Large whale entanglements off the U.S. West Coast, from 1982-2017

Lauren Saez, Dan Lawson, and Monica DeAngelis

U.S. Department of Commerce
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Executive Summary

Large whale interaction and entanglement with gear in the ocean poses a major threat to animals worldwide. Entanglement can cause mortality, minor to significant injuries that may compromise the health of the individual animal which may impact their ability to feed or reproduce. There are also economic impacts associated with large whale entanglements. Commercial and recreational fishing industries may incur expenses due to lost gear or potential gear modifications, and increased regulations to reduce future whale entanglements. A significant investment is also needed when a response is undertaken to remove gear from an animal or to remove gear from the water.

Reports from California, Oregon, and Washington were standardized and combined to form a single database. This standard database was then analyzed for spatial and temporal trends in whale species, fishing gear types and associated fisheries, known outcomes of whale entanglements, and entanglement response.

Off the coast of California, Oregon, and Washington, there were 521 whale entanglements reported and 434 confirmed entanglements between January 1, 1982 and December 31, 2017. Whale entanglement reports were confirmed using criteria that include reviewing photos or videos or through direct observation by the National Oceanic and Atmospheric (NOAA) staff or another expert. Data analyses document a recent spike in entanglements, jumping from an annual average of 9 confirmed entangled large whales between 1982 and 2013, to an average of 41 confirmed entangled large whale reports between 2014 and 2017. Multiple factors may contribute to this increase in the number of reported entanglements, including, but not limited to, an increase in public awareness and reporting, changes in the spatial distribution and abundance of whales, fishing effort, and ocean conditions.

Whale species

Gray whales (*Eschrichtius robustus*) and humpback whales (*Megaptera novaeangliae*) were the most frequently reported species, with 211 and 167 confirmed entangled whales respectively, between 1982 and 2017. Blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus*), minke whales (*Balaenoptera acutorostrata*), killer whales (*Orcinus orca*), and sperm whales (*Physeter macrocephalus*) have also been reported as entangled in gear.

Whale entanglement report location and timing

Whale entanglements were documented across the entire area off the U.S. West Coast, with additional entanglements reported from bordering countries of Canada and Mexico, of animal's gear originating from the U.S. West Coast. The majority of confirmed whale entanglements were reported from California (85%), with 7% from Washington, and 6% from Oregon, and 1% from Mexico and Canada. However, these percentages do not always reflect the geographic area where this gear originated. Entanglement reports have been received in every month of the year, with highest numbers of entanglements in March and April. These months correspond with the northern migration of gray whales along the U.S. West Coast, as well as early presence of feeding humpback whales.

Gear types associated with whale entanglement reports

Gear types were coded into general gear types: net, pot/trap, hook and line, other, and unknown. "Net" is the general category describing an entanglement where any type of netting, used for fishing is identified, including gillnet and the California swordfish/thresher shark drift gillnet. "Hook and line" is the general category describing an entanglement where the fishery identified uses hook and line to target fish. "Pot/trap" is the general category describing any entanglement where the identified fishery utilizes a trap or pot to target fish or invertebrates. "Other" is the general category describing an entanglement where the gear type identified is not hook and line, netting, or trap/pot. "Unknown" is the general category for an entanglement report where entangling gear material is unidentifiable to a specific source. Confirmed entanglements were most often attributed to gear that could not be identified (43%), with netting (34%) and pot/traps (22%) accounting for the remainder of the entangled whale reports. Since 2000, the proportion of whales entangled in pot/trap gear has increased, whereas net entanglements have decreased in prevalence. NMFS was able to identify and confirm the specific fishery or gear in 57% of confirmed entanglement reports. Gillnet had the highest number of entanglements, 85, with commercial Dungeness crab pot fishery as second with 74. Other pot/trap fisheries confirmed to be involved with large whale entanglements are commercial spot prawn, commercial sablefish, commercial lobster, recreational Dungeness crab and commercial rock crab. When the gear set location associated with the whale entanglement is known.

Relating entanglement report location to known entanglement (gear set) location

There were 92 records where gear set region was known. Of those 92 records, there were 73 records where the gear set region (and presumably the location of the entanglement) was the same as the region where the whale entanglement was reported, while the remaining 19 had a different gear set region. This suggests that a relationship exists between the patterns of entanglement reporting and the origins of entanglements, at least at a regional level, specifically in those areas where entanglements are commonly reported, such as central California. Whales were also documented carrying gear from the United States (U.S.) for thousands of miles into Mexico and Canada.

Entanglement Response

Trained entanglement responders initiated a response for 38% of the entangled live whales that were reported. Many responses ended with either full (29%) or partial (19%) removal of gear. Of the 247 reports where entangling gear or fishery was confirmed, commercial Dungeness crab gear was associated with entanglements that had the highest number of releases (full, partial, and self-releases), representing a 49% success rate for responses to entanglements with this gear type. The documentation collected during entanglement response is invaluable in gaining an understanding of entanglements towards preventative solutions.

Conclusion/Looking forward

The outcomes of this report should serve as a guide to improve the understanding of the potential for interactions between commercial and recreational fisheries and large whales along California, Oregon, and Washington, recognizing that there are still many challenges in understanding the risk of whale entanglements and identifying gear. Based on the 35 years of whale entanglement data analyzed in this review, future work is recommended in the following areas:

1) Improve reporting to NMFS: increasing public awareness and understanding of the need for early and accurate reporting, expanding geographic reporting party coverage, support large whale entanglement response network to gain better documentation (e.g., photo identification, gear identification, injuries) and quality of information collected from each entanglement report;
2) Improve understanding of the ecological drivers affecting the distribution of whales and their risks of interaction with U.S. West Coast gear, and develop tools to assist with predicting distributions based on those drivers;
3) Improve understanding of the dynamics of the West Coast fixed gear fisheries, and develop tools to assist with monitoring/predicting those distributions;
4) Enhance understanding of how behavior of whales and different gear configurations may interact to increase/decrease chances of entanglements occurring;
5) Continue gear research and development of innovative ideas in collaboration with fishermen to reduce the number and/or severity of future entanglements, specifically for the U.S. West Coast; and
6) Continue and expand fishery gear marking initiatives based on evaluations of whale entanglement report data and success/failure of current marking schemes to identify the origins of entanglements

.

List of Acronyms and Abbreviations

Ba	Minke whale (*Balaenoptera acutorostrata)*
BC	British Columbia
Bm	Blue whale (*Balaenoptera musculus*)
Bp	Fin whale (*Balaenoptera physalus*)
CA	California
CCa	Central California (Sonoma to San Luis Obispo counties)
Dcc	Dungeness crab commercial fishery
Dcr	Dungeness crab recreational fishery
Dgn	Drift gillnet fishery
DIKW	Data, Information, Knowledge, Wisdom
Er	Gray whale (*Eschrichtius robustus*)
ESA	Endangered Species Act
GAMMS	Guidelines for Assessing Marine Mammal Stocks
Gn	Gillnet
ID	Identification
IWC	International Whaling Commission
Lb	Lobster fishery
Mn	Humpback whale (*Megaptera novaeangliae*)
MMHSRP	Marine Mammal Health and Stranding Response Program
MMPA	Marine Mammal Protection Act
MX	Mexico
NCa	Northern California (Del Norte, Humboldt, Mendocino counties)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
Nt	Netting (general fishing gear type)
Oo	Killer whale (*Orcinus orca*)
OPR	Office of Protected Resources
OR	Oregon
Ot	Other (non-fishing gear entanglement)
PBR	Potential Biological Removal
PCFG	Pacific Coast Feeding Group
Pm	Sperm whale (*Physeter macrocephalus*)
Rc	Rock crab fishery
SAR	Stock Assessment Report
Sb	Sablefish trap fishery
SCa	Southern California (Santa Barbara to San Diego counties)
St	Salmon troll fishery
Sp	Spot prawn fishery
UCa	Unknown location in California
U.S.	United States
USA	United State of America
Uu/Unk	Unknown

