42.2–46.0), but those in Zona Centro Norte and Zona Centro Sur averaged >50 yr (50.8 and 51.1 yr, respectively) (Table 2). Although in all regions most respondents started fishing in their teens, the average starting age varied from 14.9 yr (BC Peninsula and Zona Norte) to 17.4 yr in Zona Centro Sur.

We conducted a Spearman rank correlation test between age and experience and found that they were positively correlated ($\rho = 0.918$, n = 1356, $p < 0.001$). Since age and fishing experience were closely related, we did not conduct analyses for experience separately because relationships would be similar to those for age.

Almost all respondents in Zona Sur (94.6%) and Zona Norte (94.5%) said that fishing was their primary occupation, closely followed by those in Alto Golfo, BC Peninsula, and Zona Centro Norte (Table 2). Fewer respondents in Zona Centro (67.4%) and Zona Centro Sur (77.2%) relied primarily on fishing for employment. Boat ownership also varied greatly across regions, with 73.8% owning a boat in Zona Norte compared to 31.6% of respondents in Zona Centro.

3.2. Fishing methods and bycatch

Overall, responses among the age groups were similar for reported gear types used, and which gear types resulted in greater bycatch (Figs. S1 & S2 in Supplement 3). One difference was the use of trawl gear, which was most common among fishers who were between 35 and 45 yr old. A slightly greater percentage of fishers 35 to 45 yr (40.4%) reported bycatch in gillnets than fishers <35 (34.8%) or >45 yr old (34.3%). Although less commonly associated with bycatch, 12.7% of fishers >45 yr reported catching sea turtles in longlines compared to 6.8% of fishers <35 yr (Fig. S2).

A chi-squared test revealed no significant differences in the ways in which sea turtle species were caught by fishers of different age groups (Fig. S3). There were some apparent differences in the total number of turtles caught among age groups, although none were statistically significant. For example, a greater percentage of those over 45 yr (58.1%) reported catching ≤10 turtles during the previous year compared to 42.4% of those under 35. Conversely, a slightly greater percentage of those under 35 (9.6%) than those over 45 (2.8%) reported catching 51–100 turtles (Fig. S4). There were no differences in the fate of caught turtles among the different age groups (Fig. S5).

Table 2. Demographic information for respondents from each region, including the number of total survey respondents; means for current age, age they started fishing, and years fishing; and percentages for those still fishing at same location, for whom fishing is their primary job, and boat owners. The number of respondents who answered those questions is the number of respondents unless indicated otherwise (in parentheses) when reporting the specific findings

	Number of respondents	Mean age (yr)	Mean age (yr) started fishing	Mean years fishing	Still fishing at same location (%)	Primary job (%)	Owned boat (%)
BC Peninsula	120	45.4	14.9	31.2 (n = 66)	97.0 (n = 66)	86.7	65.0
Alto Golfo	214	42.2	16.0	–	–	89.7	46.7
Zona Norte	325	46.0	14.9	–	–	94.5	73.8
Zona Centro Norte	196	50.8	15.1	21.5 (n = 193)	93.9 (n = 196)	90.3 (n = 195)	59.2
Zona Centro	136	43.4	16.1	25.0 (n = 134)	97.1	67.4 (n = 135)	31.6
Zona Centro Sur	126	51.1	17.4	31.2 (n = 124)	92.9	77.2 (n = 123)	46.8 (n = 124)
Zona Sur	240	43.3	15.4	–	–	94.6	50.0

