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Rapid Assessments of Leatherback Small-Scale Fishery Bycatch in Internesting Areas in the Eastern Pacific Ocean

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The East Pacific (EP) leatherback population is listed by the IUCN *Red List of Threatened Species* as Critically Endangered. Despite conservation efforts, mainly focused on nesting beaches, its population has declined by over 90% since the 1980s. A major current threat is fisheries bycatch, which has been primarily documented in small-scale gillnets and longlines within South American migration and foraging habitats, but scarcely reported in fisheries that operate in areas near nesting beaches (i.e., inter-nesting areas). To assess the impact of small-scale fisheries on EP leatherbacks inhabiting waters north of the equator we conducted rapid bycatch assessments interviews in five countries (Mexico, Nicaragua, Costa Rica, Panama and Colombia), some of which host the main EP leatherback nesting beaches and inter-nesting areas. A total of 1778 interviews were conducted across 79 fishing ports (Mexico = 37, Nicaragua = 6, Costa Rica = 5, Panama = 17 and Colombia = 14). Leatherback bycatch was reported in all countries, and in 54% of ports assessed by 7% (n = 125) of fishers interviewed. Interviews enabled identification of inter-nesting areas where leatherback bycatch was higher and periods during which fisheries interaction events were more frequent. Bycatch events were most frequently reported in gillnets and secondarily in longlines. Data were extrapolated across fishing fleets to estimate that 345 ± 210 (mean ± SD) individual leatherbacks are caught annually in the ports assessed. Our study provides a first evaluation of leatherback bycatch by small-scale fisheries in countries of the eastern Pacific Ocean where leatherbacks nest, and it highlights areas close to index nesting beaches where conservation efforts targeting bycatch reduction and bycatch mortality may be focused.

Keywords: ***Dermochelys coriacea*****, leatherback, bycatch, small-scale fisheries, interviews, rapid bycatch assessments**

INTRODUCTION

The East Pacific (EP) leatherback (*Dermochelys coriacea*) population nests from northern Mexico to Ecuador, with most nesting concentrated in the states of Michoacán, Guerrero and Oaxaca in Mexico, in Nicaragua, and in northwestern Costa Rica (Shillinger et al., 2010; Seminoff et al., 2012). EP leatherback foraging areas extend off Panama, Colombia, Ecuador, Peru, and Chile (Saba et al., 2008; Shillinger et al., 2008, 2011; Bailey et al., 2012). Since the 1980s, leatherback population abundance – reported as annual abundance of nesting females and their nests – has declined over 90% regionwide (Santidrián-Tomillo et al., 2017), making it Critically Endangered according to the IUCN Red List of Threatened Species (Wallace et al., 2013b) and one of the most endangered marine turtle Regional Management Units in the world (RMUs) (Wallace et al., 2011). Conservation efforts have been mainly focused on reducing egg and female harvest at nesting beaches (Santidrián Tomillo et al., 2007; Sarti-Martinez et al., 2007). However, incidental capture in fisheries (i.e., bycatch) is considered the main source of mortality for EP leatherbacks, despite receiving less attention than nesting beach threats (Spotila et al., 2000; Shillinger et al., 2008; Wallace et al., 2013a). Nonetheless, historical and on-going bycatch reported mainly in foraging and migratory areas off South America has been implicated in the regional population decline (Eckert and Sarti-Martinez, 1997; Spotila et al., 2000; Donoso and Dutton, 2010; Roe et al., 2014; Santidrián-Tomillo et al., 2017; Alfaro-Shigueto et al., 2018).

During the past decade, efforts have increased to quantify bycatch impacts on the EP leatherback population, focused primarily on Peruvian and Chilean fisheries operating in leatherback foraging areas (Donoso and Dutton, 2010; Alfaro-Shigueto et al., 2007, 2011, 2018). Reported leatherback bycatch rates are primarily derived from on-board and shore-based observations from longline and gillnet fisheries in Chile and Peru, and bycatch estimates are low compared to those for other sea turtle species (Alfaro-Shigueto et al., 2007; Donoso and Dutton, 2010). Longline fisheries in the region generally use ∼1,000 hooks per set and target mahi-mahi and sharks (in Peru) or swordfish (in Chile), whereas gillnets are generally 1–2 km in length and include driftnets targeting sharks, rays, mahi-mahi, and bonito or bottom-set nets targeting sharks, rays, and lobster (Alfaro-Shigueto et al., 2010; Donoso and Dutton, 2010). Low bycatch rates may reflect the EP leatherback population decline (i.e., reduced abundance overall); however, bycatch rates may be underestimated considering that observer programs usually cover an extremely small proportion of the total fishing effort (Wallace et al., 2010).

In contrast to the growing body of information about leatherback bycatch in feeding areas off South America, information about leatherback bycatch around inter-nesting and nesting areas is extremely sparse (Eckert and Sarti-Martinez, 1997; Ortega del Valle et al., 2009). This is a critical information gap because adult leatherbacks concentrate predictably in areas off nesting beaches for a well-established period each year for purposes of reproduction (Santidrián Tomillo et al., 2007; Sarti-Martinez et al., 2007; Eckert et al., 2012), and coastal areas around the world generally have high densities of fishing activity (Stewart et al., 2010). Thus, nesting and inter-nesting areas are of high importance to leatherback population recovery, particularly considering the population's significantly diminished abundance.