WA	Washington
WCR	West Coast Region

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Large whale entanglements off the U.S. West Coast, from 1982-2017

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Abstract

Worldwide, large whale entanglement can have negative consequences for whale species (individually and at a stock/population level); the high percentage of entanglements in fishing gear has negative implications for fishing industries as well. While entanglement occurring off the U.S. West Coast has been reported for over 35 years, entanglement rates have increased dramatically over the past five years. To date, there has never been a comprehensive compilation and synthesis of large whale entanglement data. In this report, we present an analysis of whale entanglements that were observed off coastal California, Oregon, and Washington waters from 1982 to 2017 (total reported n=521, confirmed n=434) to assess spatio-temporal trends in entanglement reports as a function of whale species, fishing gear types and associated fisheries, known outcomes for whales and response efforts. It is important to emphasize that the time and locations that entangled whales were reported rarely indicated when and where those whales initially became entangled. A recent spike in entanglements has been documented, jumping from an average of 9 confirmed (10 reported) entangled large whales between 1982 and 2013, to an average of 41 confirmed (50 reported) entangled large whale reports between 2014 and 2017. Gray (*Eschrichtius robustus*) and humpback (*Megaptera novaeangliae*) whales were the most frequently reported entangled whale species with 211 gray whales (240 reports) and 167 humpback whales (188 reports) entangled between 1982 and 2017. Between 1982 and 2017, confirmed entanglements were most often with gear that could not be identified (43%), with netting (34%) and pot/traps (22%) accounting for the remainder of the entangled whale reports. However, since 2000, the proportion of whales entangled in pot/trap gear has increased, whereas net entanglements have decreased in prevalence. Further, there has been an increase over time in certainty of fishery type, gear configuration, and set location associated with entanglements. We identified several factors that limit our ability to fully evaluate the underlying dynamics associated with large whale entanglements off the U.S. West Coast, including spatio-temporal bias of opportunistically collected entanglement reports and the relative lack of information available from entanglement reports that can be used to identify the entangling gear to a specific source and location. We use the results and conclusions of this review to improve the quality of data collection and analyses and to inform resource managers, the fishing industry, the scientific community, and whale entanglement response networks in order to prioritize responses to this conservation problem

Introduction

All marine mammal species, including those that occur off the U.S. West Coast (California, Oregon, and Washington) are protected by the Marine Mammal Protection Act (MMPA; 16 U.S.C. §1371), and a subset of these (blue, fin, sperm, and two distinct population segments of humpback whale off the U.S. West Coast) are further protected under the Endangered Species Act (ESA; 16 U.S.C. §1531). Many marine mammals, including large whales, are sighted and reported to the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) as entangled in various types of gear or materials each year (Table 1). Entanglements can occur as a result of incidental capture in or interactions with: actively fished fishing gear (or bycatch); lost or derelict fishing gear; and non-fishery related materials either placed (e.g., mooring buoys), or discarded or lost (e.g., marine debris) (Neilson, 2007; Johnson et. al., 2005; Henry et. al., 2017). As in other areas of the world, large whale populations observed off the U.S. West Coast were once decimated by historic whaling (Rocha et. al., 2014; Reeves et. al., 2017). Today, some of these large whale populations are increasing in abundance from historical lows, partly as a result of the protections from the MMPA and ESA (Calambokidis and Barlow, 2017; Calambokidis et. al., 2017). Due to these increasing numbers of whales, as well as increasing human activities in the ocean, interactions between whales and human activities along the U.S. West Coast would be expected to increase accordingly (Saez et. al., 2013). Despite signs of recovery by some species of whales, the bycatch of large whales in commercial and recreational fishing gear remains a concern because of long term animal welfare and the potential impacts to small or otherwise vulnerable whale populations, specifically those that remain listed as endangered or threatened under the ESA (Moore and van der Hoop, 2012; Moore et. al., 2006). Additionally, potential economic costs to fishermen can be incurred from lost or damaged gear resulting from entanglement incidents, as well as implementation of any fishery regulations designed to protect marine species that may occur in response to these types of incidents.

The NMFS Marine Mammal Health and Stranding Response Program (MMHSRP) authorizes and oversees marine mammal stranding networks, the centralized data collection of all human interactions with all marine mammals, and the coordination of large whale entanglement response teams at the national level with regional and local coordination. Since the early 1980s, NMFS Regional Offices have collected, verified, documented, and responded to reports of large whale entanglements along the U.S. West Coast. These reports have been evaluated and used in the preparation of Marine Mammal Stock Assessment Reports (SARs)[1] produced annually by NMFS. Reports of entangled whales originate from a variety of opportunistic and systematically collected sources including: recreational boaters, members of the general public, commercial and recreational fishermen, whale watch vessels, scientific researchers, NMFS commercial fishery observers, the United States (U.S.) Coast Guard, other law enforcement or marine resource agencies, and members of marine mammal stranding networks. Entangled whales have been reported as free-swimming, anchored, stranded alive on shore, or stranded dead (floating or on shore). The documentation of entangled whales by NMFS relies on opportunistic sightings and reports, and some percentage of entangled whales go unreported (Robbins and Mattila 2001a,

[1] Marine mammal stock assessment reports: https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessments

Robbins and Mattila, 2001b, Neilson *et al.* 2009). As a result, NMFS assumes that many large whale entanglements are not observed or not reported, and reports of large whale entanglements represent an unknown fraction of the total number of whales that have been entangled over time.

Factors Affecting Entanglement Reporting

The likelihood of an entangled whale being reported depends on three major factors: whale spatio-temporal distribution, reporting party effort, and reporting party awareness (Robbins and Mattila, 2001). We assume that the probability of detecting an entangled whale increases when the whale is in closer proximity to human population centers and high use ocean areas, owing to more "eyes on the water." Familiarity with reporting procedures and confidence in agency response greatly increases the chances that someone who opportunistically observes an entangled whale will report the sighting. Given the relatively recent development of more formalized entangled whale reporting and response infrastructure, the level of detail and extent of documentation provided in entanglement reports has varied significantly over time and is likely influenced by observer expertise, awareness, and attitude of various reporting sources (Robbins et. al., 2007). When NMFS has received reports, there have often been inconsistencies with the information received that limit the ability to fully assess the nature and origins of individual entanglement events.

The ability of NMFS West Coast Region (WCR) to positively identify the origins of entangled gear on the U.S. West Coast has often been limited by a number of factors including:

1) incompleteness of descriptions or documentation (photos or video) provided by reporting parties;
2) inability of reporting party to identify various types of commercial fishing gear (*i.e.,* the general public is typically not familiar with most types of gear);
3) lack of accessible and comprehensive information regarding the types of gear used by specific commercial and recreational fisheries as well as other activities in the marine environment;
4) the use of relatively generic line types across a range of marine activities and fishing gear types (e.g., ¾" polypropylene line); and,
5) lack of markings or other characteristics on fishing gear that would facilitate unambiguous associations with specific fishery types.

Finally, weather conditions, sea state, and the partially submerged nature of entangling gear often limits the ability of reporting parties to provide comprehensive and definitive information that allows NMFS to fully characterize the nature of entanglements and accurately identify their origins. Initial reports, although sometimes limited, are a very important part of the process of documenting the entangled whale. Expert responders, who have increased capability and authorization to document and ID gear are not always able to respond or relocate the animal.