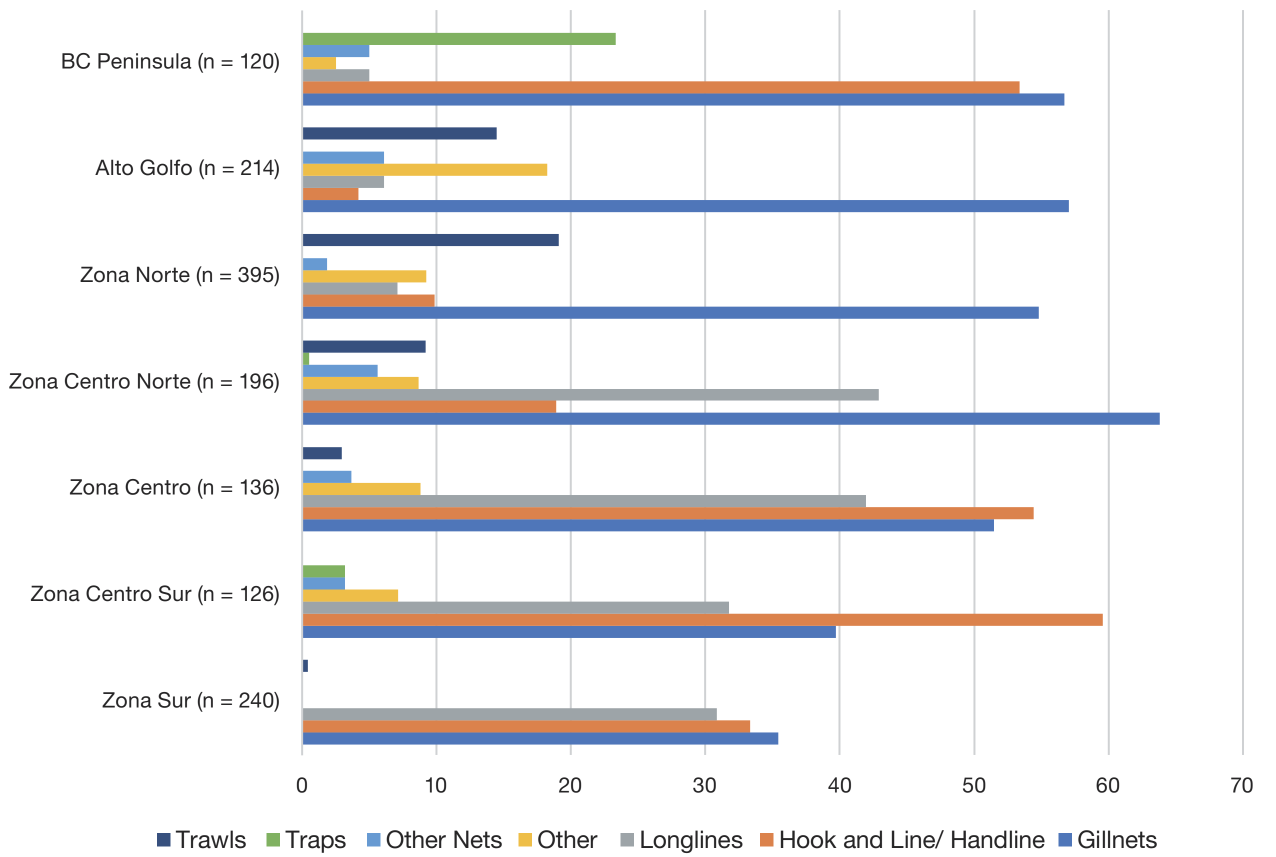

Fig. 2. Percentage of respondents using each fishing gear by region

3.3. Comparisons among fishing gears and regions

Overall, fishers reported bycatch in at least 7 categories of fishing gears. Gillnets (i.e. drifting or set nets used either at the surface or at the bottom, with variable mesh sizes and soak times) were the most frequently mentioned gear (50%) (Fig. 2), followed by longlines (i.e. lines with multiple hooks with bait, used either at the bottom or the surface of the water, with variable soak times) (24%) and hook and line/handlines (referring to a hook with bait fixed on a hand-held line and immersed in the water for the time necessary to catch a fish) (15%). Other gears mentioned to have bycatch were artisanal trawls (i.e. nets that are towed through the water for 1–2 h and 'scoop up' fish) (4%), other types of nets used locally (2%), traps (i.e. wooden or metal traps used for fish or shellfish species, generally set overnight or for a variable amount of time) (1%), and other fishing gears (4%).

Gillnets were the most frequently used fishing gears in most regions (Fig. 2), but in several regions, the use of hook and line/handlines and longlines approached (e.g. BC Peninsula, Zona Sur) or exceeded (e.g. Zona Centro, Zona Centro Sur) gillnets as the most frequently used gear (Fig. 2). Although other gear types (i.e. other nets, traps, trawls, and other gear types) were less frequently used in all regions, there were some differences between regions. For example, >15% of respondents in Alto Golfo and Zona Norte used trawls, as opposed to Zona Centro Sur and Zona Sur, where trawls were not mentioned.

Reported bycatch was typically dominated by 1 or 2 sea turtle species, while others were less frequently reported. These patterns, however, varied by region. Olive ridley turtles were the most frequently reported species overall, accounting for 47% of all mentions, followed by green turtles at 31%. Among regions, olive ridleys dominated reports in Zona Sur (67%), Zona Centro Sur (56%), and Zona Centro (46%), while green turtles were the most frequently mentioned species in the BC Peninsula (76%) and Alto Golfo (38%) (Fig. 3). Bycatch of hawksbill, leatherback, and loggerhead turtles was reported less frequently, comprising 8, 7, and 6% of all species mentions, respectively. Hawksbill turtle bycatch was most frequently