The use of fishers' knowledge, gathered through rapid bycatch assessments (i.e., direct interviews of fishers), to obtain information about fisheries interactions with threatened species (e.g., marine turtles) has been implemented in various locations (Moore et al., 2010; Lucchetti et al., 2017a; Alfaro-Shigueto et al., 2018). Rapid assessments represent a standardized, low-cost, and relatively fast methodology when compared to the implementation of on-board monitoring programs (Lucchetti et al., 2017b). Rapid assessments are also particularly affordable considering the large geographic areas where fishing activities operate and when funds are limited.

Our goal in this study was to address this critical data gap about leatherback bycatch in small-scale fisheries, extending the range of available information from foraging and sporadic nesting areas in South America northward to nesting and inter-nesting areas in Central America and Mexico. To accomplish this, we coordinated with in-country partners of the Laúd OPO conservation network (La Red de Conservación de la Tortuga Laúd en el Océano Pacífico Oriental) to conduct rapid assessments in five countries: Mexico, Nicaragua, Costa Rica, Panama, and Colombia. Assessments were designed to collect information about (1) leatherback bycatch (i.e., number of individuals, spatio-temporal areas, fishing gears); (2) leatherbacks' fate and condition after fisheries interactions, and; (3) general information on the bycatch of other sea turtle species. These types of information are critical for holistic population assessments as well as targeted conservation efforts in areas where interactions between leatherbacks and small-scale fisheries occur.

MATERIALS AND METHODS

Study Area

We conducted rapid assessments in fishing ports in five countries: Mexico, Nicaragua, Costa Rica, Panama, and Colombia. Surveys were completed between October 2016 and March 2017 in Nicaragua and Costa Rica, between May 2017 and March 2018 in Mexico, between November 2016 and October 2017 in Colombia and between January 2017 and September 2018 in Panama. Ports were assessed near or adjacent to key nesting beaches in Mexico, Nicaragua, and Costa Rica, as well as in areas without regular nesting (e.g., Gulf of California, northern Mexico; Panama; Colombia). Nesting beaches vary widely in terms of length (∼10–20 km in Mexico; 2–3 km in Costa Rica) and size of nearby human communities (**Figure 1**).

Survey Design and Data Collection

Ports were selected by each in-country survey team based on a combination of variables including port size, presence of small-scale vessels, vicinity to nesting areas and the potential for interactions of fishing vessels with sea turtles. Interviews relied on a structured questionnaire based on the protocol described within Alfaro-Shigueto et al. (2018) that consisted of 44 questions (open and closed) focused on collecting information on fishing effort and sea turtle bycatch. Interviews were conducted with randomly selected vessel captains who were willing to participate. Interviews (**Supplementary Document 1**) were comprised of four sections: (1) "background information" with questions related to fishers and fishing areas; (2) "vessel characteristics," related to aspects of the fishing vessels (e.g., size, motor); and (3) "fisheries and bycatch," with questions about fishing activity characteristics (e.g., gear, target species), bycatch species most frequently caught (frequency, fate), and fisher behavior related to handling such species. The final section (4) included an assessment of the honesty/reliability of the interviewee responses that was completed by the interviewer. Responses from fishers considered by the interviewer to be unreliable were eliminated from the analysis.

A separate bycatch sub-section (under section 3) was designed to collect information specifically about leatherback bycatch. Questions in this section included: (1) bycatch seasonality (i.e., months of bycatch occurrence); (2) fishing gear used when capture occurred; (3) turtle condition and fate; and (4) number of leatherbacks caught in the year previous to when the interview was conducted. Data on turtle condition when captured were divided into four categories: good condition, injured (an impaired specimen but active), poor condition (a significantly impaired specimen in an apparent lethargic state), and dead. Fate of turtles caught was divided into five categories: released alive, discarded dead, consumption, marketable for sale, and for use as bait.

Illustrated identification guides assisted fishers in sea turtle species identification. If the interviewee reported the use of more than one fishing gear, the "fisheries and bycatch" section was completed for each fishing gear reported; a maximum of two gears were recorded per interview. For all questions, a "no response" (i.e., the fisher did not answer the question) was counted as an option and included in the analysis as "unknown."

In June 2016, prior to implementing the rapid assessments, a multi-day training session hosted by the Comisión Nacional de Áreas Naturales Protegidas in Mexico City was conducted for project partners responsible for conducting interviews in each country. Survey methodology and interview format were revised to comport with country- and site-specific terminology and practices as appropriate.

Prior to each interview, participants verbally consented to participate and were informed that their participation was voluntary and anonymous, that the information would not be shared with anyone, and was for research purposes only. Interview questions were designed and tested to ensure that they were framed correctly, provided useful information and were not overly intrusive. All researchers involved in interviews were fluent in the language and colloquial terminology of the study area.

