



Vessel Strikes of Large Whales in the Eastern Tropical Pacific: A Case Study of Regional Underreporting

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Vessel strike is recognized as a major modern threat to the recovery of large whale populations globally, but the issue is notoriously difficult to assess. Vessel strikes by large ships frequently go unnoticed, and those involving smaller vessels are rarely reported. Interpreting global patterns of vessel strikes is further hindered by underlying reporting biases caused by differences in countries' research efforts, legislation, reporting structures and enforcement. This leaves global strike data "patchy" and typically scarce outside of developed countries, where resources are more limited. To explore this we investigated vessel strikes with large whales in the Eastern Tropical Pacific (ETP), a coastal region of ten developing countries where heavy shipping and high cetacean densities overlap. Although this is characteristic of vessel strike "hotspots" worldwide, only 11 ETP strike reports from just four countries (~2% of total reports) existed in the International Whaling Commission's Global Ship Strike Database (2010). This contrasts greatly with abundant reports from the neighboring state of California (United States), and the greater United States/Canadian west coast, making it a compelling case study for investigating underreporting. By reviewing online media databases and articles, peer review publications and requesting information from government agencies, scientists, and tourism companies, we compiled a regional ETP vessel strike database. We found over three times as many strike reports ($n = 40$), from twice as many countries ($n = 8$), identifying the geographic extent and severity of the threat, although likely still underestimating the true number of strikes. Reports were found from 1905 until 2017, showing that strikes are a regional, historic, and present threat to large whales. The humpback whale (*Megaptera novaeangliae*) was the most commonly hit species, and whale-watch industries involving small vessels in areas of high whale densities were recognized as a conservation and management concern. Industrial fishing fleets and shipping were suggested to be underrepresented sectors in the database, and are likely high-risk vessels for strikes with whales. We demonstrate the implications of known vessel strike reporting biases and conclude a more rapid assessment of global vessel strikes would substantially benefit from prioritized research efforts in developing regions, with known vessel strike "hotspot" characteristics, but few strike reports.

Keywords: anthropogenic threat, ship strikes, vessel collisions, reporting bias, recovering populations, threatened species, large whale conservation, underreporting

INTRODUCTION

Intensive commercial harvesting of large whales in the nineteenth and twentieth century reduced most populations to a fraction of their original size, and left many species on the brink of extinction (Clapham et al., 1999). After early international protection of only the most heavily harvested and endangered populations, the International Whaling Commission (IWC) voted for a full moratorium on commercial whaling in 1982, that came into effect in 1986 (Clapham and Baker, 2008). In the decades that have followed, large whale populations have undergone varying levels of recovery. Some populations are considered to have reached near to their carrying capacities (e.g., the eastern North Pacific gray whale, *Eschrichtius robustus*, Punt and Wade, 2012; and both populations of Australian humpback whale, *Megaptera novaeangliae*, Bejder et al., 2016), whilst others remain at critically low levels (e.g., the North Atlantic right whale, *Eubalaena glacialis*, Pettis et al., 2018). Concurrently, there has been continual growth of global maritime traffic, which has ultimately increased the risk of vessel/whale collisions (Guzman et al., 2013; Thomas et al., 2016). Today, vessel strike and entanglement are considered to be the two major modern threats to large whales at the population level (Thomas et al., 2016). While vessel strike can threaten the recovery of large whale populations (e.g., the North Pacific blue whale, *Balaenoptera musculus*, Carretta et al., 2015; Rockwood et al., 2017), it is small and endangered whale populations (or population segments) that are most vulnerable to anthropogenic threats (Clapham et al., 1999; Cates et al., 2017). For example, for the critically endangered North Atlantic right whale, 45% ($n = 39$) of diagnosed mortalities between 1970 and 2010 were attributed to vessel strike, and it was recognized as the major threat to the survival of the species (Van der Hoop et al., 2013). An additional concern is the welfare of the whales that (initially) survive a strike, with numerous reports globally of large whales exhibiting severe injuries believed to have been caused by vessels (Kraus, 1990; Osmond and Kaufman, 1998; Laist et al., 2001; Van Waerebeek et al., 2007; Neilson et al., 2012), which likely caused suffering for extended periods.

Vessel strikes can also be a serious threat to human welfare and safety, when boats sink after strikes (Neilson et al., 2012; Ritter, 2012; Peel et al., 2018), or due to human injuries (Dolman et al., 2006; Ritter, 2010) and mortalities (De Stephanis and Urquiola, 2006) caused by an impact with a whale. Furthermore, vessel strikes can also have significant economic impacts to multiple maritime industries, such as vessel loss (Laist et al., 2001; Ritter, 2012), re-routing of major shipping lanes and speed limits (National Oceanic and Atmospheric Administration (NOAA), 2012; Gonyo et al., 2019), and cancellations of ferries due to vessel strike risk (e.g., Hawaii Superferry, McGillivray et al., 2009). The magnitude of the threat of vessel strikes to whale populations and human interests is recognized by it being one of the main management and mitigation “Strategic Plans” of the Conservation Committee of the IWC (Cates et al., 2017) and perhaps most significantly, an important agenda item within the International Maritime Organization (IMO) (International Maritime Organization (IMO), 2009; Silber et al., 2012). Furthermore, it is a conservation priority for many government

agencies and departments globally, e.g., the United States government’s National Oceanic and Atmospheric Administration (NOAA), and the Australian government’s Department of the Environment and Energy (Silber et al., 2012; Commonwealth of Australia (COA), 2017), as well as for many of the largest international wildlife charities, e.g., the International Fund for Animal Welfare (International Fund for Animal Welfare (IFAW), 2019) and the World Wildlife Fund (World Wide Fund for Nature (WWF), 2019).

It is only in the last few decades that vessel strike has been recognized as a serious issue. Vessel strikes with large whales were once seen as a rarity, and strike events were reported in the late nineteenth and early twentieth century newspapers more as a curiosity (Laist et al., 2001; Peel et al., 2018), than as having any kind of impact on whale stocks or human interests (Figure 1). The true recognition of vessel strikes as a significant threat to large whales began in the 1970s, with the introduction of marine mammal stranding programs, predominantly in North America and Europe. These programs provided a basis, for the first time, for the documentation of the minimum frequency and impacts of vessel strikes on large whale populations (e.g., Kraus, 1990; Wiley et al., 1995). However, it was not until the global review of Laist et al. (2001), that the true extent of the threat to large whales was revealed. This review included evidence for vessel strikes with 11 different whale species and documented strikes events from all around the globe. Building on Laist et al. (2001)’s work and using other published accounts and additional sources, Jensen and Silber (2003) then produced the first “Large Whale Ship Strike Database” and found evidence for 292 possible ship strike events in 13 different countries and Antarctica, up until 2002. This motivated more research investigating vessel strikes with large whale populations world-wide (Félix and Van Waerebeek, 2005; Dolman et al., 2006; Panigada et al., 2006; Van Waerebeek et al., 2007; Douglas et al., 2008) and led to the formation of the IWC Ship Strikes Working Group in 2005.