Although information regarding large whale entanglements has been collected and maintained by NMFS for many years, there has been no comprehensive formal review and analysis of the frequency of entanglements along the U.S. West Coast, the types of gear involved, the location and date of the reported entanglement, and where the entanglement may have actually occurred. A spike in entanglement reporting activity occurred on the U.S. West Coast increasing concern

and the need to provide comprehensive information and analysis to inform the public and other interested stakeholders on the extent of available knowledge surrounding entanglements. We are providing a review of the complete historical record of large whale entanglements reported to NMFS for the contiguous U.S. West Coast, as well as relevant information from neighboring countries.

Data Summarized

We compiled and analyzed the available information provided in the reports of large whale entanglements from the U.S. West Coast from 1982-2017 to:

1) document spatial and temporal patterns and trends in the reports of large whale entanglements from the U.S. West Coast, in total and across species;
2) review the available information on the type of gear and specific fisheries that have been associated with entanglements along the U.S. West Coast;
3) compare the relative location of entanglement reporting to the origins of entanglements, where known;
4) review the outcomes of entanglements and disentanglement response efforts to date; and,
5) highlight the key questions surrounding large whale entanglements and the limitations of the information that has been gathered to date to help focus efforts to improve the quality and utility of future entanglement reporting.

Table 1 List of large whale species reported entangled with commercial fishing gear off the U.S. West Coast since 1982 (Barlow et al., 2009; Forney et al., 2012). ESA status with associated population (Distinct Population Segment, DPS) and MMPA stocks are included for reference, but are not distinguished for the species of entangled whale.

Species	Suborder	Family	Endangered Species Act status	MMPA stock
Blue whale (*Balaenoptera musculus*)	Mysticeti (baleen)	Balaenopteridae	Endangered	Eastern North Pacific
Fin whale (*Balaenoptera physalus*)	Mysticeti (baleen)	Balaenopteridae	Endangered	California/ Oregon/ Washington
Gray whale (*Eschrichtius robustus*)	Mysticeti (baleen)	Eschrichtiidae	Eastern North Pacific: Not listed Western North Pacific: Endangered	Eastern North Pacific; Western North Pacific
Humpback whale (*Megaptera novaeangliae*)	Mysticeti (baleen)	Balaenopteridae	Central America DPS: Endangered Mexico DPS: Threatened	California/ Oregon/ Washington
Killer whale (*Orcinus orca*)	Odontoceti (toothed)	Delphinidae	Eastern North Pacific Southern Resident DPS: Endangered	Eastern North Pacific Offshore;

Species	Suborder	Family	Endangered Species Act status	MMPA stock
			Eastern North Pacific Offshore stock: not listed	Eastern North Pacific Southern Resident
Minke whale (*Balaenoptera acutorostrata)*	Mysticeti (baleen)	Balaenopteridae	Not listed	California/ Oregon/ Washington
Sperm whale (*Physeter macrocephalus*)	Odontoceti (toothed)	Physeteridae	Endangered	California/ Oregon/ Washington

Methods

Data Processing, Standardization and Organization

All large whale entanglement records that were reported to NMFS West Coast Region (WCR) were stored in various locations and maintained in a "raw" format in various locations. After initial review, the available historical records represented the following time periods:

- California: January 1, 1982 – December 31, 2017
- Washington and Oregon: January 1, 1995 – December 31, 2017

A Review Team of staff from the NMFS WCR Protected Resources Division[2] collected these "raw" data and compiled them into a single database. During this review, it became evident to the Review Team that the information extracted from the reports needed to be standardized. Sources of entanglement reporting included: the marine mammal stranding network Level A forms[3]; other reports from stranding networks; records from large whale entanglement response networks; the Marine Mammal Authorization Program (fishermen self-reports); NMFS commercial fishery observer records; reports from members of the public, U.S. Coast Guard and other law enforcement agencies; and, marine science organizations. The geographic location of these reports included entangled whales reported off the U.S. West Coast (Washington, Oregon, and California), but also included Canada and Mexico if the entangling gear was known to have originated from the U.S.. Entanglement reports also included descriptions of the entangled whale status such as: whether the animal was observed swimming, anchored, stranded (alive on shore); or if the animal was dead (floating or on shore), and descriptions of fishing gear or other entangling material attached.

The Review Team standardized and condensed all the entanglement report data into a single database (e.g., source, geographic location, details of the entanglement) that captured all of the information from the individual reports. When available, photos, videos, and other descriptive information were reviewed from each report and included in the database. This information was used to flag entangled whales that were reported by multiple individuals, erroneously receiving multiple entries in the database, and these redundant reports were combined into a single record.

Over 60 separate data fields or attributes (see Appendix 1) were included in the standardized database. The general categories of information captured include: details related to the animal and its condition and behavior during the observation; the nature of the entanglement and associated injuries observed; description and identification of the entangling gear; information about the reporting party; any response activities that occurred; and, other general record keeping information related to the extent of the documentation and any assessment that may be provided as part of the report. We then used this resulting large whale entanglement dataset to assess how patterns of whale entanglement changed over time off the U.S. West Coast.

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[2] Review Team: Monica DeAngelis, Lauren De Maio, Laura McCue, Justin Greenman, Dan Lawson, Lauren Saez, Justin Viezbicke, and Kristin Wilkinson

[3] Level A Form: A stranding form used as part of NOAA's Marine Mammal Health and Stranding Program response to stranded marine mammals.

Analysis and Synthesis of Database

We used information from a subset of the data fields (see Appendix 2) to assess patterns or trends in whale entanglement that occurred over time. Specifically, we characterized the spatial and seasonal patterns of: 1) entanglement reports and 2) gear associated with those reports, aggregated by species over time. Definitions of data fields summarized in this paper can be found in Appendix 1.

Whale entanglement reports are first reviewed to confirm the report. A confirmed entanglement report is an observation of a whale with human-made materials (including rope, net, monofilament line, buoys, traps, hooks, or debris) attached to it. A confirmed report does not need to contain all of the possible details that may be relevant to describing the entanglement (e.g., exact species of whale, location, type of gear, etc.).

Criteria used to deem a report "confirmed" include:

- Photos or video of the gear on the whale
- NOAA staff has direct visual observation
- The report came from a trusted source (trained or professional reporting party)
- An experienced network member or NMFS expert interviewed the reporting party and the information provided is detailed and specific enough to confirm entanglement.
- Multiple sources providing reports with detailed descriptions of the animal and the entanglement.

Entanglement report locations were coded and summarized at a regional level, shown in the map in Figure 1. Because entanglement report locations ranged from Canada to Mexico, the regions defined below were used to assess any potential trends at a smaller spatial scale rather than evaluating the entire west coast. Further, the State of California was split into three regions: North, Central, and Southern California. This delineation is consistent with California commercial fishery management areas and also captures environmental factors and features that may be causing some of the spatial distribution patterns that have been observed for certain whales.

Codes for location are:

- Bc= Canada
- Wa=Washington
- Or= Oregon
- NCa= Northern California (Del Norte, Humboldt, Mendocino counties)
- CCa= Central California (Sonoma to San Luis Obispo counties)
- SCa=Southern California (Santa Barbara to San Diego counties)
- UCa= Unknown California
- Mx=Mexico
- Uu= Unknown

Figure 1 Map showing regional codes used for entanglement report location and gear set location for this paper.