All research protocols, including interview questions, underwent prior internal institutional review by Pro Delphinus and were revised and approved by all countries' research teams. Pro Delphinus is a Peruvian Non-Governmental Organization based on Lima with experience on research and conservation of threatened and endangered marine species.

Data Analysis

Fisheries Characteristics

In-country teams collected information about ports including total number of vessels and vessel characteristics (e.g., length). Additional information for Colombia was obtained from government documents published by the National Fisheries and Aquaculture Authority (Rueda et al., 2011).

Based on the section "fisheries and bycatch" (Q9 to Q19) and the total number of interviews conducted, we present data as percentage per port and country for gear types and fishing activities seasonality and per country for bycatch of sea turtle species other than leatherbacks. Regarding analysis of sea turtle bycatch (Q13 to Q17), we only consider fishers' primary responses and bycatch events were assigned to the port where the interview was conducted. However, we acknowledge that fishers sometimes operate from multiple ports and report bycatch related to different locations, not necessarily from the port in which they were interviewed.

Leatherback Interactions

Reports of leatherback bycatch were only included in analyses when fishers reported interactions with leatherbacks in response to the leatherback bycatch question (Q20), as some fishers recognized leatherbacks as one of the sea turtle species captured incidentally (Q14) but did not report leatherback bycatch in the leatherback specific section (Q20 to Q25).

Numbers of leatherbacks captured were provided as ranges by some fishers, in which case we used the minimum value of the range provided in analyses. Data are presented as percentages based on the total number of leatherbacks reported captured per port and country. For condition and fate questions (Q24 and Q25) we included only the fishers' primary response.

For analysis purposes, when fishers answered "No" to leatherback bycatch question (Q20) or answered "Yes" but did not report the number of leatherbacks caught (Q22) we assigned zero animals caught. In addition, Colombia data per port were grouped per coastal municipality because of fleet size data availability on governmental documents (Rueda et al., 2011).