The aim of the work of the IWC Ship Strikes Working Group is to prioritize the issue of vessel strikes in the agenda of the IWC, and to develop a global strike database to aid in a greater understanding of the threat and more effective management and mitigation (Cates et al., 2017). The 2010 “IWC Global Ship Strike Database” is the most recent, publicly available, centralized global database of vessel strike events with cetaceans. It contains over 500 confirmed vessel strike reports from 27 different countries, increasing previously known published events in Jensen and Silber’s (2003) database by 40%, and finding reports from more than twice as many countries. The most up to date version of the database is not publicly available. However, new reports are continuously being added and the database continues to grow (Winkler et al., 2020). Reports are collected via an online questionnaire or by Annual National Progress Reports of member IWC countries submitted to the Scientific Committee. They are then accessed and classified by a Data Review Group against set criteria (Ritter and Panigada, 2018). However, even with such efforts and such a large increase in the number of reports, it is unlikely that the global reporting patterns seen in the database are truly reflective of world-wide vessel strike distribution and frequency. As concluded by

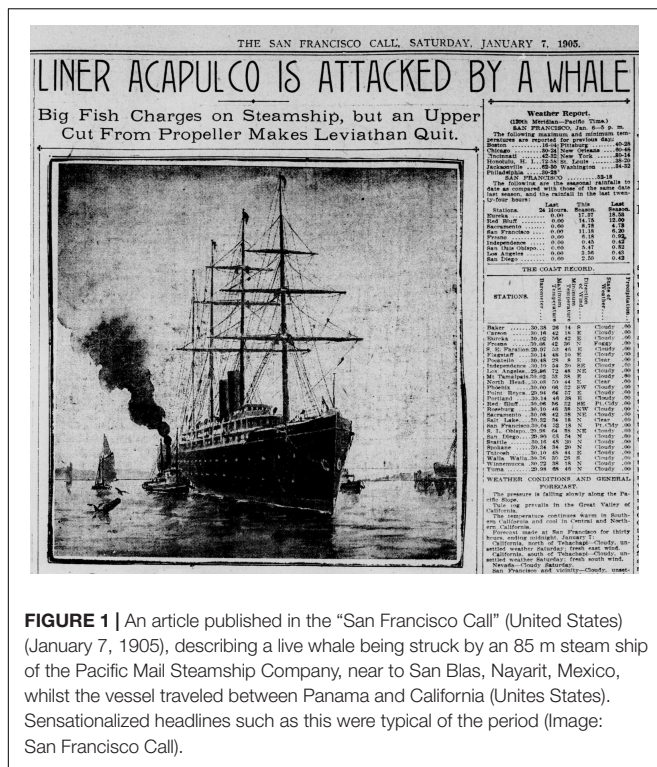


FIGURE 1 | An article published in the “San Francisco Call” (United States) (January 7, 1905), describing a live whale being struck by an 85 m steamship of the Pacific Mail Steamship Company, near to San Blas, Nayarit, Mexico, whilst the vessel traveled between Panama and California (United States). Sensationalized headlines such as this were typical of the period (Image: San Francisco Call).

Laist et al. (2001), after their first attempts in compiling global strike events, “varying amounts of speculation are required to evaluate” the validity of patterns found when interpreting strike data. Known reporting biases include strikes involving large ships and whales regularly going undetected, low recovery rates of carcasses, insufficient reporting protocols and regulations, fear of reprisal for reporting strikes, unreliable species identification, and a lack of thorough necropsies in most countries (Laist et al., 2001; Jensen and Silber, 2003; Van Waerebeek et al., 2007; Williams et al., 2011; Peel et al., 2018).

In the last few decades, there has been increased efforts in monitoring anthropogenic impacts on marine wildlife in some countries and regions, which has increased vessel strike reporting and aided in a growing understanding of the threat. For example, in the United States, the 1972 Marine Mammal Protection Act (and amendments of 1992 and 1994) mandates periodic marine mammal stock assessment reports, evaluation of the status of marine mammal species and impacts of incidental takes, as well as co-ordination of a national marine mammal stranding network (National Oceanic and Atmospheric Administration (NOAA), 2021), all of which facilitates a more comprehensive understanding of the vessel strike threat to large whales. However, in many developing countries, resources are stretched and government funds for cetacean research are limited, which can potentially exacerbate reporting biases. Therefore, even today vessel strike data remains “patchy,” with over half (52.8%) of all strike reports in the IWC database coming from just six countries; the United States, Canada, France, Spain, Australia, and New Zealand, and 48 countries accounting for less than 1%

each (Winkler et al., 2020). One region where there is a lower-than-expected frequency of vessel strike reports is the Eastern Tropical Pacific (ETP), which includes the jurisdictional waters of 10 developing countries (Figure 2). “Hotspots” for vessel strikes around the world are characterized by an overlap of heavily used shipping lanes and high densities of cetaceans (Carrillo and Ritter, 2010), both of which are found throughout much of the ETP. For example, the shipping lanes connecting North America (and Asia) with the Panama Canal, which run through the center of the ETP, are some of the most heavily used in the global cargo ship network (Kaluza et al., 2010). Additionally, some of the most commonly encountered large whales in the ETP are classified as “Data Deficient” e.g., the Bryde’s whale, *Balaenoptera edeni* (International Union for the Conservation of Nature (IUCN), 2020), “Threatened” e.g., the Mexican humpback whale (National Oceanic and Atmospheric Administration (NOAA), 2016) or “Endangered” e.g., the North Pacific blue whale (International Union for the Conservation of Nature (IUCN), 2020) and the Central American humpback whale (National Oceanic and Atmospheric Administration (NOAA), 2016). This means for conservation reasons the issue of vessel strikes warrants further investigation.

Highlighting international concern for the region, in the last five years the IMO have introduced mitigation measures [including Traffic Separation Schemes (TSS), seasonal speed limits and restricted areas] in Panama and Costa Rica to reduce vessel strike risk to breeding humpback whales (Guzman et al., 2020), whilst similar measures have also recently been proposed in Peru (Jeri et al., 2020). However, despite sporadic reports showing that vessel collisions are occurring in parts of the ETP range, the number of documented events in all 10 of the countries that make up the ETP is very low. In the IWC Global Ship Strike Database (2010), only eleven reports from four countries come from the ETP region (Figure 2), representing approximately 2% of the global vessel strike records (International Whaling Commission (IWC), 2010). This low number of reports strongly contrasts with the number of reported events from neighboring California, United States ($n = 28$), and the greater west coast of the United States and Canada ($n = 60$) (International Whaling Commission (IWC), 2010). We know of no previous dedicated effort to collate records specifically for the ETP, and the disparity between reporting frequency of the ETP and neighbouring California (United States), make it a compelling case study to examine underreporting in a developing region. In this study we aim to create a regional vessel strike database and evaluate known causes of underreporting to aid in a better understanding of the threat of vessel strikes to large whales in the ETP.