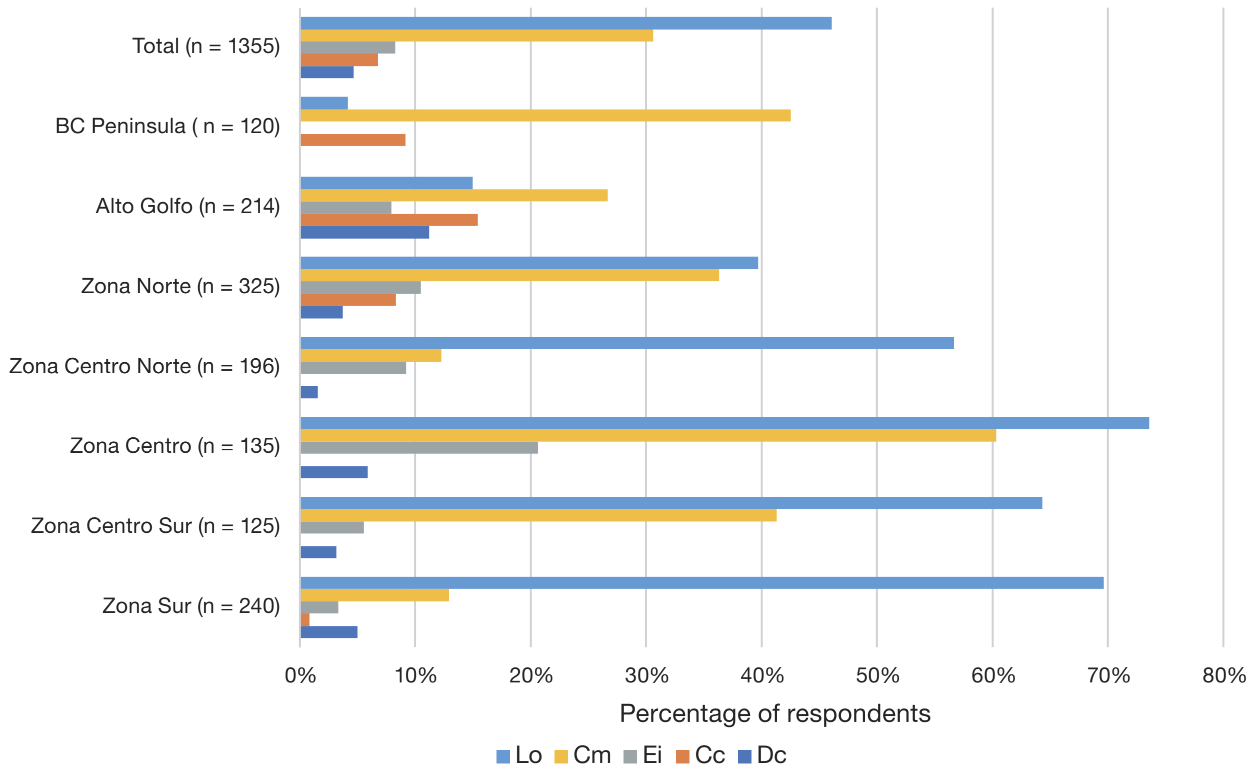

Fig. 3. Percent of fishers in each region who reported bycatch of each turtle species: Lo: olive ridley *Lepidochelys olivacea*; Cm: green turtle *Chelonia mydas*, Ei: hawksbill *Eretmochelys imbricata*; Cc: loggerhead *Caretta caretta*; Dc: leatherback *Dermochelys coriacea*

reported in Zona Norte (30%), Zona Centro Norte (16%), and Zona Centro (25%). Loggerhead turtle bycatch reports were concentrated in the BC Peninsula (15%), Alto Golfo (45%), and Zona Norte (37%), which together accounted for 97% of all loggerhead records. Leatherback turtles were primarily reported in Alto Golfo (10%) and Zona Norte (29%) (Fig. 3).

Among fishers who reported bycatch, 58.7% reported catching between 1 and 10 turtles in the previous year (Fig. 4). In Alto Golfo, Zona Norte, and Zona Sur, all respondents confirmed bycatch of at least 1 turtle. Almost 95% of BC Peninsula respondents reported either no bycatch or 1–10 turtles caught, with almost an even split between these 2 responses. Although most fishers reported catching a few turtles, some fishers, especially from Zona Norte, Zona Centro, and Zona Sur, reported extremely high bycatch numbers (>100 turtles) (Fig. 4).

Overall, fishers reported that bycatch occurred most frequently in gillnets, followed by longlines and hook and line/handlines (Fig. 5). Because reported bycatch numbers were small for some gear types, we refer to numbers of people reporting bycatch using a specific gear instead of percentages. Therefore, comparisons should only be made among gear types within each region. Gillnets were the most frequent gear that resulted in turtle bycatch in Zona Norte (n = 120), Zona Centro Norte (n = 82), Zona Centro (n = 56), Alto Golfo (n = 64), and BC Peninsula (n = 57). In Zona Centro, the amount of bycatch in longlines closely followed the amount reported in gillnets. Bycatch was equally reported to occur in gillnets and longlines in Zona Sur. In contrast, more fishers in Zona Centro Sur reported turtle bycatch using hook and line/handline (Fig. 5).