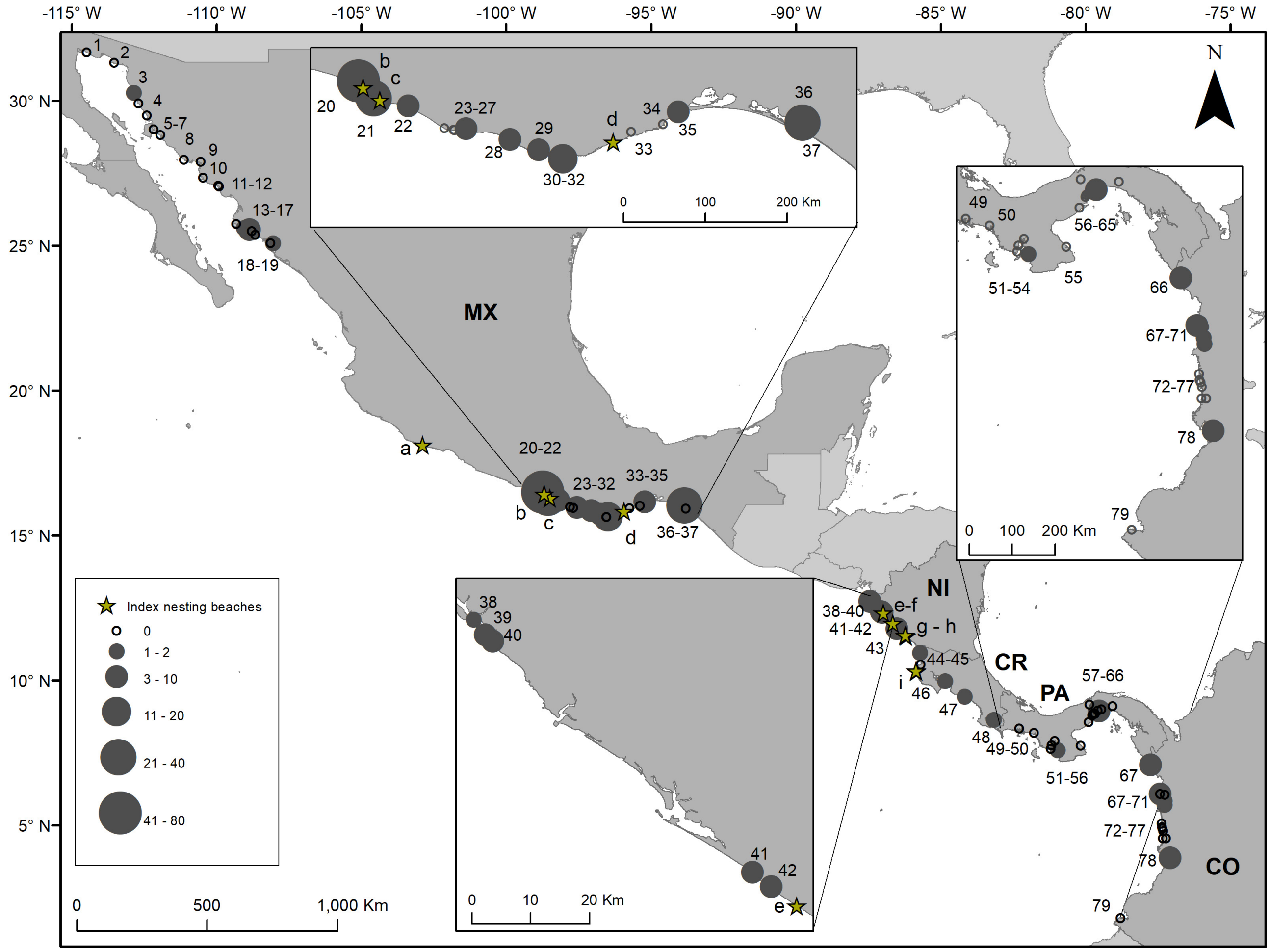

FIGURE 1 | Number of leatherbacks reported caught for each surveyed port in Mexico (MX), Nicaragua (NI), Costa Rica (CR), Panama (PA), and Colombia (CO). Yellow stars and letters represent index nesting beaches along area surveyed and numbers represent ports surveyed. (a) Santuario Playa de Mexiquillo, (b) Santuario Playa de Tierra Colorada, (c) Playa Cahuitán, (d) Playa Barra de la Cruz-Playa Grande, (e) Reserva Nacional Isla Juan Venado, (f) Salamina, (g) RVS Río Escalante-Chacocente, (h) Veracruz de Acayo, and (i) Parque Nacional Marino Las Baulas (Playa Langosta, Ventanas and Playa Grande). (1) Golfo de Santa Clara, (2) Puerto Peñasco, (3) Puerto Lobos, (4) Puerto Libertad, (5) Desemboque, (6) Punta Chueca, (7) Bahía Kino, (8) La Manga, (9) La Guasima, (10) Bahía Lobos, (11) Paredonctio, (12) Paredón Colorado, (13) El Colorado, (14) Topolobampo, (15) El Huitussi, (16) Cerro Cabezón, (17) Boca del río, (18) La Reforma, (19) Costa Azul, (20) Barra Tecoanapa, (21) Punta Maldonado, (22) Corralero, (23) El Azufre, (24) San Juan, (25) Bahía Chacahua, (26) Cerro hermoso, (27) Zapotalito, (28) Puerto escondido, (29) Huatulco, (30) Mazunte, (31) San Agustinillo, (32) Puerto Ángel, (33) Morrto Ayuta, (34) Chipehua, (35) Ventosa, (36) Paredón, (37) Puerto Arista, (38) Estero Padre Ramos, (39) Los Zorros, (40) Jiquilillo, (41) Poneloya, (42) Las Peñitas, (43) Masachapa, (44) Guajiniquil, (45) Playas del Coco, (46) Puntarenas, (47) Quepos, (48) Golfito, (49) Chiriquí, (50) Puerto Remedios, (51) Puerto Playa Bermejos, (52) Puerto Mutis, (53) Puerto Palo Seco, (54) Mensabe, (55) Chame, (56) Playa Leona, (57) Puerto Caimito, (58) Puerto Vacamonte, (59) Muelle Fiscal/Puerto Panama, (60) Juan Diaz, (61) Playa Chiquita/La chorrera, (62) Puerto Coquira, (63) Puerto Cañita, (64) Hicaco, (65) Puerto La Boca/Diablo, (66) JuradóJurado, (67) Bahía Solano, (68) El Valle, (69) Jurubirá, (70) Guineal, (71) Nuqui, (72) Piliza, (73) Pizarro, (74) Usaraga, (75) Siviru, (76) Orpua, (77) Buenaventura, (78) Tumaco, and (79) Pomeño.

Generating Annual Bycatch Estimates

We estimated leatherback bycatch per year per port using the following steps: (i) we tallied the number of leatherbacks reported per fisher by port (or country); (ii) for each port we resampled the observations, and; (iii) we used bootstrap analyses with 1,000 replications to generate the mean and standard deviation (Chernick and Labudde, 2011). Fishing effort was defined on a per year basis for each port. To obtain an estimate of annual bycatch based on ports assessed, we estimated the proportion of fishers reporting leatherback bycatch per port. Then, for each port we extrapolated the proportion to the port fleet size and scaled the mean and standard deviation generated by the bootstrap analysis to the proportion of the fleet in each port where, in accordance with our previous analyses, leatherback bycatch was occurring.

To study the effect of covariates, e.g., latitude and fishing gear, and their interactions on leatherback bycatch events probability we used a Generalized Linear Model (GLM) with linear and interaction effects based on fishers' reports of leatherback bycatch event on the previous year to the interview conduction (Q40). The GLM is a flexible generalization of ordinary linear regression which generalizes linear regression by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value (Nelder and Wedderburn, 1972). Because bycatch data are Presence/Absence data, we chose the binomial distribution with a logit link function. An asymptotic chi-square significance test was used to test the significance of each of the covariates. We combined different models to test the importance of each covariate and used the Akaike Information Criterion (AIC) as a method to choose the best model. All statistical analyses were performed in the statistical program R 3.5.2 (R Core Team, 2018).