MATERIALS AND METHODS

We compiled the first database of vessel strikes exclusively for the ETP region, using a variety of data sources. In this study, the ETP was classified as starting at the coastal region of the land border of the United States and Mexico (32° 32' N) south to mid-Peru (12° 6' S) and offshore to 140° W. This includes jurisdictional



FIGURE 2 | The number of historical vessel strike records in the IWC's Global Ship Strike Database (International Whaling Commission (IWC), 2010) in California (United States) and from the 10 ETP countries. The number above the name represents the number of vessel strike records from that location (countries (red) with no number had no historical vessel strike records).

waters of 10 developing countries with Pacific coastlines: Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Ecuador and Peru (**Figure 2**). Our classification of developing or developed countries and regions follows those defined by the United Nations as having a low or high Human Development Index (HDI), an index based on life expectancy, education, and gross domestic product (United Nations Development Programme (UNDP), 2020). We used the definition of a “vessel strike” from the IWC’s Ship Strike Strategic Plan (Cates et al., 2017), as “a forceful impact between any part of a watercraft, most commonly the bow or propeller, and a live cetacean.” We choose to use the term “vessel strike” throughout, which is interchangeable with the terms “ship strike” and “vessel collisions” that are often used to describe the threat in other studies and regions.

The following sources/methods were used to compile a comprehensive database of vessel strikes within the 10 countries of the ETP, up to September 2017:

1. The 2010 “IWC Global Ship Strike Database.”
2. Information was elicited from the specialist marine mammal email list MARMAM, and online social media site Facebook’s group page “Cetal Fauna.” A written request was made to the scientific community asking for information on vessel strikes in any of the ETP countries.
3. Information requests via email were made to government officials, local research groups/researchers, non-governmental organizations (NGOs) and whale-watch companies in each of the ETP countries.
4. Published literature was searched for mention of vessel strikes, including investigation of IWC resources and Annual National Progress Reports submitted by member countries. For peer review publications, the scientific search engines “Google Scholar” and Web of Science” were used.
5. Online databases of historic newspaper articles were searched (British Newspaper Archive, California Digital Newspaper Collection, NYS Historic Newspapers, Fulton Historic Newspapers, Hemeroteca Nacional Digital de Mexico) for articles relating to vessel strikes.

6. The internet search engine “Google” was used to find online media articles relating to vessel strikes.

When searching online media databases and articles, we used key words and phrases in both English and Spanish to find records of strike events, such as “whale hit,” “whale strike” “whale collision” and “dead whale.” We also searched combinations of words such as dead/whale/bow, stranded/whale/injuries and ship/whale/accident.

To be included in this review, reports also had to meet the following protocols:

- 1) The whale was alive (or thought to be alive) when hit by the vessel.
- 2) The vessel strike was with one of the 15 recognized large whale species (Society for Marine Mammology Committee on Taxonomy (SMM), 2018), or an animal described as an “unidentified large whale,” “unidentified large baleen whale” or “unidentified large cetacean.”
- 3) A dead whale had injuries described as, or concluded to be caused by a vessel strike, which occurred antemortem and caused the death of the whale.
- 4) A free-ranging whale’s injuries were identified as being caused by a vessel (e.g., diagnostic parallel lines caused by a propeller) and described as/or photographed and assessed to be “fresh” open wounds. A fresh wound was defined as a wound where fresh blood was visible, and no or little healing had taken place. The incident was recorded to have taken place in the country where the sighting occurred. Although many free-ranging large whales with healed large diagnostic vessel strike injuries are known from the ETP, they were not included in this analysis, as there was no evidence that the collision event occurred in the range of the ETP.
- 5) Reports from whaling activities or involving “whale hunting” or “whale chasing” were not included in this review.

When including anecdotal accounts of vessel strikes, or the discovery of whale carcasses killed by a strike, where possible the following information was recorded from each event: date; time; location; vessel type; vessel speed; species of whale; age class of whale; details of impact; outcome and injury for whale; outcome and damage to vessel. We included only first-hand accounts of confirmed vessel strikes made by people onboard the vessel involved or from observers on nearby vessels, or reports made by people who were investigating the event. We did not include cases of “probable vessel strike,” “probable post-mortem collision” or “near-miss events.”

Records of strikes from dead whales were only made when injuries suggested that the strike occurred antemortem. In the case of whales brought into port on the front of a large ship, we have listed the location of the event as where the whale was discovered. We used the same protocol for whales found stranded in coastal areas or floating at sea. We recognize that whale carcasses may float large distances and potentially be carried for considerable amounts of time by fast moving vessels, but in the absence of a confirmed strike location, this was deemed the

most appropriate alternative. The one exception to this is a whale strike from the IWC database (2010), where the location country (Mexico) was inferred from the ship’s log and recorded changes in the ship’s speed (Event 5 in **Supplementary Table 1**).

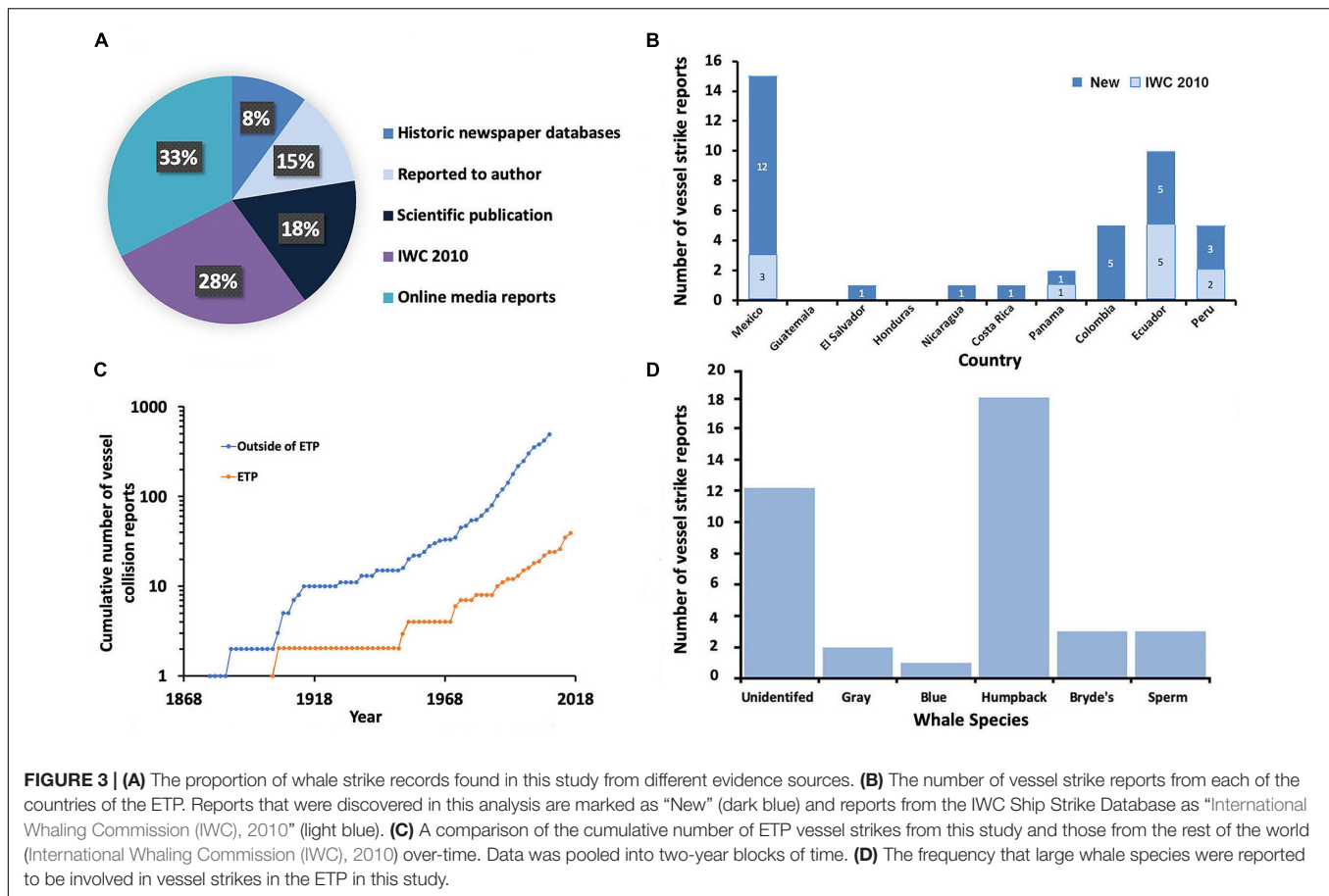
The outcome of the vessel strike for a whale was recorded as either “Killed” (when the whale was known to have died, or seen sinking after strike), “Serious Injuries” (when large amounts of blood or injuries were seen post-accident, but the whale involved was seen swimming away), “Survived/Minor Injuries” (when injuries observed were judged as superficial and similar to known healed injuries in free-ranging animals) or “Unknown” (when no evidence of the whale was seen after the event). If taken from the IWC global database, we took their conclusion and associated category for the outcome of the event.