In addition, when information on the origin of gear was identified, we compared it with the location where entanglements were observed. Gear set locations require confirmation by either the fisherman who set the gear or from a NMFS Fishery Observer. General geographic information (e.g., state) could also sometimes be inferred using other available information such as the shape and color of buoy tags (e.g., gear marking associated with a trap limit program, Saez et. al., 2013) observed on entangling gear. Gear set location information is typically only obtained during follow-up interviews with the owner of the entangling gear once it has been identified. Fisherman often report setting their gear in a range of areas within the regions defined in Figure 1, therefore, gear set locations were also coded at a regional level.

The identification of the entangling gear or the determination that the entangling gear came from a specific fishery relies on information and any documentation provided by the reporting party and/or responders to the NMFS WCR. This includes photographs, video, or the gear retrieved off the animal. Along the U.S. West Coast, certain fisheries have gear marking requirements that are put forth under State and Federal regulations, as well as other characteristics that may be identifiable. NMFS works with State, Federal, tribal fishery managers, and other experts to identify and verify that the entangling gear is accurately identified and assigned to the appropriate fishery.

Entangling gear was coded into general gear types: hook and line, net, pot, other and unknown. Hook and line is the general category describing an entanglement where the fishery identified uses hook and line to target fish. Net is the general category describing an entanglement where any type of netting, used for fishing, is identified, including gillnet. Pot is the general category describing any entanglement where the identified fishery utilizes a trap or pot to target fish or

invertebrates. Other is the general category describing an entanglement where the gear type identified is not hook and line, netting, or trap/pot. Unknown is the general category for an entanglement report where entangling gear material is unidentifiable to a specific source.

Entangling gear was coded to specific fisheries when possible.

The fishery codes are:

- Dcc= Dungeness crab commercial (trap fishery)
- Dcr= Dungeness crab recreational (trap fishery)
- Dgn= Drift gillnet, CA thresher shark/swordfish large mesh (net fishery)
    - assigned to an entanglement when it is reported from a NMFS commercial fishery observer or MMAP self-report.
- Gn= Gillnet (net fishery)
    - assigned to an entanglement report when there is a detailed description of the net and/or photos to support this designation. It is often difficult to assign to a specific fishery.
- Lb= Lobster (trap fishery)
- Nt= Netting (net fishery)
    - assigned to an entanglement report when "netting" is the description used by the reporting party and/or in absence of other identifying characteristics such as mesh size or netting materials.
- Rc=Rock crab (trap fishery)
- Sb= Sablefish pot (trap fishery)
- St= Salmon troll (hook and line fishery)
- Sp= Spot prawn (trap fishery)
- Un= Unknown
- Ot= Other (e.g., cables, weather buoys)

We also reviewed the entanglement response records related to whale species and gear type. Entanglement response is defined as any attempt to further interact with an entangled whale, including: measures attempted by a trained disentanglement team, and includes searching for the entangled whale, even if the whale is not found, and further documentation of the gear or entanglement. Entanglement reports were coded for entanglement response, then coded to determine if the entanglement was removed. Possible outcomes of entanglement response are: full removal of gear, partial removal of gear, no gear removed, and self-release (whale freed itself). By summarizing the information using this methodology, we were able to evaluate the information for important characteristics and identify underlying trends in entanglement reporting to help improve understanding of the whale entanglement issue on the U.S. West Coast.

Results

Summary of Historical Whale Entanglement Data from U.S. West Coast

There were 521 large whale entanglements reported along the U.S. West Coast between 1982 and 2017. Most of the reports (498; 96%) came from opportunistic sightings of entangled whales from members of the public on the water or observed from shore, trained marine mammal disentanglement response and stranding networks, and other sources such as U.S. Coast Guard and other law enforcement or marine science organizations. The remaining reports were received from NMFS fishery observer reports (23; 4%) and commercial fishermen self-reporting through the MMPA Marine Mammal Authorization Program (2; <1%). The 521 large whale entanglement reports included: 8 blue whales, 7 fin whales, 240 gray whales, 188 humpback whales, 2 killer whales, 6 minke whales, 14 sperm whales, and 56 unidentified whales (Table 2).

Confirmed reports - Of the 521 total whale entanglement reports along the U.S. West Coast between 1982 and 2017, 83% of the reports (434) were determined by the Review Team to be confirmed entanglements. The 434 confirmed reports included: 211 gray whales; 167 humpback whales, 14 sperm whales, 7 blue whales, 7 fin whales, 6 minke whales, 2 killer whales and 20 unidentified whales (Table 2). There were 369 confirmed reports from California, 29 from Washington, 27 from Oregon, 5 from Mexico, and 4 from Canada (Figure 2). NMFS is able to confirm the majority of entanglement reports. The confirmation rate of entanglement reports per year has remained relatively stable, on average, around 83%, throughout the study time frame, while ranging in any given year from 25% to 100% (Table 2).

Table 2 NMFS West Coast Region's whale entanglement records; all (All) records and confirmed (C) records, by whale species, and by year. California records are from 1982-2017, Oregon and Washington are from 1995 to 2017. %C is the percentage of all records that are confirmed and the %C averaged over all years is included in the Total row.

	Species																		
	Blue		Fin		Gray		Humpback		Killer		Minke		Sperm		Unidentitifed		Total		
Year	All	C	All	C	All	C	All	C	All	C	All	C	All	C	All	C	All	C	%C
1982	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	**1**	**1**	100%
1983	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	**1**	**1**	100%
1984	0	0	0	0	3	3	2	2	0	0	0	0	0	0	0	0	**5**	**5**	100%
1985	0	0	0	0	23	18	0	0	0	0	0	0	0	0	1	1	**24**	**19**	79%
1986	0	0	0	0	19	17	0	0	0	0	0	0	0	0	0	0	**19**	**17**	89%
1987	0	0	0	0	12	12	0	0	0	0	0	0	0	0	0	0	**12**	**12**	100%
1988	0	0	0	0	12	10	0	0	0	0	0	0	2	2	0	0	**14**	**12**	86%
1989	0	0	0	0	9	6	0	0	0	0	0	0	0	0	1	1	**10**	**7**	70%
1990	0	0	0	0	5	5	1	1	0	0	0	0	0	0	0	0	**6**	**6**	100%
1991	0	0	0	0	4	4	0	0	0	0	0	0	1	1	0	0	**5**	**5**	100%
1992	0	0	0	0	4	4	0	0	0	0	0	0	4	4	0	0	**8**	**8**	100%
1993	0	0	0	0	1	1	1	1	0	0	0	0	3	3	0	0	**5**	**5**	100%
1994	0	0	0	0	4	4	1	1	0	0	2	2	0	0	1	1	**8**	**8**	100%
1995	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	**4**	**4**	100%
1996	0	0	0	0	6	6	0	0	0	0	1	1	1	1	1	0	**9**	**8**	89%
1997	0	0	0	0	6	4	1	1	0	0	0	0	0	0	2	2	**9**	**7**	78%
1998	0	0	0	0	5	5	2	2	0	0	0	0	1	1	0	0	**8**	**8**	100%
1999	0	0	1	1	7	7	3	3	0	0	1	1	0	0	0	0	**12**	**12**	100%
2000	0	0	0	0	6	6	4	3	0	0	0	0	0	0	0	0	**10**	**9**	90%
2001	0	0	0	0	0	0	3	1	0	0	0	0	0	0	1	0	**4**	**1**	25%
2002	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	**3**	**3**	100%
2003	0	0	0	0	5	5	5	5	0	0	0	0	0	0	0	0	**10**	**10**	100%
2004	0	0	0	0	7	7	3	3	0	0	0	0	0	0	2	0	**12**	**10**	83%
2005	0	0	0	0	6	6	3	3	0	0	0	0	0	0	1	1	**10**	**10**	100%
2006	0	0	1	1	4	3	5	4	0	0	0	0	0	0	2	0	**12**	**8**	67%
2007	0	0	0	0	5	5	4	4	0	0	0	0	0	0	5	2	**14**	**11**	79%
2008	0	0	0	0	0	0	6	4	0	0	0	0	0	0	3	2	**9**	**6**	67%
2009	0	0	2	2	4	4	2	2	0	0	0	0	0	0	2	0	**10**	**8**	80%
2010	0	0	0	0	6	6	8	7	0	0	1	1	2	2	4	0	**21**	**16**	76%
2011	0	0	1	1	2	2	6	5	0	0	1	1	0	0	2	0	**12**	**9**	75%
2012	0	0	0	0	13	11	4	3	0	0	0	0	0	0	1	0	**18**	**14**	78%
2013	0	0	0	0	14	10	0	0	0	0	0	0	0	0	1	1	**15**	**11**	73%
2014	0	0	0	0	7	6	17	16	0	0	0	0	0	0	4	1	**28**	**23**	82%
2015	1	1	2	2	12	10	34	31	1	1	0	0	0	0	11	8	**61**	**53**	87%
2016	4	3	0	0	3	3	53	48	1	1	0	0	0	0	9	0	**70**	**55**	79%
2017	3	3	0	0	17	12	20	17	0	0	0	0	0	0	2	0	**42**	**32**	76%
Total	8	7	7	7	240	211	188	167	2	2	6	6	14	14	56	20	**521**	**434**	83%