RESULTS

Summary of Fisheries Results

A total of 1778 interviews (n) were conducted in 79 fishing ports across all countries (Mexico: n = 709, 37 ports; Nicaragua: n = 110, 6 ports; Costa Rica: n = 114, 5 ports; Panama: n = 284, 17 ports; Colombia: n = 561, 14 ports). Mean interview coverage per country, based on number of vessels per port was 25% for Mexico, 34% for Nicaragua, 39% for Costa Rica, 26% for Panama and 39% for Colombia (**Supplementary Table 1**). Interviews indicate that fishing is the main economic activity for over 90% of participants in all countries and it is practiced year-around by more than 60%. Additional descriptive information is provided in **Supplementary Table 1**.

Across countries, the most frequently reported small-scale fishing gear was gillnets (40%) followed by handlines (28%) and longlines (17%). Costa Rica was an exception to this pattern, with more than 50% of fishers reporting longlines and only 13% gillnets. Among longlines, J-hooks were most frequently reported compared to circle hooks, with the latter hook type reported by 8% of fishers from Mexico, 12% of fishers Costa Rica, and 0.4% of fishers from Panama. More detailed fishing gear information is provided in **Supplementary Table 2**.

Leatherback Bycatch

Bycatch Estimates and Fishing Gears

Leatherback bycatch was reported in all countries, in 54% of ports surveyed, and in 125 interviews (7% of the total) (**Supplementary Table 3**). Combining leatherback bycatch data across countries, we estimated that approximately 345 (±210) animals were captured in the year prior to the assessments (**Table 1**), of which 291 (±187) leatherbacks were captured in Mexico (**Supplementary Table 4**). The estimated mortality rate was approximately 1% (**Table 1**). Our interviews were not designed to collect biological information about turtles captured (e.g., body size, sex.); thus, it is possible that in addition to nesting females, males or immature turtles were also among the individuals reported as captured.

Nicaragua and Mexico were the countries with the highest percentage of fishers reporting leatherback bycatch (15 and 11%, respectively), while in Costa Rica, Panama and Colombia, less than 5% of fishers interviewed reported leatherback bycatch events (**Table 1**). Although most leatherback interactions were reported in gillnets (62%), no gillnet interactions were reported in Costa Rica, where 80% of interactions were reported in longlines. Bycatch in handlines, was frequently reported in Colombia (**Supplementary Table 5**). Additionally, in Nicaragua one handline fisher reported having leatherback interactions, but did not report animals captured for the period assessed by the interview.

TABLE 1 | Summary of Leatherback bycatch per country.

Country	% Fishers reporting bycatch	Number reported (n)	% Mortality	Bycatch per year (mean ± SD)	Estimated bycatch (mean ± SD)
Mexico	11	197	0	0.36 ± 0.24	291 ± 182
Nicaragua	15	17	18	0.22 ± 0.12	52 ± 27
Costa Rica	4	5	0	0.04 ± 0.04	1.2 ± 1.1
Panama	3	4	0	0.004 ± 0.004	0.20 ± 0.20
Colombia	3	17	0	0.01 ± 0.01	1.09 ± 0.56
Total	–	240	1	–	345 ± 210

Percentage of fishers reporting leatherback bycatch events. Total number of leatherbacks reported incidentally captured (n) and percentage of leatherback reported as dead when captured. Mean number of leatherbacks incidentally captured per year and estimated total number of leatherbacks incidentally captured (bycatch) per year.

Spatio-Temporal Patterns

Generalized linear model results showed that the variation in leatherback bycatch reported by fishers in the survey area was best described by the interaction between latitude and fishing gear (Model 3) (**Table 2**). Leatherback interactions increased toward latitude 15°– i.e., around index nesting beaches (**Figure 1**). According to our scaled estimate, ports with highest bycatch were in Mexico: Paredón (118 ± 106), Barra Tecoanapa (72 ± 30), and Punta Maldonado (51 ± 20). The latter two are located close to index nesting beaches, Playa Tierra Colorada and Playa Cahuitán (**Figure 1**).

Although leatherback bycatch was most prevalent at a regional scale between October and May (**Figure 2**), periods of highest bycatch as indicated by fishers varied among countries. For instance, according to Mexican and Nicaraguan fishers,

TABLE 2 | Summary results of binomial Generalized Linear Models (GLMs) to test the (i) effect of latitude on the presence/absence (P/A) of the leatherback bycatch, (ii) effect of fishing-gear on the presence/absence (P/A) of the leatherback bycatch, and (iii) effect of the interaction between latitude and fishing gear on the presence/absence (P/A) of the leatherback bycatch.