RESULTS

Data Sources and Spatial and Temporal Distribution of Vessel Strike in the ETP

Approximately one-third (32.5%, $n = 13$) of the vessel strike reports were found in online modern media reports, 27.5% ($n = 11$) from the IWC’s database, 17.5% ($n = 7$) from scientific sources (peer review publications and government reports), 15.0% ($n = 6$) reported directly to the author and 7.5% ($n = 3$) were found in online historic newspaper databases (**Figure 3A**). Just over half of “new” reports (56.5%, 13/23) were discovered by searching these data sources in English, whereas just under half (43.5% 10/23) were discovered when searching in Spanish. The IWC Global Ship Strike Database (2010) accounts for over one quarter of reports, containing 11 vessel strike reports from four ETP countries (Mexico, Panama, Ecuador, and Peru). However, we found an additional 29 unique vessel strikes with large whales during our new regional search effort, from a further four countries (El Salvador, Nicaragua, Costa Rica, and Colombia). This results in a total of 40 vessel strike reports from eight countries of the ETP (**Figure 3B**). No records of vessel strikes were found from the Pacific coastlines of Guatemala or Honduras. We found evidence for 13 new vessel strike reports with large whales prior to 2010 that were not reported in the International Whaling Commission (IWC) (2010) database (32.5%), and evidence of 16 vessel strikes (40%) that have occurred since. We note that due to the IWC database providing publicly available reports only up until 2010, it is not known if the 16 new strikes after 2010 have been reported to the IWC.

The earliest ETP record of a vessel strike with a large whale was found in Mexico in 1905 (Event 1 in **Supplementary Table 1** and **Figures 1, 3C**). After this, only sporadic reports of strike events were found until the 1990s, when reports became more frequent. In the last 10 years, annual reports of vessel strike in the ETP have risen notably, with nine reports in 2015 alone (**Figure 3C**). The general trend of reporting of vessel strikes in the ETP closely resembles that of global reporting; sporadic reports were made around the turn of the twentieth century, until around the mid-twentieth century when report numbers started to increase and have continued to steadily rise till the end of the study period (**Figure 3C**). More than



half (57.5%, $n = 23$) of reported events came from eyewitness accounts of collisions with whales, followed by 22.5% ($n = 9$) from primary evidence of collisions based on: injuries on the bodies of stranded dead whales, 7.5% ($n = 3$) from whales found floating dead at sea (Figure 4A), 7.5% ($n = 3$) from injuries on live whales (Figure 4B), and 5.0% ($n = 2$) from an unknown source.

Species Involved in Vessel Strikes

In almost one third of vessel strike reports (30.0%, $n = 12$) the species of whale was not identified. When species identification was made the humpback whale was reported as the most commonly hit whale species in the ETP (45.0%, $n = 18$; Figure 3D). The Bryde's whale (*B. edeni*) and sperm whale (*Physeter macrocephalus*) were each reported in three vessel strike reports (7.5%), the gray whale in two (5.0%), and the blue whale and the Omura's whale (*Balaenoptera omurai*) were each reported in one collision event (2.5%). It should be noted that the inclusion of an Omura's whale in the IWC Ship Strike Database (International Whaling Commission (IWC), 2010) from an incident in 2005 in Guayaquil, Ecuador, involving a ship which entered port with a whale slung over the bow bulb (Event 31 in Supplementary Table 1), is likely an error in the database. Félix and Van Waerebeek (2005) originally reported it as a Bryde's whale and, to date, the Omura's whale has not been reported in

the ETP region (Society for Marine Mammology Committee on Taxonomy (SMM), 2018).

Vessel Types Involved and Severity of Vessel Strikes

The type of vessel involved in vessel strikes in the ETP was not known in half of the cases (50%, $n = 20$). In eleven reports (27.5%) small vessels of less than 15 m in length were involved in the strike, one report (2.5%) involved a medium sized vessel (15–80 m), seven reports (17.5%) involved large ships (>80 m), and three reports (7.5%) involved sailing vessels. Two whale fatalities were reported to have occurred following strikes of small vessels in Mexico (Events 6 and 11 in Supplementary Table 1; Urbán et al., 2003), in small open hulled fiberglass boats known regionally as a “panga”, which are typically 8 m in length. One strike involved the death of a one month-old humpback whale calf (Figure 4A) and one involved the death of a gray whale of unknown age-class and a vessel that was described as traveling “fast” (Urbán et al., 2003).

In approximately one-half (47.5%, $n = 19$) of vessel strikes from the ETP, the whale was reported to have died. There were 16 reports where the fate of the whale was unknown (40.0%), three whales were believed to have survived a vessel strike (7.5%) and severe external injuries (which likely to lead to the