Species-specific patterns of bycatch in certain types of gear were also apparent, likely a result of these gear types being more frequently used and differences in species distribution and abundance. Among all fishers in our sample, all species of sea turtles were most frequently caught with gillnets, which held true for most regions as well (Fig. 6). However, in Zona Centro, more leatherbacks were caught in longlines compared to other regions. In Zona Centro Norte, Zona Centro Sur, and Zona Sur, olive ridleys were equally or more frequently caught by hook and line/handlines or longlines than gillnets. In Zona Centro Sur, hawksbill bycatch was reported with

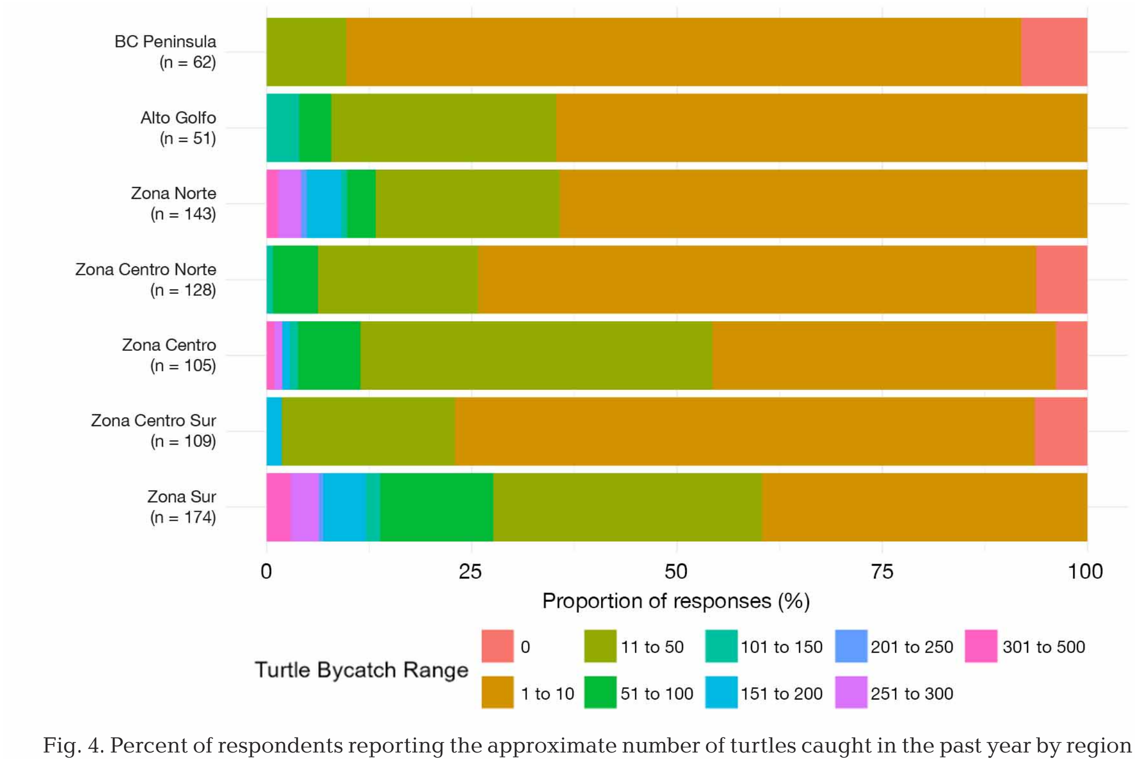

Fig. 4. Percent of respondents reporting the approximate number of turtles caught in the past year by region