Added terms	Df	Deviance	Resid. D.F.	Resid. dev	P	AIC	Pseudo adj. R^2
Null	–	–	123	139.5	–	141.5	–
+Latitude	1	0.9	122	138.5	0.3	142.5	0.07
+Fishing-gear	5	20.4	117	118.1	0.001	132.1	0.15
+Latitude× fishing−gear	5	44.4	112	73.7	1.00E-07	97.7	0.47

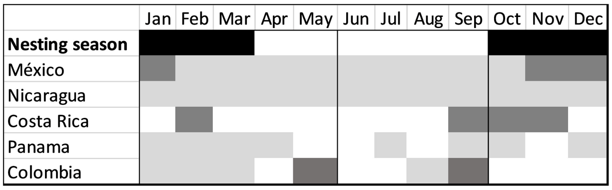

FIGURE 2 | Temporal distribution, within a calendar year, of leatherback bycatch frequency among countries assessed and overlap with the nesting season period. Based on the number of fishers reporting leatherback bycatch. Dark gray = more than 20% of fishers reporting bycatch. Light gray = less than 10% of fishers reporting bycatch. Black = leatherback nesting season.

leatherback events occur year-around while for other countries bycatch was reported to occur only during certain months.

Condition and Fate After Bycatch Events

Among reports of leatherback condition following bycatch interactions, 50% were released in good condition, and only 1% (only in Nicaragua) were reported as discarded dead. One-third (33%) of leatherbacks were reported in poor condition, and 5% were reported as injured. The remaining responses (11%) correspond to fishers that did not reply to the question (unknown condition).

Among reports of leatherback fate, 62% of animals were reported as released alive and only 0.4% were discarded dead. However, some fishers reported the use of leatherbacks for consumption (14%) or sale (0.4%). Nearly a quarter (23%) of respondents did not provide information, which included 13% of fishers in Mexico, 53% of fishers in Nicaragua, and all fishers in Colombia and Panama.

Furthermore, we found that J-hook longlines and gillnets were the most harmful fishing gears. Dead animals were reported only in association with gillnet interactions, while most animals caught in J-hook longlines were reported as injured or in poor condition when captured. Animals caught on circle hook longlines were reported in good condition when captured (**Figure 3**).

Other Sea Turtle Bycatch

Although the main objective of the study was to gather information on leatherback bycatch, we also asked about bycatch of other sea turtle species. Olive ridley turtles (*Lepidochelys olivacea*) were the most frequently reported species in all countries; however, other turtle species were also reported (**Supplementary Table 6**). Similar to results for leatherbacks only, bycatch was most frequently reported (over 50%) by gillnet fishers, except in Costa Rica, where longlines are the most frequent fishing gear, and Panama where events were mostly reported when using "J" hook longlines (**Supplementary Table 6**). Over 60% of fishers among all countries reported releasing sea turtles alive, but there were also reports of use for consumption (20%), bait (0.2%), and sale (0.6%), and 3% of turtles were discarded dead (**Supplementary Table 7**). Consumption and/or sale were reported in all countries except Costa Rica. The use of turtles as bait was only reported by one fisher from Tumaco, Colombia.

DISCUSSION

Incidental captures in fisheries have contributed to the long-term decline of EP leatherbacks, and a lack of information – particularly in areas near nesting beaches – has hindered regional prioritization of bycatch reduction efforts. We coordinated a comprehensive, multi-country rapid bycatch assessment in countries that host critical leatherback reproduction areas to extend baseline information on leatherback bycatch from foraging areas in the southern end of the population's distribution (i.e., South America) to nesting beach countries in the north. We now have a regional-scale baseline of leatherback bycatch in small-scale fisheries that can inform conservation efforts at regional, national, and local scales.

Our results show that leatherback bycatch, while present in all countries and in half the ports evaluated from Mexico to Colombia, is less frequent than bycatch of other sea turtle species. This finding, similar to that documented by rapid bycatch assessments conducted in Ecuador, Peru, and Chile (leatherback foraging areas), is likely due to the lower abundance of EP leatherbacks compared to other sea turtle species in the same region (Alfaro-Shigueto et al., 2011, 2018; Seminoff et al., 2012; Wallace et al., 2013b). Nonetheless, based on the ports we surveyed, we estimated that a minimum of 345 (±210) leatherbacks are caught annually by small-scale fisheries from Mexico to Colombia. This newly identified source of bycatch mortality will be in addition to those animals already at risk at the South American foraging grounds (Alfaro-Shigueto et al., 2018). If there are differences in bycatch rates between nesting and foraging areas they are likely going to be driven by differences in the numbers of animals present; abundance may be higher in forging areas because foraging cohorts include not only nesting females, but non-breeding adults (females as well as males), and immature animals, as documented in leatherback foraging areas elsewhere (James et al., 2007).

However, our bycatch estimates in this study are biased low for two main reasons. First, while our assessment achieved over 50% of vessel coverage in some ports, it did not include the complete fleet size of each port assessed. Second, some areas of central Mexico and countries such as Guatemala, El Salvador, and Honduras were not included in this study. Nevertheless, our results provide an important baseline for the distribution and relative magnitude of leatherback bycatch events near nesting areas.