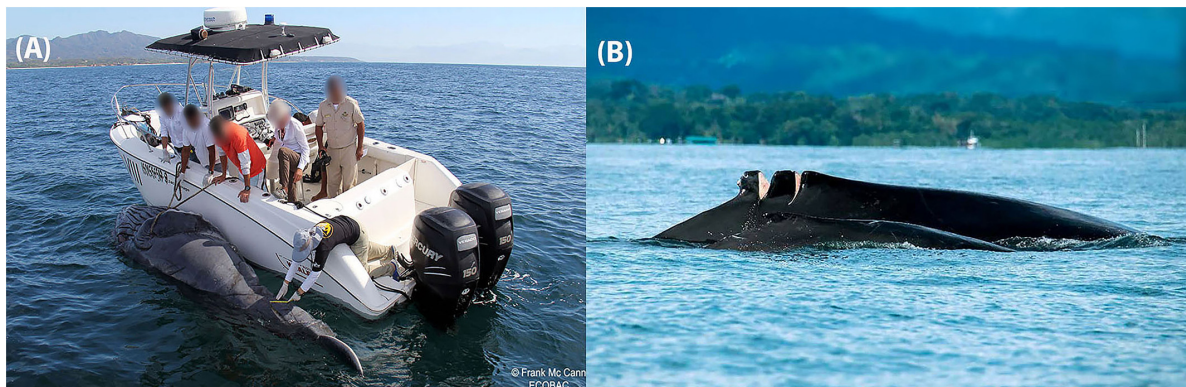


FIGURE 4 | (A) The carcass of a humpback whale calf (4.3 m in length) found floating in the Bay of Banderas, Nayarit, Mexico (December 31, 2014), with several deep, parallel cuts, some of which extended through the spinal column. Vessel strike was the concluded cause of death (Information and image: ECOBAC, Jalisco, Mexico). **(B)** A female humpback whale and calf photographed in Golfo Dulce, Costa Rica (September 16, 2017), showing open and fresh sharp trauma injuries, likely caused by a large ship's propeller (Image: Deivis Salazar Ruiz, Acacia Tours).

death of the whale) were reported for two whales (5.0%). In the three cases in which the whales were classified as having survived, the whales exhibited recent external, open injuries concluded as being caused by vessel strike (Events 9, 13, and 18 in **Supplementary Table 1** and **Figure 4B**). In one of these cases from Mexico, the female humpback whale has been sighted regularly since the vessel strike in 2011 and recorded with at least five different calves since the event (author, NR, unpublished information).

We found two reports of vessel strikes with small vessels and humpback whales that resulted in human fatalities; one human death in Baja California, Mexico in 2015 (whale-watch vessel; Event 14 in **Supplementary Table 1** and **Figure 5A**), and two human deaths from one strike in Ecuador in 2017 (fishing vessel; Event 35 in **Supplementary Table 1** and **Figure 5B**). Another whale strike involving a small vessel, which occurred during the night in Pacific Mexico, resulted in eight of the passengers being rushed to hospital; three (including the skipper) had severe but non-critical injuries (Event 15 in **Supplementary Table 1**). In addition, there were three reports of sailing vessels involved in vessel strikes with whales, all of which led to the vessel sinking, although in each case all crew members survived (Event 8, 20, and 26 in **Supplementary Table 1**).

DISCUSSION

Trends and Patterns of Vessel Strike Events in the ETP

Number and Geographic Distributions of Vessel Strikes

In total, we found evidence for 40 vessel strikes from eight of the ten ETP countries between 1905 and 2017, demonstrating that vessel strikes to large whales are more prolific throughout most of the ETP region than previously thought. Of the 40 vessel strike reports, 29 were new reports, increasing the documented

reports of vessel strikes in the region by 264% (**Figure 3B**). As is true globally, the actual number of vessel strikes occurring in the ETP each year is likely far higher than documented in this study. Guatemala and Honduras were the only ETP countries where vessel strike evidence was not found, although this does not mean vessel strikes with large whales are not occurring. The absence of reports is more likely due to their small coastlines; Guatemala has 300 km of Pacific coastline and Honduras has only 153 km of Pacific coastline. Although we have managed to find 29 new records of vessel strikes, this still contrasts strongly with the 28 recorded prior to 2010 from just the neighboring state (California) of the United States (International Whaling Commission (IWC), 2010).

Vessel strike reports in the ETP dated back to 1905 (**Figures 1, 3C**), demonstrating that it is an historic and present threat to large whales in the region. However, most occurred from the 1950's onward, similar to global patterns in vessel strike reports (**Figure 3C**). Laist et al. (2001) attributed this pattern in the global data to a sharp increase in the number and speed of large commercial vessels (>100 gross tonnage). The number of reported whale strikes in the ETP database then substantially increased from the 1990's. This coincides with a global increase in awareness and reporting of the threat of vessel strikes to large whales, as well as the recovery of the humpback whale (Bettridge et al., 2015), the most commonly struck species in the ETP. It was also the period that whale research projects commenced regionally, and that whale-watching industries were developed in several ETP countries, such as Mexico, Costa Rica, and Ecuador (Hoyt and Iñíguez, 2008).

Within the ETP, Mexico constitutes the greatest number ($n = 15$) of vessel strike reports, which is likely related to a combination of high whale density and heavy vessel traffic. However, this high co-occurrence in whale and vessel density is not unique to Mexico in the ETP, and the high number of strike reports may also be influenced by several reporting biases. Mexico is one of the biggest international tourism markets in the world (United Nation's World Tourism Organization (UNWTO), 2019),



FIGURE 5 | (A) An online article from the BBC reporting on a vessel strike between a humpback whale and a tourism boat in Baja California, Mexico (March 12, 2015), which resulted in the death of one of the passengers. **(B)** An online article from Ecuadorian TV channel, Ecuavisa, (June 23, 2017) describing a vessel strike of a large whale near to Salinas, Santa Elena, Ecuador. A boat carrying five fishermen capsized on impact with the whale. Three men survived, one man was found dead, and one man was still missing after 24 h (at the time this article was published) and was never found.

it has the largest whale-watching industry in the ETP both in terms of the number of whale-watching boats and the value of the industry (Hoyt and Iñíguez, 2008). In total, six of the 15 vessel strike reports we collated from Mexico involved tourist vessels. Vessel strikes during tourism trips are particularly likely to be reported due to members of the general public being onboard to witness, discuss and report the event (Laist et al., 2001; Lammers et al., 2013). Another contributing factor for the high reporting rates in Mexico could be related to what we term “investigator bias.” Jensen and Silber (2003) proposed the same bias to explain the high number of reports from the United States in their study, which could result from an increased likelihood of reports from countries/areas that investigators are most familiar. In the case of the ETP, the lead author is a Mexican resident and lives and works on the Pacific coast. There is therefore an inherent bias of discovering an increased number of reports from the country, due to greater familiarity with the people, animals and industries of Pacific Mexico.

Species Involved in Vessel Strikes

The humpback whale was the most commonly reported whale species involved in vessel strikes in the ETP and was implicated in 45% ($n = 18$) of the total strikes documented (Figure 3D). When only including the strike reports where the species of whale was identified, humpback whales were involved in nearly two-thirds of all known strikes in the ETP (66.7%, 18/27). Although more people in the region will have heard of humpback whales and possibly encountered them, lending to a possible bias in reporting of the species, we believe that our findings likely reflect the true pattern of vessel strikes on whale species regionally. World-wide, humpback whales are commonly involved in vessel strikes and appear to be susceptible to such accidents. In the IWC’s database (2010) of strike events, the humpback whale is the second most commonly hit whale species ($n = 119$), just behind the fin whale (*Balaenoptera physalus*, $n = 125$), and in Alaska (Neilson et al., 2012), Hawaii (Lammers et al., 2013), and Australia (Peel et al., 2018) the humpback whale

is the most commonly reported species struck. The ETP hosts two humpback whale populations that winter in the region; both the North and South-eastern Pacific humpback whale populations breed and calve in the ETP’s coastal waters and the two hemispheres’ population ranges overlap in the waters of Central America in Nicaragua, Costa Rica, and Panama (Acevedo and Smultea, 1995; Flórez-González et al., 1998; Rasmussen et al., 2007; Best, 2008; De Weerd et al., 2020). This is unique to the region and makes it one of the only known areas in the world that have humpback whales present year-round.