Summary of Whale Entanglements

All Whale Species

A total of 521 whale entanglements, 434 confirmed, along the U.S. West Coast have been reported from 1982-2017, but the number of reports of entangled whales received by NMFS each

year has varied. The highest number of entanglement reports received during a single year was 70 in 2016, of which, 55 were confirmed. The annual average of total entanglement reports received by NMFS from 1982-2017 was 14, with an average of 12 confirmed entanglement reports per year.

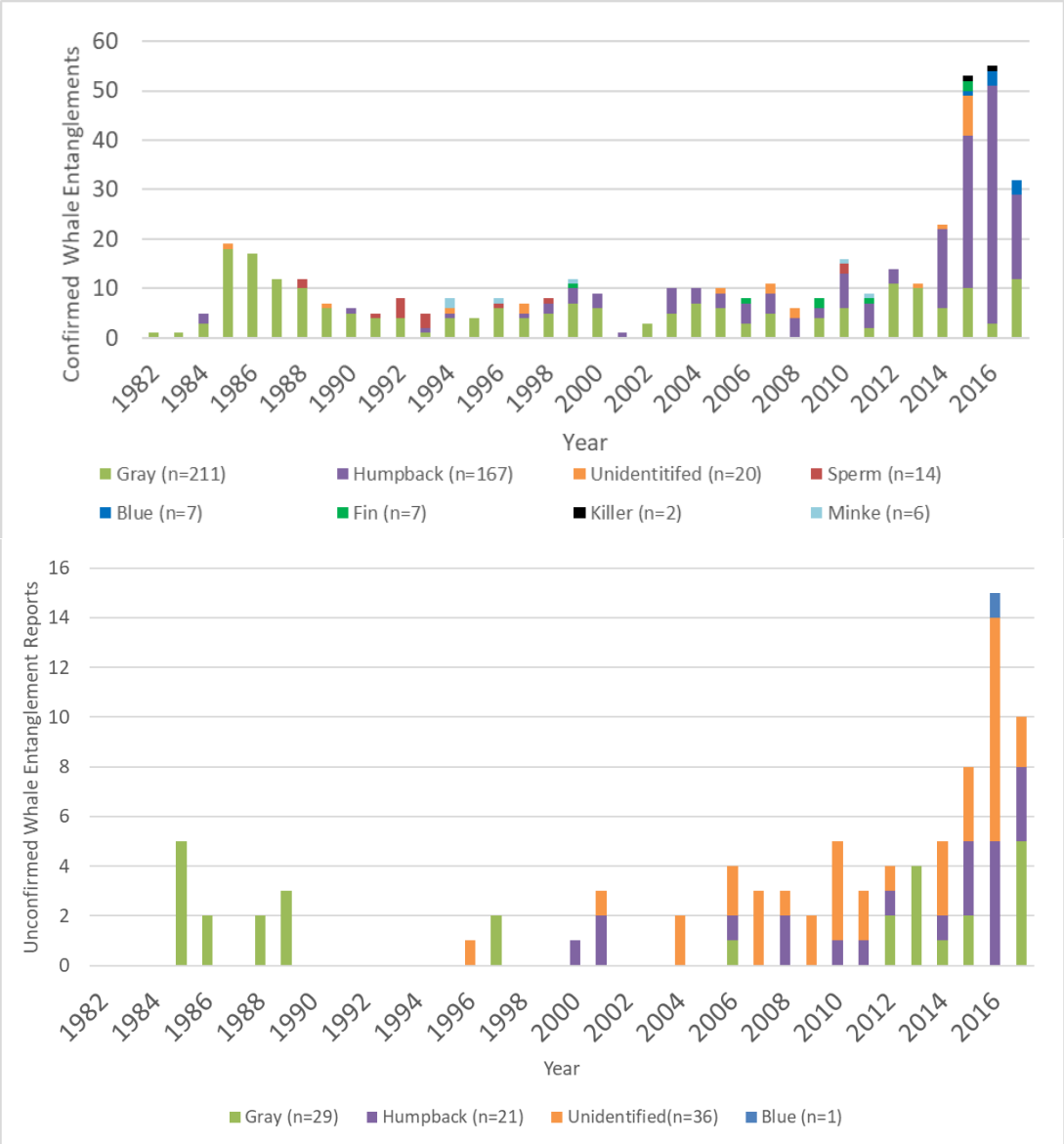

Figure 2 Top: Confirmed whale entanglement reports by year, by whale species; 1982-2017 (n=434). Bottom: Unconfirmed whale entanglement reports by year, by whale species; 1982-2017 (n=87). Each bar represents the reporting year, color coded sections on the bar represent the number of reports by whale species for that year.[4]

[4] For example, in 2016, there were 55 confirmed entanglements reported; 3 blue, 3 gray, 48 humpback, and 1 killer whale. There were 15 unconfirmed entanglements reported in 2016; 1 blue whale, 5 humpback whales and 9 unidentified whales.

Seven whale species (blue, fin, gray, humpback, killer, minke, and sperm whales)[5] have been reported as entangled along the U.S. West Coast since 1982. Of the 434 confirmed whale entanglement records from 1982-2017 (Figure 2), the two most common species reported entangled were gray whales (211; 49% of confirmed reports) and humpback whales (167; 38% of confirmed reports). The other whale species had the following number of confirmed reports, over the 35-year time-span: sperm whales (14; 3%), blue whales (7; 2%), fin whales (7; 1%), minke whales (6; 1%), and killer whales (2; <1%). Approximately 5% (21) of confirmed entanglement reports could not be identified to species because the report was lacking sufficient information or documentation to support an identification.

The geographic location of entanglement reports has spanned the entire area off the U.S. West Coast, with reports of entanglements with gear originating from the U.S. West Coast and bordering countries of Canada and Mexico. The highest concentrations of entanglement reports have been made in central and southern California, near areas of higher human populations including San Francisco, Los Angeles, Monterey, and San Diego, which have active waterfronts with high concentrations of boating, shipping, fishing, and other maritime activities (Figure 3). The majority of confirmed whale entanglement reports have originated from California (85%; 369), with 7% (29) from Washington, and 6% (27) from Oregon, and 1% from Mexico (5) and Canada (4) (Figure 3; Appendix 2). Within California, the region with the most confirmed entanglements was southern California (209), central California was the second highest (135), and northern California had the least number of confirmed entanglements (26) (Figure 3). There has been a recent increase in the number of confirmed whale entanglements reported in central California since 2014, and especially in 2016 (Figure 3).[6] The recent increased and variable levels of entanglement reporting likely reflect a variety of dynamic factors, including changes in the abundance and distribution of whales and their prey, changes in environmental conditions, shifting patterns in fishing and other human activities, and increased public reporting.