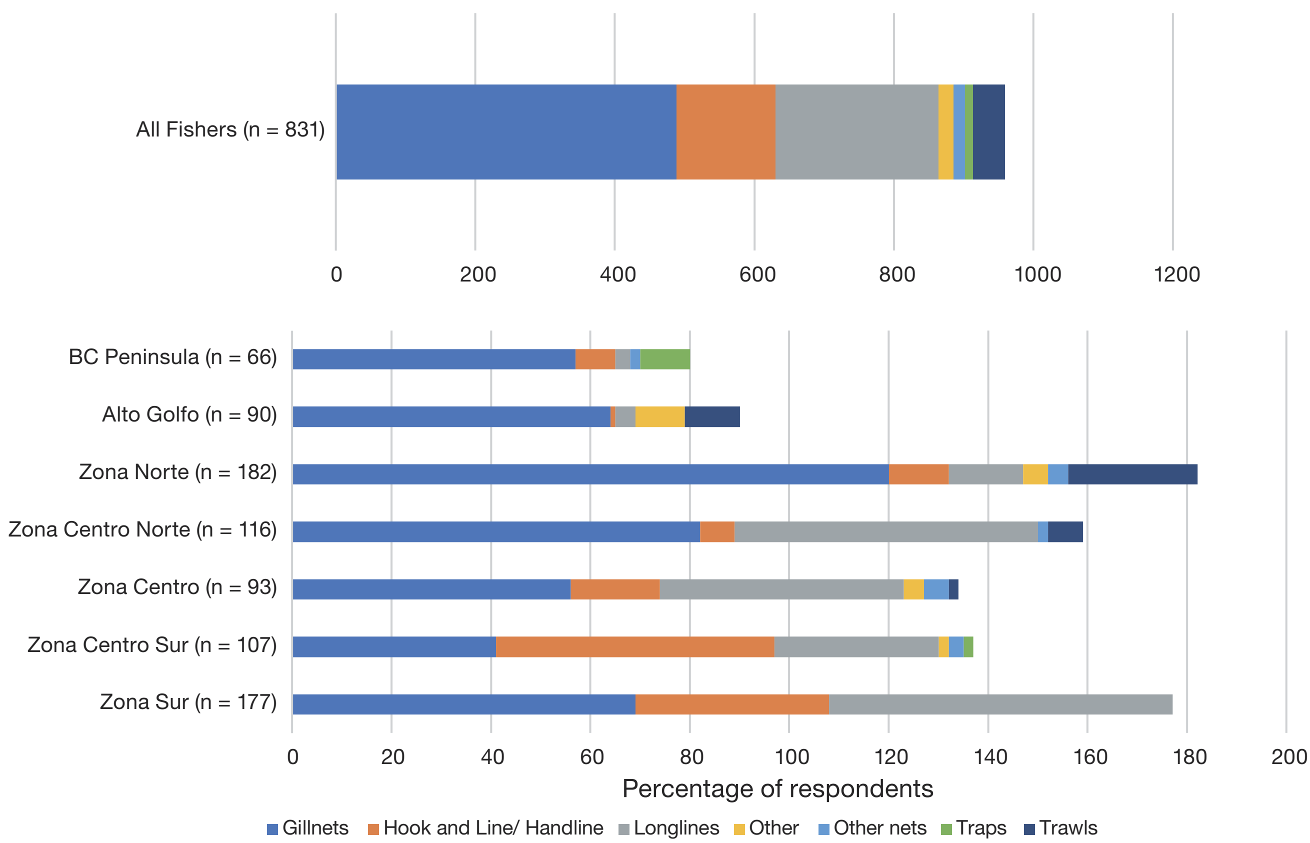

Fig. 5. Number of respondents who reported bycatch in each gear type by region

Fig. 6. Minimum bycatch estimates by region, by fishing gear, and by species. The numbers within the tiles represent the minimum estimated bycatch levels. Gear types are displayed on horizontal axes and species are displayed on vertical axes. Turtle abbreviations as in Fig. 3

almost the same frequency in gillnets, longlines, and hook and line/handlines. In Zona Centro, the frequency of reported hawksbill bycatch was similar in longlines and gillnets. The number of green sea turtles caught was similar for gillnets and longlines in Zona Centro and Zona Sur. Distinctively, in Zona Norte, olive ridleys and green turtles were more frequently caught in trawls (Fig. 6).

Although 64% of all fishers reported that bycaught sea turtles were released alive, the fate of bycaught sea turtles varied among regions (Fig. 7). In Zona Centro, Zona Centro Norte, Zona Centro Sur, and