The humpback whale is predominantly a coastal species (Dawbin, 1966), and vessel collisions are most commonly reported to occur over the continental shelf (Laist et al., 2001). Furthermore, mother and calf pods are known to be particularly vulnerable to vessel strike during the winter calving season (Figure 4A; Laist et al., 2001; Guzman et al., 2013; Lammers et al., 2013). Our findings that almost half of strike events with humpback whales in the ETP involved mother and calf pods strongly supports this (Events 7, 8, 11, 13, 18, 21, and 22 in Supplementary Table 1; 41.2%, 7/17). Due to the ambiguity of many reports, the true proportion is likely higher. Mother and calf humpback whales’ preference for shallow near-shore waters (Smultea, 1994; Craig and Herman, 2000; Ersts and Rosenbaum, 2003; Frankel et al., 2008; Félix and Botero-Acosta, 2011; Smith et al., 2020), their short dive times, and resting behavior near the surface (Cartwright and Sullivan, 2009), make them vulnerable to vessel strike in coastal water. We found several reports of vessel strikes in the ETP with humpback whales near to marinas and ports (Events 1, 4, 12, 14, 15, and 35 in Supplementary Table 1). This should be given special management consideration in areas known to be used by humpback whales for calving and nursing, and which support large marine commercial industries.

Lastly, most whale-watching industries throughout the ETP are based around the humpback whales’ annual winter migration to breeding and calving areas, and the species is often the target of uncontrolled tourism. Whale-watch boats are particularly at risk of striking whales, considering they purposefully travel in areas of high whale densities. Hoyt and Iñíguez (2008) reviewed the state

of whale-watching in Latin America and described low-cost trips being offered by fisherman in multiple ETP countries, and noted that in Mexico there are “operators who don’t follow whale-watch regulations or guidelines with regard to approaching whales.” We found many similar reports of such navigation behavior all over the ETP, which likely greatly increases the risk of vessel strike with the species.

Vessel Types

Of the 40 unique vessel strikes included in this analysis, only seven vessel strikes (17.5%) involved large ships (>80 m in length), whereas small vessels (<15 m in length) were the most commonly reported vessel size to hit whales in the ETP vessel strike database ($n = 11$, 27.5%). This under-representation of large ships in vessel strike records has been found in other studies (Félix and Van Waerebeek, 2005; Neilson et al., 2012; Peel et al., 2018) and is likely an underestimate of the true proportion and number of vessel strikes involving large ships in the ETP, given the large volume of shipping that transits through the region (Kaluza et al., 2010). Globally, underreporting of vessel strikes involving large ships is often attributed to vessels being so large that crew is oblivious to strike events occurring (Laist et al., 2001; Félix and Van Waerebeek, 2005). Many vessel strike reports in the IWC’s database involved mariners that were likely unaware that a strike had occurred until the ship arrived into port with a whale slung over the “bow-bulb” ($n = 82$; International Whaling Commission (IWC), 2010). We note that the most reported bow-bulb slung whale, the streamlined fin whale is absent throughout much of the ETP (Edwards et al., 2015), and the region’s most common large whale species, the rotund humpback whale, is not normally encountered on the bow bulb of ships (Laist et al., 2001; Douglas et al., 2008). This may be an additional reporting bias which contributes to underreporting of vessel strikes regionally.

Another underrepresented sector in our sample corresponds to industrial fishing fleets. Extensive purse seiners and trawling fleets exist in Peru, Ecuador and Mexico, whose activities are concentrated in high productivity areas such as the Gulf of California in Mexico, the dome of Costa Rica off Central America, the Gulf of Guayaquil in Ecuador and the coastal upwelling zone in Peru, where whales also aggregate (Comisión Permanente del Pacífico Sur (CPPS), 2014). The anchovy (*Engraulis ringens*) fishery in Peru is the largest mono-specific fishery in the world (Food and Agriculture Organization of the United Nations (FAO), 2020). Ecuador has the largest tuna fleet in the ETP and Mexico the largest trawler fleet. It is difficult to believe that collisions do not occur with thousands of fishing vessels working every day in the region. A recent assessment on the effectiveness of regulations to protect whales in Panama showed that the tuna fishing fleet had the lowest level of compliance among assessed vessels (Guzman et al., 2020). This suggests strike reporting by the fishing sector could be even more challenging, and we believe this is likely another potential major source of underreporting of vessel strike reports regionally.

Lastly, the high number of vessel strike reports involving small vessels from the ETP has particular importance in reference to the

safety of humans. Collisions between whales and vessels are more dangerous to humans in smaller boats (Laist et al., 2001). In our study, two vessel strikes with humpback whales and small vessels resulted in human fatalities in this study (Figure 5), one strike led to eight people being injured, and three strikes resulted in sailing vessels sinking (Events 8, 20, and 26 in Supplementary Table 1), putting human lives at great risk (Ritter, 2012). Fortunately, there were no fatalities due to the sailing vessels that sunk, although one couple was afloat for 66 days in a raft before being rescued (Event 20 in Supplementary Table 1). Vessel collisions in the ETP clearly threaten human safety and well-being and this should be an important consideration in the management of the threat regionally. Serious human injuries and death may result from the impact of the vessel hitting the whale, e.g., in the Canary Islands, Spain (De Stephanis and Urquiola, 2006; Dolman et al., 2006), part of the whale making contact with a passenger, e.g., in Mexico, (Event 14 in Supplementary Table 1 and Figure 5A) or the sinking of the vessel due to the collision with the whale, e.g., in Ecuador, (Event 35 in Supplementary Table 1 and Figure 5B). The latter is of great concern because reports of vessels sinking as a result of whale strikes are increasing world-wide (Jensen and Silber, 2003; De Stephanis and Urquiola, 2006; Neilson et al., 2012; Ritter, 2012).

Severity of Vessel Strikes

It is difficult to quantify the severity of vessel strikes to large whales in free-ranging populations (Lammers et al., 2013). Of the 40 vessel strike reports included in our analysis from the ETP, 19 (47.5%) resulted in the death of the whale involved. However, these results will be weighted heavily toward fatal strikes, given 30.0% ($n = 12$) of collision records included in this analysis came from dead whales (either found at sea floating or stranded dead on the coast) and in nearly half of the reports ($n = 19$, 47.5%), the fate of the whale hit was unknown. Additionally, it is believed that the majority of carcasses of whales that are hit and killed by large ships at sea are never seen and/or recovered (Laist et al., 2001). Furthermore, there is often no way of knowing that a whale has survived a vessel strike event, apart from non-lethal vessel strike injuries or scarring (whales with this type of scarring were not included in this study as the incident may have occurred outside of the ETP), or unless the whale was photo-identified during the incident, or identifiable afterward due to the unique injuries it suffered. These reporting biases are major issues in the accurate assessment of the impact and severity of vessel strikes to large whales and their populations globally.