[5] In this report, we do not assign or assume entanglements of any particular whale species belong to any specific stock as defined under the MMPA or species listing under the ESA. More information on stock assignments of entangled whales and other marine mammals can be found in the SARs published annually by NMFS http://www.nmfs.noaa.gov/pr/sars/species.htm

[6] In this review, we focus primarily on the confirmed entanglement records for illustration of patterns and variation in the temporal, spatial, etc., attributes of entanglement reports received by NMFS. Due to the uncertain nature of unconfirmed reports and limited information they typically contain, the quality and confidence in that information is considered low. However, in general, the overall pattern in the distribution and timing of unconfirmed entanglement reports follows along the same patterns as confirmed reports, at a correspondingly lower scale given that confirmed reports constitute 83% of all reports received.

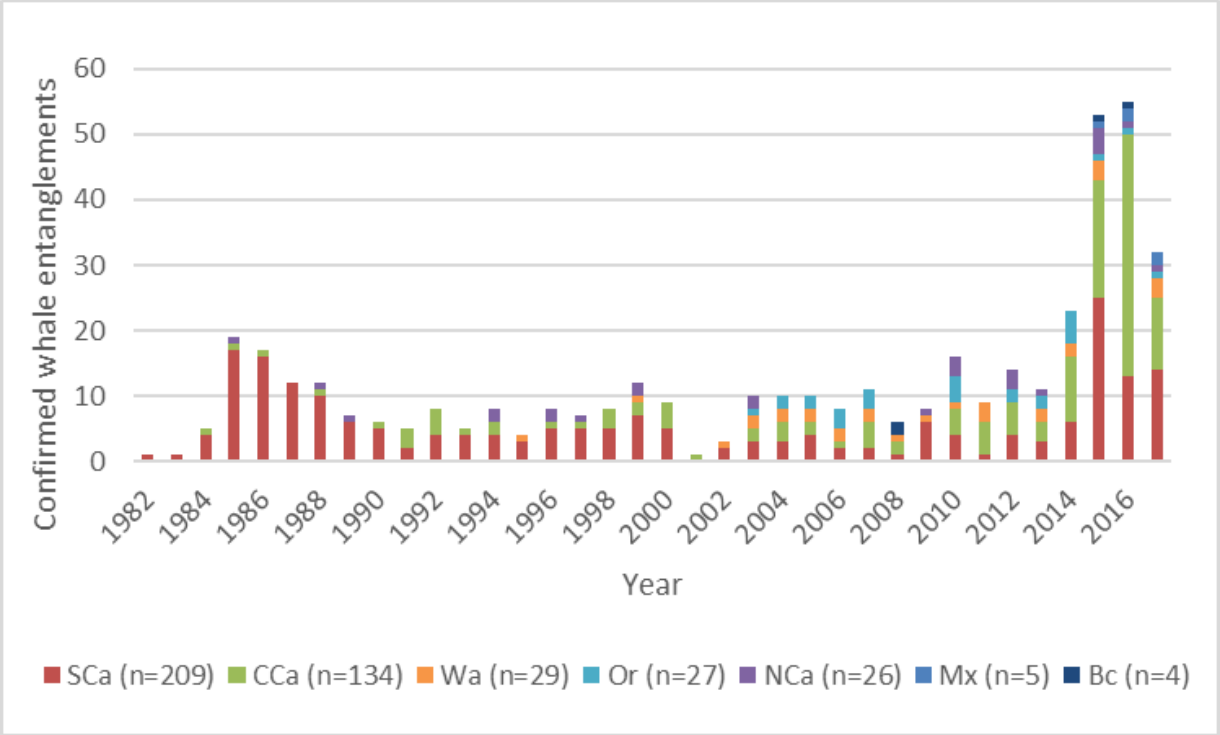

Figure 3 Confirmed whale entanglement reports by region and by year, 1982-2017 (n=434); SCa Southern California, CCa= Central California, Wa= Washington, Or= Oregon, NCa= Northern California, Mx= Mexico, Bc= British Columbia

Reports of large whale entanglements along the U.S. West Coast have been increasing considerably relative to the long term average since 2010 (Figure 2). Entanglement reports have been received in every month of the year, with a trend showing that the highest numbers of entanglements are reported during the months of March and April (Figure 4). These months represent the northern migration of gray whales along the U.S. West Coast, as well as early presence of humpback whales coming to feed.

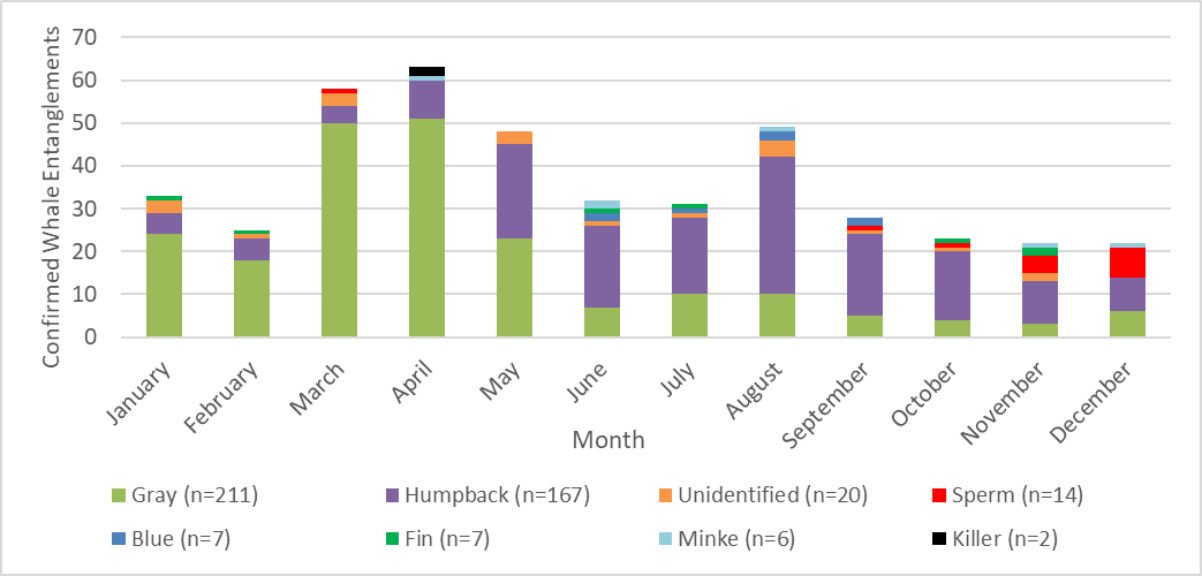

Figure 4 Confirmed whale entanglement reports by month, by whale species; 1982-2017 (n=434). Each bar represents a month of data, summed from 1982-2017, color coded sections represent the number of reports by whale species during the month.

Gray Whales

A total of 240 reports of entangled gray whales were received between 1982 and 2017, with 211 reports confirmed. Gray whales have been reported as entangled as early as 1982, with an average of 6 confirmed entanglement reports per year, and maximum of 18 which occurred in 1985. There was a significant increase of entanglements reported from 1985 to 1988 and more recently starting in 2012 (Figure 5, Appendix 2). Changes in gillnet fishing regulations helped address the 1980's increase which was primarily gray whales entangled with gillnets. The more recent increase has been associated with a mix of fisheries and unknown gear types.