Leatherback bycatch reports were most frequently associated with gillnets and increased toward 15°, near Mexican nesting beaches (**Table 2**). Leatherback interactions were most frequently reported occurring within gillnets, which was the most common fishing gear used in all countries except Costa Rica. This scenario of high bycatch in gillnets comports with patterns previously reported for leatherbacks and other sea turtle species in South American foraging areas (Wallace et al., 2013b; Alfaro-Shigueto et al., 2018). Regarding the spatial component of leatherback bycatch, Mexican small-scale fisheries from the ports assessed accounted for 80% of estimated annual captures among the countries surveyed. Mexico is one of the major contributors to coastal fisheries in the Latin American and Caribbean Region; its

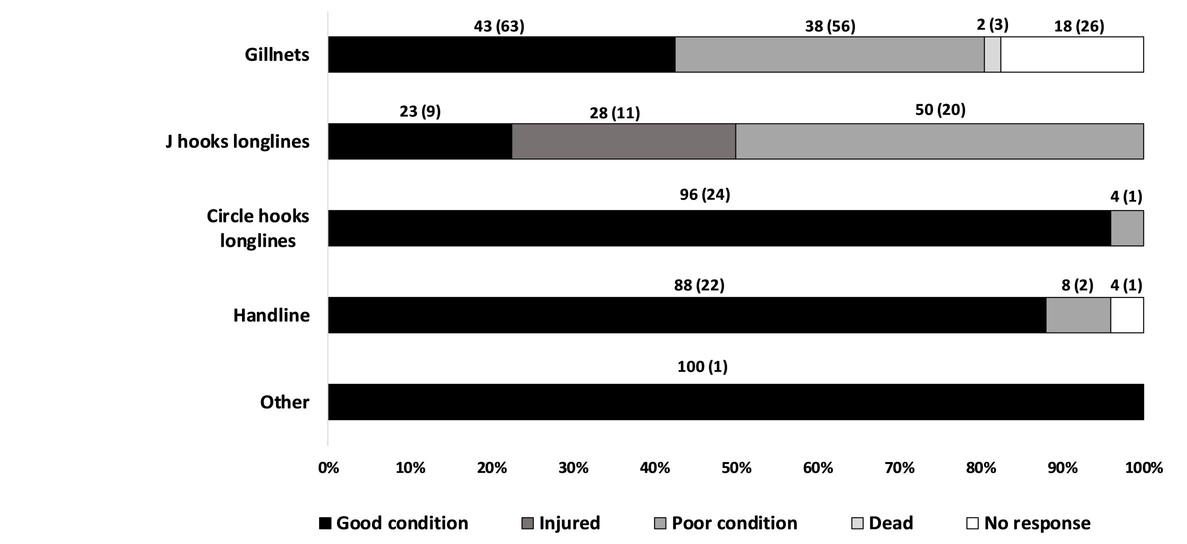

FIGURE 3 | Leatherback condition (% [*n*]) upon capture per fishing gear type as reported by interviewed fishers express in percentages (%) and based in the total number of animals reported (*n*).

small-scale fleet of 56,412 vessels along its Pacific coast, is larger than the combined fleet size for the other countries included in this study, based on statistics reported by FAO and national governmental authorities (Salas et al., 2011).

Regarding temporal patterns of leatherback bycatch, our results showed that leatherback bycatch occurs most frequently between September and January in Mexico, Nicaragua, and Costa Rica, corresponding to the arrival of adult female and male leatherbacks to breeding areas in September and their residence in these areas for the first half of the nesting season, during which time peak density of leatherbacks would be expected (Reina et al., 2002; Sarti-Martinez et al., 2007). In contrast, most fishers in southern ports (e.g., Colombia and Panama) reported that leatherback bycatch occurred in other times of year. For example, fishers from Colombian ports reported that bycatch events occurred mostly during May, likely coinciding with the timing of leatherback migration from nesting beaches in Mexico to distant South American foraging habitats (Shillinger et al., 2008). Colombia and Panama host only sporadic leatherback nesting (Seminoff et al., 2012), but likely provide important migratory and foraging habitats linking reproduction areas to the north and primary feeding areas to the south.

Additionally, interviews allowed for the identification of areas where leatherback bycatch is most likely to occur. Leatherback bycatch was more frequently reported in ports (i.e., Barra Tecoanapa and Punta Maldonado) close to EP leatherback nesting beaches with highest annual abundance (i.e., Tierra Colorada, Cahuitán, and Barra de la Cruz in southern Mexico). Regarding Paredón port, the port with the highest leatherback bycatch estimate (∼118 individuals/year), only 5% vessel coverage was achieved; additional effort is recommended to develop a more robust bycatch estimate. While noting specific ports with particularly high leatherback bycatch, our results showed that bycatch occurs in all countries and in 54% of ports assessed. It is possible that this percentage would change if we consider that bycatch events were assigned to the ports where the interviews were conducted, which underestimated the operational range of fishers' activities. The further inclusion of additional ports in central Mexico and other countries would further clarify spatio-temporal patterns of leatherback bycatch.

Information on turtle condition when captured and final fate, either dead or alive, is critical to informing best practices for reducing bycatch impacts on turtles. Our results indicate that only 1% of leatherbacks died upon capture, while the majority were reported alive after interactions (88%), most of which were released in good condition. If appropriate handling and release techniques were also used, long-term survival probabilities could likely be increased.