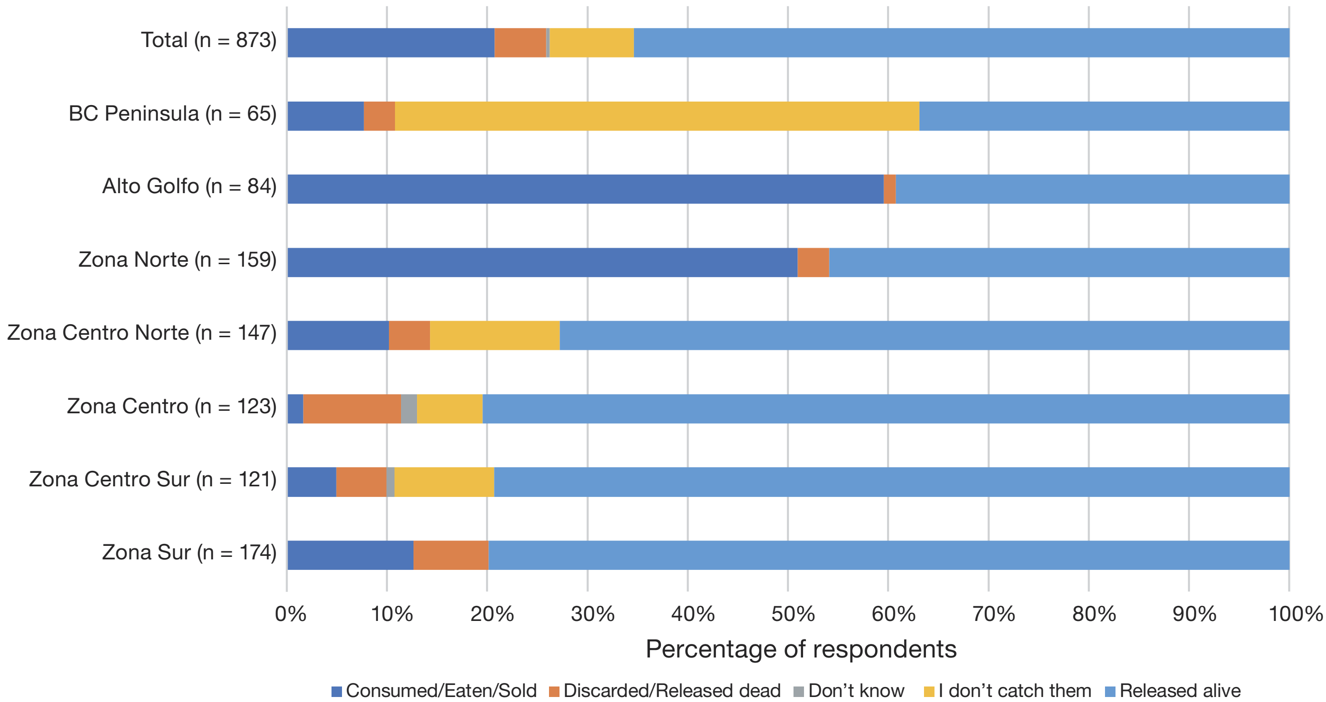

Fig. 7. Percentage of respondents reporting on the fate of bycaught turtles by region

Zona Sur, more than 70% of all respondents said they released the turtles alive. In the BC Peninsula, 52.3% of the 65 respondents said they did not catch turtles, while 36.9% said they released them alive. In contrast, most fishers in Alto Golfo (59.5%) and Zona Norte (50.9%) said they consumed or sold bycaught turtles. They did not state whether these turtles were caught alive, injured, or dead.

3.4. Estimates of turtle bycatch

Using conservative minimum and midpoint bycatch ranges as provided by fishers' responses, we estimated a bycatch of 14 118 to 22 974 sea turtles in 1 year at the entire regional level (Table 3). Bycatch estimates were highest for olive ridleys (6904–11 235) and green turtles (4376–7121) (Table S1 in Supplement 3; for all tables). In terms of fishing gears, gillnets were associated with the highest bycatch estimates (7160–11 652 turtles), followed by longlines (3596–5851 turtles) (Table 4; Table S2). Combining final status of bycaught turtles with the bycatch range estimates, the number of animals that were reported dead after bycatch was between 3894 and 6189 (Table S3).

Table 3. Sea turtle bycatch estimates by species using minimum and midpoint values of annual fisher-reported bycatch per region (see Section 2.4 and Figs. S1–S5 for details)

Species	Number of respondents	Minimum bycatch estimates	Midpoint bycatch estimates
Loggerhead *Caretta caretta*	59	704	1145
Green turtle *Chelonia mydas*	367	4376	7121
Leatherback *Dermochelys coriacea*	81	966	1572
Hawksbill *Eretmochelys imbricata*	98	1169	1902
Olive ridley *Lepidochelys olivacea*	579	6904	11235

Table 4. Sea turtle bycatch estimates by fishing gear type using minimum and midpoint values of annual fisher-reported bycatch per region (see Section 2.4 and Figs. S1–S5 for details)

Fishing gear	Number of respondents	Minimum bycatch estimates	Midpoint bycatch estimates
Gillnets	460	7160	11652
Hook and line/handline	144	2241	3647
Longlines	231	3596	5851
Other	15	233	380
Other nets	16	249	405
Traps	12	187	304
Trawls	29	451	735

4. DISCUSSION

Small-scale fishing is a major source of food and livelihoods for millions of people worldwide, and can have disproportionately large impacts on marine ecosystems, especially for protected megafauna like sea turtles. Overall, our results demonstrate the importance of assessing impacts of SSFs on protected species using methods that do not require onboard observers (Alfaro-Shigueto et al. 2018, Putman et al. 2023). This study filled a major information gap for Pacific Mexico, where SSFs are typically multispecies and multi-gear, and most catches are sold locally and a portion retained for household consumption (Schuhbauer et al. 2019).