Reports of entangled gray whales have been most common during the winter and spring, with the most entanglements reported in March (63 total, 50 confirmed) and April (56 total, 51 confirmed; Appendix 2). This period encompasses the peak of the northbound gray whale migration and when animals are closest to shore. Gray whales were also reported as entangled during the timing of the southbound migration, December through February, but in lower numbers. Confirmed entangled gray whales are primarily detected in southern California (SCa, 142). Entangled gray whales have also been reported in central California (CCa, 22), and northern California (NCa, 14). Beginning in 2003, there have also been reports of entangled gray whales from Oregon (16), and Washington (17) (Figure 4).

Groups of gray whales observed feeding between northern California and northern Vancouver Island (regional codes: NCa, Or, Wa, and Bc) outside of the typical migration period between June 1 and November 30 each year are known as the Pacific Coast Feeding Group (PCFG[7]; IWC

[7] US domestic policy defines the PCFG as gray whales observed between 1 June and 30 November from Northern California through Northern British Columbia (recognized as the Pacific Coast Feeding Aggregation by the U.S.).

2011). Between 1982 and 2017, 17 of the 41 (42%) entanglements reported between June 1 and November 30, where reported within the PCFG area[8] (Appendix 2).

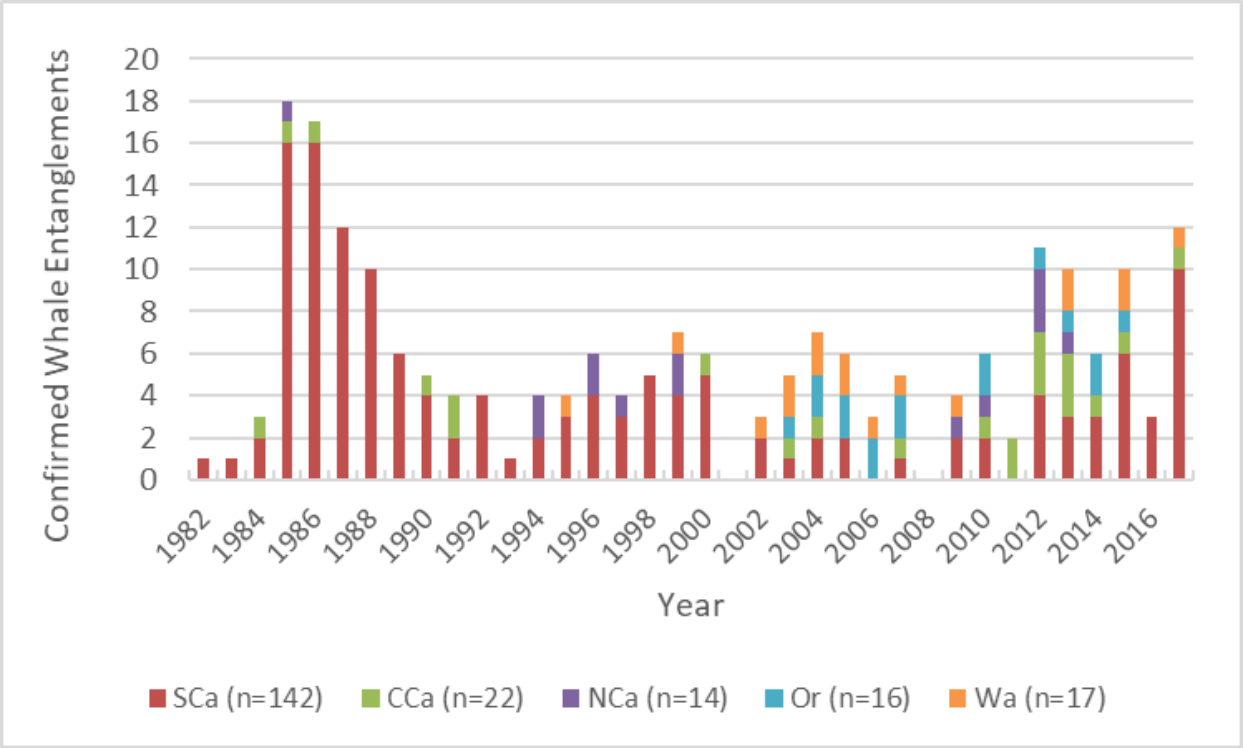

Figure 5 Confirmed gray whale entanglements by year and report region; 1982-2017 (n=211); SCa= Southern California, CCa= Central California, NCa= Northern California, Or= Oregon, Wa= Washington

The IWC has refined this definition to a new working definition: PCFG whales are gray whales observed between 1 June and 30 November from 41°N to 52°N in two or more years.

[8] This includes entanglement report locations from NCa, Or, and Wa in Appendix 2.

Gillnets were the most commonly confirmed gear type associated with gray whale entanglements (Figures 5 and 6). Gillnet entanglements (Nt, Gn, and Dgn) were more frequently reported in the 1980s, especially during the pulse of entanglements in 1985-1987 (Appendix 2). After increased gillnet fisheries regulations in the late 1990s, gray whale entanglements have been more commonly associated with trap/pot fisheries (Dcc, Rc, and Lb; Figure 5). Entangling gear type is known for 123 (58%) of the confirmed gray whale entanglement reports (Figure 6).

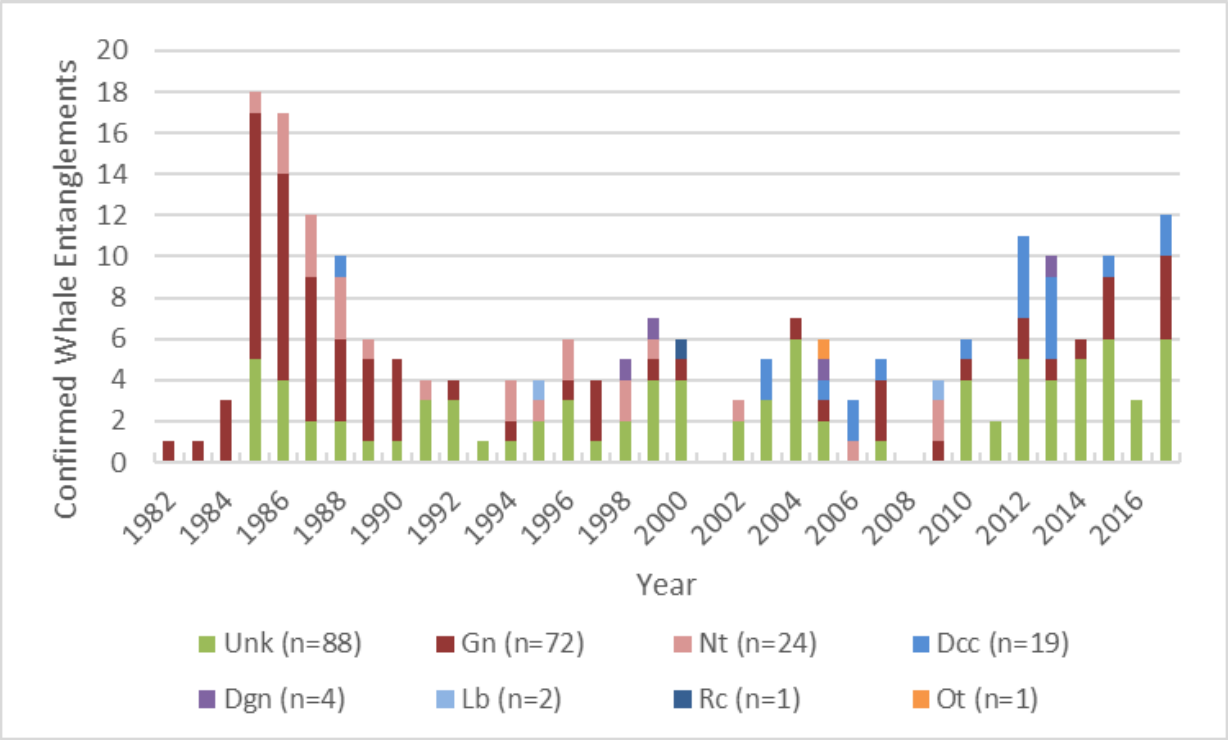

Figure 6 Confirmed gray whale entanglement reports by entangling gear type and by year; 1982-2017 (n=211); Unk= Unknown, Gn= Gillnet, Nt= Netting, Dcc= Dungeness crab commercial, Dgn= Drift gillnet, Lb= Lobster, Rc= Rock crab, Ot= Other