Leatherbacks were only reported dead from gillnet interactions, corroborating previous information suggesting that net fisheries are a major source of sea turtle mortality when compared to longlines (Gilman et al., 2010; Lewison et al., 2013). No dead leatherbacks were reported in longline interactions, but most animals caught with circle hooks were in good condition while those caught in J-hooks were classified either as in poor condition or injured. Previous studies have reported circle-shaped hooks potentially causing less injuries to sea turtles as chances of swallowing the hook are lower and in case of occurrence, the hook slips out of the esophagus (Stokes et al., 2011; Parga et al., 2015). However, to maximize chances for turtle survival, appropriate skills are required to reduce handling time and avoid further injuries during hook removal (Piovano et al., 2009; Parga, 2012). In this regard, our study provides an opportunity for revisiting the effects of circle hooks on the leatherback injury type and severity. Moreover, improving the survival of large animals (adults) may disproportionately benefit the population because these animals are associated with higher relative contribution to overall population dynamics

(Crouse et al., 1987). Incorporating size class information in future bycatch assessments would elucidate potential differential bycatch impacts on different life-stages.

Our results highlighted that, while most leatherbacks were released alive or discarded dead, the remainder were used for human consumption, sale, or bait. Retention of sea turtles for subsistence or commercial purposes has been reported in Peru (Alfaro-Shigueto et al., 2007), and in some Caribbean areas of Colombia and Panama (Ankersen et al., 2015; Barrios-Garrido et al., 2017), and commercial exchange of turtle products (i.e., leatherback oil) has been reported between Venezuelan communities and its counterparts from Colombia and Panama (Barrios-Garrido et al., 2017). The use of sea turtles as a food source has been previously reported to occur on the Pacific coast of Mexico, specifically in Sonora and Guerrero states (Delgado and Nichols, 2005; Mancini and Koch, 2009), despite a national prohibition on consumption and trade of sea turtle products (1990). These reports coincide with our results as Mexican fishers from Boca del Rio in Sinaloa and Barra Tecoanapa in Guerrero reported the use of leatherbacks for consumption. In contrast, in Nicaragua (>50% of leatherbacks have unknown fate), where sea turtles are protected by law (Ley de Pesca y Acuicultura N° 489) allowing only subsistence use by communities along the Atlantic coast, consumption of or trade in leatherback products have not been documented along the Pacific coast.

Our results indicate that most leatherbacks caught throughout the region were released alive, but we acknowledge that fishers' responses might be biased by the potential negative repercussions of accurate reporting of bycatch (Lucchetti et al., 2017a), especially the subsequent usage of leatherback byproducts. Many fishers interviewed (20% regionally, 100% in Panama and Colombia) were not willing to respond about the fate of leatherbacks when captured. This unwillingness to report leatherback fate might reflect fishers' fears of negative consequences, which could lead to underestimating the magnitude of the usage of leatherback byproducts in the assessed areas. Conservation initiatives in these countries should include socio-cultural factors to better understand communities' behavior and customs toward not only leatherbacks but all sea turtles. Addressing this topic will be of importance for the successful implementation of bycatch solutions and strategies or those targeting the reduction of mortality (Komoroske and Lewison, 2015). Considering that olive ridley turtles were most frequently reported caught, other sea turtle species could also be included in future initiatives. Olive ridleys are the most abundant sea turtle species in the EP region, with enormous nesting populations (>10,000 females) in Mexico and Costa Rica, which, in addition to its opportunistic diet, likely increases bycatch risk for this species (Seminoff et al., 2012; Dapp et al., 2013; Peavey et al., 2017).

FUTURE STEPS AND CONCLUSION

The use of rapid assessments in our study has provided a regional-scale baseline and first estimate of leatherback bycatch in small-scale fisheries in nesting and inter-nesting areas of the Eastern Pacific Ocean. Our results highlighted fishing ports around Mexican index nesting beaches as particularly important areas where efforts are needed to reduce fisheries interactions. However, regional strategies should also be reinforced as leatherback bycatch was reported across all countries assessed. Furthermore, over 80% of leatherbacks captured are reported as released alive after fisheries interaction, which underscores the importance of conservation initiatives focused not only on reducing bycatch but also on good practices for safe handling and release of bycaught animals to enhance post-release survival. Finally, this study provides national-scale information through the identification of priority ports for conservation efforts and highlights opportunities to work more collaboratively with fishers toward leatherback conservation.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

BW, JA-S, JM, and VG conceived the research. CO-A prepared the original draft of the manuscript with important intellectual contributions from MPa, JM, BW, JA-S, PS-T, LS, and GS. CO-A prepared the data and conducted formal analysis with MPa and DG. MA, AR, MB, AC, LF, VG, JR-B, PS-T, LS, HS-H, GS, MPr, AW, and AZ-N were responsible for data acquisition and key partners for project implementation along with the countries included in the study.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2019.00813/full#supplementary-material

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Conflict of Interest: BW was employed by the company Ecolibrium.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.