Our results show that sea turtle bycatch was a common occurrence in small-scale fishing activities (Figs. 3–6). Estimates derived from the surveys ranged from ~14 000 to ~23 000 incidents of turtle bycatch with an adjusted mortality level of ~4000 to ~6000 turtles during the year previous to the survey. These estimates are aligned with bycatch estimates from surveys reported in a combined study of small-scale gillnets in Ecuador, Perú, and Chile, where annual bycatch level was estimated at almost 4500 sea turtle interactions (Alfaro-Shigueto et al. 2018), but are lower than those reported in Italy using an interview-based approach and where 52 000 turtles were estimated as bycatch (Lucchetti et al. 2017). Mortality rate across fishing gears in our study was estimated as 27% (see Table S3), which is in line with the casualties reported in Italy (19%) (Lucchetti et al. 2017). Regionally, Zona Norte and Zona Sur were the 2 areas with the highest bycatch levels, probably as a consequence of being respectively the most densely fished area (ca. 40% of all small-scale vessels in the Mexican Pacific region; CONAPESCA 2023) and the area with the highest concentrations of sea turtles, particularly olive ridleys (Ocana et al. 2012).

It is important to point out that our estimates of turtle bycatch are underestimates for 3 main reasons. First, some communities and fishing activities (e.g. industrial fishing) within the study area were not surveyed. Second, although we aimed for surveys to cover at least 20% of fishing vessels in the communities — and we sometimes achieved over 50% coverage — our assessment and thus our bycatch estimates are based on a sample only of willing participants. Third, despite the surveys being confidential, sea turtles are protected by Mexican law, which means that fishers' responses might be biased by the potential negative repercussions of accurate reporting of bycatch (Lucchetti et al. 2017, Ortiz-Alvarez et al. 2020). Despite these issues, our results from over 1300 fisher survey responses represent the most comprehensive small-scale fisheries survey to date in Pacific Mexico, and provide important baseline information about fishing effort and the distribution and magnitude of sea turtle bycatch in the region's SSFs.

While most reports of sea turtle bycatch in the previous year were of few individuals, there were also several reports of large numbers of accidentally captured turtles (>100) (Fig. 4). With few exceptions, the bycatch level reported in our study (58.7% of respondents reported catching 1–10 turtles during the previous year) places small-scale fishers in Mexican Pacific in a scenario with low, widespread, and highly variable (by region and gear types) bycatch levels, which greatly complicates identifying a 'one-size-fits-all' solution to mitigate the problem.

Similar to previous studies using RBA methods (e.g. Alfaro-Shigueto et al. 2018, Ortiz-Alvarez et al. 2020), gillnets were the most prevalent fishing gear, but many respondents described using multiple fishing gears to catch different target species throughout the year (Fig. 2). This flexibility to use multiple types of fishing gears and methods exemplifies that small-scale fishing practices can respond quickly to changing environmental and market conditions (e.g. Alfaro-Shigueto et al. 2011). The most frequently used gears were also the gears that most frequently captured sea turtles, a finding reported in previous studies (Alfaro-Shigueto et al. 2011, Ortiz-Alvarez et al. 2020). Trawls also appeared somewhat frequently as a gear in which turtles are accidentally captured, but these responses were concentrated in the northern end of the study area. This could reflect the large shrimp trawl fisheries centered in the state of Sinaloa and southern Gulf of California (Meraz-Sánchez et al. 2013). Regional differences in gear types used might vary because of differences in target catch, local marine protected area laws, local cultural and community traditions, and the number and type of permits issued by the government.

Species-specific bycatch patterns reflected variation in documented turtle distributions, abundance, and life cycles. Olive ridleys followed by green turtles were the sea turtle species most frequently reported as bycatch (Fig. 3). For example, reported bycatch across species appeared highest in the Gulf of California regions (Alto Golfo and Zona Norte), which are known feeding and juvenile nursery areas for sea turtles and many other migratory species, as well as productive fishing areas (Seminoff & Nichols 2007, Rodríguez-Quiroz et al. 2012). The high frequency of green turtle and olive ridley bycatch likely results from ongoing recovery of these species throughout the eastern Pacific, owing to protection under Mexican law since 1990 and decades of effective protection efforts both on nesting beaches and in marine habitats (Delgado Trejo & Alvarado Díaz 2012, Early-Capistrán et al. 2018, Senko et al. 2022, Seminoff 2023).