Our analysis included three cases where the whales were classified as having survived a vessel strike, based on injuries consistent with vessel strike and fresh wounds indicating it happened recently and within the country’s waters. However, often it is impossible to know if the whales’ long-term survival was affected (unless the animal is regularly resighted e.g., Event 9 in Supplementary Table 1). Additionally, a case study of a North Atlantic right whale, which survived for 12 years after a severe ship strike, but died after pregnancy caused the re-opening of an old healed propeller wound

(Campbell-Malone et al., 2008), highlights that although some animals originally survive a strike event, they may suffer ill health, lower fitness or ultimately die from injury related complications.

Although small vessels are usually presumed not to be fatal to large whales (Laist et al., 2001; Peel et al., 2018), there were two reports of whale fatalities in the ETP resulting from collisions with small vessels (Events 6 and 11 in **Supplementary Table 1**). These events suggest that with young whales and/or fast-moving boats, strikes even by small vessels may be deadly. This should be considered in the management and mitigation of the threat of vessel strike in the ETP, especially in large whale calving areas where whale-watch activities in small boats are popular.

Application of Known Causes of Underreporting of Vessel Strikes to the Eastern Tropical Pacific

Lack of Necropsies

It was the introduction of necropsies and stranding networks in the United States and Europe in the 1970s that initially drew global attention to the severity of the vessel strike threat to large whale populations (Laist et al., 2001). When constructing this regional database we found that although there were numerous records of large whales stranding annually throughout the ETP region, reports of necropsies were very rare. There is no legislation in any of the ETP countries that makes undertaking a necropsy of a stranded cetacean mandatory. We found only 30.0% ($n = 12$) of the evidence for reported vessel strikes in the ETP was sourced from dead whales. Necropsies provide the most reliable data on the minimum number of fatal vessel collisions that occur in a large whale population or region (Moore et al., 2004). Often when a large whale has been involved in lethal vessel strikes, the carcass may show no obvious external injuries of the event. To detect subtle “blunt force” trauma injuries caused by vessel strikes (e.g., broken skull or jawbones and internal bleeding/bruising) a dead whale needs to be flensed to the bone with a full examination of soft tissue and skeletal elements (Campbell-Malone et al., 2008; Moore et al., 2013). Consequently, if the whale carcass is not necropsied, or if the necropsy is not sufficiently thorough, the cause of death may go undocumented. For example, we found two recent cases in the ETP where thorough necropsies were performed, one in Ecuador in 2015 (Event 33 in **Supplementary Table 1**), and one in Peru in 2014 (Event 38 in **Supplementary Table 1**); both necropsies found internal injuries and concluded that vessel strike was the cause of death. In these cases, the necropsies were performed under government direction and involved internal examinations and inspection of bone integrity and tissue sampling. This clearly highlights the potential for underestimating vessel strikes in the ETP, and the need for more thorough necropsies in the region.

Long-term necropsy programs and stranding networks, once scarce in many regions, are being initiated world-wide (Van Waerebeek et al., 2007; International Whaling Commission (IWC), 2011; Chan et al., 2017). However, only four of the ETP countries; Colombia, Costa Rica, Guatemala and Mexico, have official networks listed in the IWC Whale Stranding Networks

List (International Whaling Commission (IWC), 2011). One surprising result from this analysis was that only one vessel strike report from Mexico involved collision evidence from a dead whale (Event 11 in **Supplementary Table 1** and **Figure 4A**). Mexico has a very impressive and comprehensive marine mammal stranding network the “Stranding Network of the Mexican Society of Marine Mammalogy,” made up of stranding teams in each coastal state (International Whaling Commission (IWC), 2011). However, the head of the Mexican stranding network confirmed that there were no other records of dead stranded whales with vessel strike injuries prior to September 2017 (Fernando Elorriaga Verplancken, Coordinator of the Stranding Network of Mexico 2012–2018, pers. comm.). Each year large whales are found stranded along Mexico’s extensive coastline. However, thorough necropsies on large whales are rarely performed. Often dead whales are only inspected externally for signs of vessel strike injuries, or the necropsy may only involve minimal inspection, incisions and/or tissue and blood sampling. This is due to a lack of skilled large whale necropsy personnel in most areas, and limited funding. Therefore, an assessment of vessel strike as the “cause of death” is likely negatively biased by the inability to observe cryptic blunt trauma injuries. Additionally, logistical challenges may also make conducting effective necropsies difficult (e.g., the size and remoteness of much of the coastline, tides, time of day, extreme weather conditions, state of decomposition, difficult location of stranded whale), which are global problems, not restricted to the ETP (Neilson et al., 2012).

A Need for Regional Efforts and Country Co-ordination to Collate Vessel Strike Data

The compilation of global vessel strike data, and the process of accessing all the information that exists on vessel strikes from many different sources and from all regions of the world, is a considerable task. Van Waerebeek et al. (2007) suggested when compiling vessel strike records that much “useful information may be buried in largely inaccessible ship logbooks”; this is likely true with a multitude of different secondary sources, all over the world. In this study we have shown the value of dedicated regional efforts to investigate the vessel strike threat, and highlighted the need for more regional efforts worldwide, especially in developing areas. The source that provided the most records of vessel strike in the ETP was online media reports (32.5%) found using the search engine Google. This shows that information about vessel strike events in the region is potentially easily available. Additionally, searching in languages other than English that are spoken in the area of interest, will further aid in the discovery of vessel strike reports. This is evidenced by just under half of reports (43.5%, 10/23) in our study being found through searching the internet, scientific documents, and newspaper databases in Spanish.

A trend we observed in our data was that when a focused national effort to investigate vessel strikes was made it led to a large increase in the number of collision reports. This effort was often by a research group or by an individual with a strong interest in the vessel strike issue. For example, Ecuador had the second highest number of vessel strike reports ($n = 10$), which is

likely in part related to the high density and diversity of cetaceans found in Ecuadorian waters and heavy vessel traffic. It is also likely due to significant and consistent effort by a local research group, over several decades, to systematically compile evidence of vessel strikes. This has included assessments on the cause of death of stranded animals, conducting basic necropsies where possible (Félix et al., 1997; Félix and Van Waerebeek, 2005; Félix, 2006, 2009; Van Waerebeek et al., 2007), and direct reporting of cetacean fatalities caused by vessel strike to the IWC. This success in increasing reported strikes with focused effort, is a pattern which has been seen in all the global vessel strike databases, e.g., Best et al. (2001) with southern right whales (*Eubalaena australis*) in South Africa found in Laist et al. (2001), and Peel et al. (2018) in their historical database of vessel strikes in Australia.