Green turtles were frequently reported as bycatch in Baja California, Alto Golfo, and Zona Norte, and in Zona Centro and Zona Centro Sur, regions that host important feeding and reproduction areas, respectively (Hart et al. 2015, Seminoff et al. 2021, Bedolla-Ochoa et al. 2023). Similar to green turtles, olive ridley bycatch was reported throughout the study area, related to high at-sea abundance (Eguchi et al. 2007) and broadly distributed and highly abundant nesting along the Mexican Pacific, especially in Zona Sur, where 'arribada' nesting sites occur (Ocana et al. 2012). Abundance of both green turtles and olive ridleys has increased significantly in the eastern Pacific in recent decades, which evidently has increased the frequency of incidental capture of these species in Pacific Mexican fisheries.

Leatherbacks, loggerheads, and hawksbills — the most endangered sea turtle species that inhabit coastal Pacific Mexico (Wallace et al. 2025) — were less frequently reported, but bycatch was confirmed in multiple regions and gear types. Loggerheads, in particular, were only reported as bycatch in the northwestern zones of the study area (Fig. 3), coinciding with the known feeding distribution of juveniles along the coast of the Baja California peninsula and in the Gulf of California (Peckham et al. 2007, Seminoff et al. 2014, Zavala-Norzagaray et al. 2017). Further, leatherback bycatch was reported most frequently at the northern and southern ends of the study area (Fig. 3), which overlap with feeding areas used by turtles from the western and eastern Pacific leatherback regional management units (Wallace et al. 2023) and eastern Pacific leatherback index nesting sites (Sarti Martínez et al. 2007, Laúd OPO Network 2020), respectively. These patterns highlight opportunities to develop species-specific bycatch reduction strategies targeting specific communities adjacent to areas where identified overlaps occur between fishing activities and important turtle habitats.

Overall, most respondents indicated that turtles accidentally captured in their fishing gear were ultimately released alive (Fig. 7). However, at least some respondents in all regions indicated that turtles were retained for personal consumption or (less frequently) sale, and the frequency of retention varied regionally. This is especially so for Alto Golfo and Zona Norte, where a majority of surveyed fishers in both zones responded that they consumed and/or sold turtles (Fig. 7). Mexico has a long cultural and Indigenous tradition of use of turtles and turtle products. Legal turtle fisheries and harvest regimes that targeted primarily green and olive ridley turtles on the Pacific coast were widespread until a national prohibition on consumption and trade of sea turtle products (e.g. eggs, meat, skin) in 1990 (DOF 1990, Delgado Trejo & Alvarado Díaz 2012, Early-Capistrán et al. 2018). Despite this prohibition, the continued direct take of sea turtles for use as a food source has been reported to occur on the Pacific coast of Mexico (Delgado & Nichols 2005, Mancini & Koch 2009). In addition, the practice of retention of bycaught sea turtles for food or revenue is relatively common among small-scale fishers who often struggle economically (Alfaro-Shigueto et al. 2011), particularly in coastal Mexico (Mancini & Koch 2009).

The remoteness of coastal fishing communities, especially in northwest Mexico, promotes strong traditions of self-sufficiency and dependence on local resources, including sea turtles, to meet livelihood needs (Villaseñor-Derbez et al. 2019, Lara-Mendoza et al. 2022). These characteristics of remote fishing communities also coincide with weak to non-existent monitoring and enforcement of fishery regulations and resource management policies. While some level of consumption and commercialization of fishery-captured sea turtles is probably inevitable, the fact that a majority of respondents in the Gulf of California region reported that turtles are consumed and/or sold shows clearly that these traditions persist. Given the sensitivity related to the consumption of sea turtles, and its lack of legal support in Mexico, it is likely that these responses underestimate the true prevalence of these practices.

5. CONCLUSIONS

This study presents fundamental information about sea turtle bycatch in small-scale fisheries in Pacific Mexico, which highlights many opportunities for follow-up efforts to collaboratively develop activities that reduce bycatch impacts through improvements in fishing sustainability. With the data from this study, we can better identify specific fishing areas, gear types, seasons, and utilize suggestions gathered from the local fishers to co-develop activities to improve gillnet selectivity, to enhance use of fishing practices like hand-held hook and line methods that are less lethal for sea turtles, and to bolster efforts to develop alternative economic opportunities for fishers. Community-led alternative economic activities could strengthen the resilience of coastal fishing communities and reduce reliance on unsustainable fishing practices in the long-term. Because there is no 'one-size-fits-all' approach to reducing SSF bycatch, holistic strategies must be developed that are customized to each community's perspectives, interests, needs, and characteristics. At the same time, coordination with management authorities is warranted to enhance capacity for enforcing existing regulations that promote fishing sustainability and reduce bycatch impacts. Sea turtles and coastal fishing communities in Mexico have been intertwined for many generations, and such holistic approaches are needed to ensure that this coexistence persists for many more generations in the future.

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