Mexico was the only ETP country that submitted Scientific Committee Annual National Progress Reports to the IWC during our vessel strike compilation period (prior to 1st September 2017). The submission of these reports is beneficial in that it creates an official platform for vessel strike incidents to be documented internationally. However, between 2000 and 2018, only two vessel strikes were included in Mexico's Annual Progress Reports, while we uncovered a further seven during this time, indicating that greater national research effort dedicated to the issue is necessary. In contrast, in Colombia, a research group investigating the issue reported on five vessel strikes in a published peer review journal and a conference workshop report (Capella Alzueta et al., 2001, 2006), but these records were not present in the IWC Scientific Committee National Progress Reports or in the global database (International Whaling Commission (IWC), 2010) despite occurring before 2010 (Events 21–25 in **Supplementary Table 1**). The introduction of formal reporting to the IWC through Annual National Progress Reports has been shown to dramatically increase the number of vessel strike reports, even in developed countries e.g., Australia (Peel et al., 2018). Clearly, critical components for better quantifying the rate of vessel strikes with whales, is the combination of, (a) national efforts in researching the threat combined with, (b) a formal reporting structure with a clear reporting procedure (e.g., Annual National Progress Reports) to an overall governing body (e.g., the IWC) and, (c) a centralized database (e.g., the IWC Global Ship Strike Database). We therefore recommend the introduction or refinement of the inclusion of vessel strikes in Annual National Progress Reports for all IWC countries of the ETP, and that the non-member countries, Guatemala, El Salvador, and Honduras (International Whaling Commission (IWC), 2020) submit incident reports using IWC protocol (Cates et al., 2017). We suggest that these reports include as detailed account as possible for each event, following the methodology listed in this study, to avoid the problem of “vague” and “incomplete” reports which cannot be included in the global database (Van Waerebeek and Leaper, 2008).

Absence of Reporting Protocols and Fear of Reprisal and Legal Repercussions

Through the construction of a regional vessel strike database for the ETP, the information from the strike events sheds new light on underreporting from the region. While our aim was not to

investigate the full scope of reporting biases in the ETP there is great value in the application of the information in our database to known causes of underreporting. The data suggests that two additional and well referenced biases are also affecting reporting regionally in the ETP. They are: (1) the lack of national reporting protocols for mariners to report vessel strikes and, (2) mariners' fear of reprisal and legal repercussions for harming large whales. Both merit further investigation, and although information from our database was insightful, it was also limited in its application to investigating these factors further. Throughout much of the region where no national reporting protocols for vessel strikes are in place, we found that if a large ship does enter a port with a bow-bulb slung whale, and the event does not reach the attention of the local media or is not reported to local biologists, no reports may exist of the collision. For example, a stranded unidentified large whale which came ashore in Paita, Peru in November 2014. It was reported to have fallen off the bow-bulb of a docking ship, and only made the regional news headlines because of the large number of people appearing on the beach to cut off parts of the whale to take away for food (Event 39 in **Supplementary Table 1**).

Globally, it is well recognized that fear of reprisal for hitting a whale is one of the major causes for underreporting (Lammers et al., 2003; Weinrich, 2004; Neilson et al., 2012). Captains and crew involved in vessel strikes with large whales may not report a strike event due to fear of punishment (both legally and within organizations), or the negative publicity involved with harming wildlife (e.g., whale-watching companies), or to avoid the commercial implications of involvement in vessel strikes (e.g., ferries, cruise ships, and fishing fleets) (Weinrich, 2004). We used Mexico as a case study, and spoke to several mariners when investigating vessel strikes who said confusion over legislation and fear of punishment strongly influenced their decision to not report a strike or admit to an accident with a whale. All large whales are classified as a protected species under Mexican legislation (NOM-059), and if a whale is killed due to irresponsible navigation, the captain could face prosecution [Diario Oficial de la Federación (DOF), 2020]. Additionally, other legislation “Artículo 420 del Código Penal Federal” (in English “Article 420 of the Federal Penal Code”) states that a penalty of up to nine years imprisonment is faced by any person(s) who “capture, damage or deprive of life any turtle or marine mammal specimen” (Cámara de Diputados (CDD), 2020). Further in-depth social studies throughout the region are warranted to investigate fear of reprisal as a potential major cause of underreporting in the ETP, such as the approach of a mariner questionnaire adopted by Lammers et al. (2003) to investigate vessel strikes in Hawaii. This could include addressing how ambiguity in legislation may contribute to underreporting, or in contrast how complete ignorance of rules, regulations, legislation and reporting protocols also leads to the fear of unknown consequences. We suggest the facilitation of anonymous online reporting in each nation for accidents with whales, to address the problem of fear of reprisal and increase reporting of vessel strikes.

CONCLUSION

Our study demonstrates the need for focused regional efforts to investigate vessel strikes, to aid in filling reporting gaps in world-wide strike data. It also identifies factors that are contributing to the absence of knowledge of the vessel strike threat in the ETP, which is likely similar in other developing areas of the world with a scarcity of vessel strike information. We believe that prioritizing research in developing regions, with known “hotspot” characteristics but few strike reports, will facilitate more effective rapid assessments of the global threat of vessel strikes. Several human deaths and injuries in the last five years in the ETP due to vessels strikes, highlight a serious cause for management concern. Likewise, reports of large whale deaths and injuries (particularly calves) due to vessel strikes in ETP large whale calving and nursing areas, highlight a priority conservation and management issue. Specifically, concern is warranted in areas of high whale densities and large tourism industries where whale-watch trips are commonly carried out in smaller vessels, and particularly around marinas, ports or beach departure points which appear to be hotspots for accidents with large whales. We believe that underreporting may be especially significant for whales struck by vessels of the large industrial fishing fleets and the heavily used shipping lanes. Areas where these industries overlap with high densities of large whales also represent critical areas of management concern. Encouragingly, there have been several major efforts recently to address the vessel strike threat to large whales, through the introduction of mitigation measures by the IMO in Panama and Costa Rica (Guzman et al., 2020).

We suggest the following recommendations to facilitate better collection of strike event information regionally: (1) the training of personnel to conduct thorough necropsies (including flensing to the bone) in each country, to ensure cryptic blunt trauma vessel strike injuries are recorded; (2) the encouragement of the study of vessel collisions of large whales in each ETP country, by research groups, independent researchers, students and/or government bodies. This will ensure more efficient collation of strike event information nationally; (3) improvements in reporting structures via the introduction of national vessel strike protocols and programmed annual reporting of events to the IWC. This will promote the dissemination of vessel strike information internationally; (4) increasing public education and awareness of the threat of vessel collisions and laws and guidelines around strikes and reports. This should involve efforts to publicize the need to report collisions with whales (e.g., signs in marinas and on slipways) throughout the region; (5) building better relationships between local biologists and harbor masters/port workers to encourage the reporting of vessel strikes involving large ships, and; (6) enabling anonymous strike reporting in each country, combined with greater education about the subject, reporting protocols and the laws involved in vessel strikes during industry meetings of fisherman/tour companies/mariners. This will lead to an increase in reporting of vessel strikes (and reduce fear of reporting) and improve the quality of strike information. In time, these actions will allow a greater understanding of the scope and scale of the issue in each country and enable high-risk areas for whale strikes regionally to be identified.

New effective management and mitigation actions can then be considered to try to reduce the threat of vessel strike for large whales in the ETP.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/ **Supplementary Material**. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

NR: conceptualization of the study, collection of data, analysis and preparation of first draft of the manuscript, incorporating changes from co-authors, and completion of final draft. NRL and JNS: conceptualization of the study, discussions on directions of study, analysis and preparation of first draft of the manuscript feedback on structure of manuscript and contributions to drafts of manuscripts. LM-G and FF: feedback on structure of manuscript and contributions to drafts of manuscripts. All authors contributed to the article and approved the submitted version.

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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.2021.675245/full#supplementary-material>

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