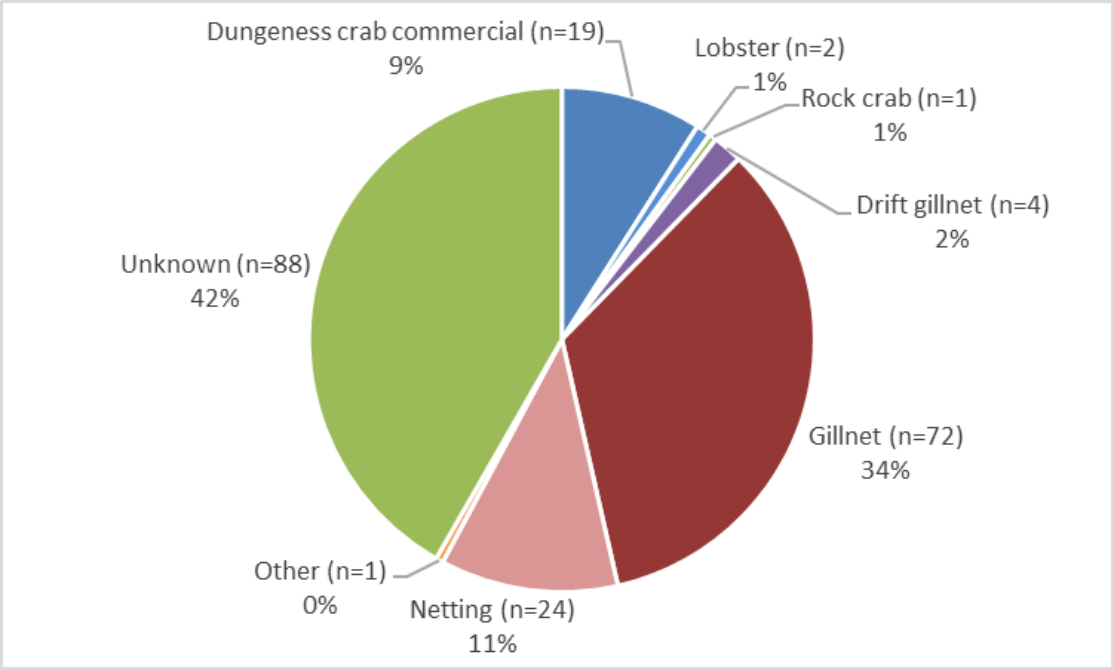

Figure 7 Confirmed gray whale entanglement reports by gear type; 1982-2017 (n=211)

Humpback Whales

A total of 188 entangled humpback whales were reported between 1982 and 2017 with 167 (89%) reports confirmed. Humpback whale entanglement reports have generally been increasing in frequency since 2000, with a sharp increase in the years 2014 to 2017, reaching a record high of 53 entanglements reported in 2016, of which 48 (91%) were confirmed (Figure 8, Appendix 2).

Entangled humpback whales have been reported across the U.S. West Coast and from Los Cabos, Mexico to British Columbia, Canada (as well as areas outside the scope of this report including Alaska). Humpback whales are primarily first detected and confirmed as entangled in central California, CCa, 90, (54%), with 66 (73%) reported between 2014 to 2017. Reports most frequently came from Monterey, within the central California area. There have also been humpback whale entanglements reported in southern California SCa (40), northern California NCa (9), Oregon (9), Washington (10), Mexico (5) and British Columbia (4) (Figure 8, Appendix 2).

Reports of entangled humpback whales have been most common during the late spring and summer, with most entanglements reported in August (35 total, 32 confirmed) and in May (26 total, 22 confirmed) (Figure 4, Appendix 2). Reports from Mexico were received in November, December, January, and March, which coincides with their migration between the summer feeding grounds and winter breeding grounds.

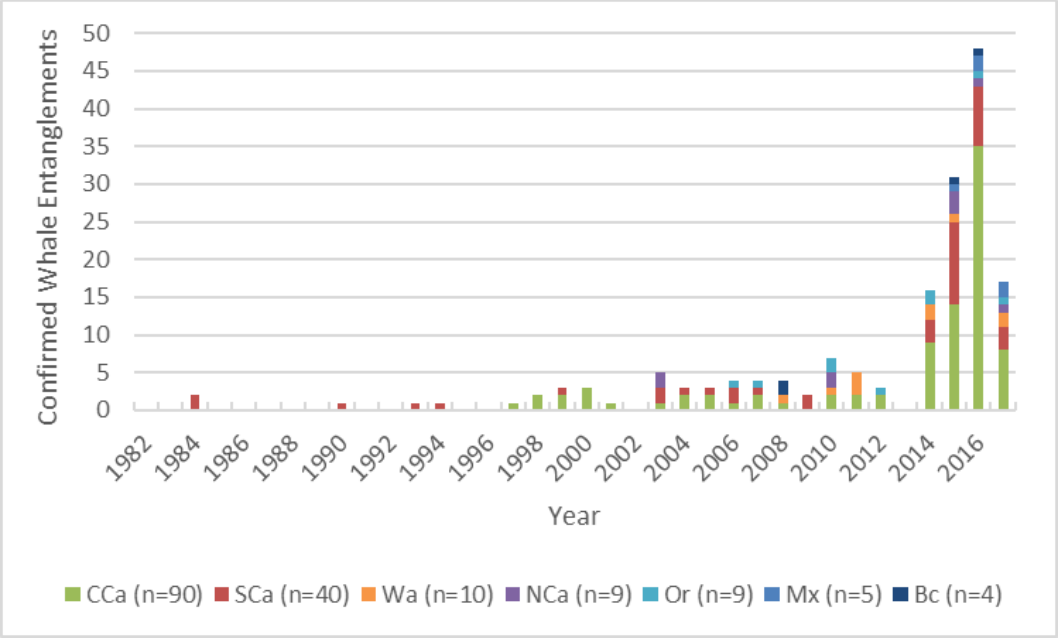

Figure 8 Confirmed humpback whale entanglement reports by year and by reporting region; 1982-2017 (n=167); CCa= Central California, SCa= Southern California, Wa= Washington, NCa= Northern California, Or= Oregon, Mx= Mexico, Bc= British Columbia

Entangling gear type was identified for 91 (55%) confirmed humpback whale entanglement cases (Figures 9 and 10). When entangling gear type is known, humpback whales are most often reported as entangled in pot gear 67 (73%) with the majority confirmed as commercial Dungeness crab, 48 (53%) (Figures 9 and 10). Other confirmed pot gear types associated with humpback whale entanglements are presented in Figure 10.

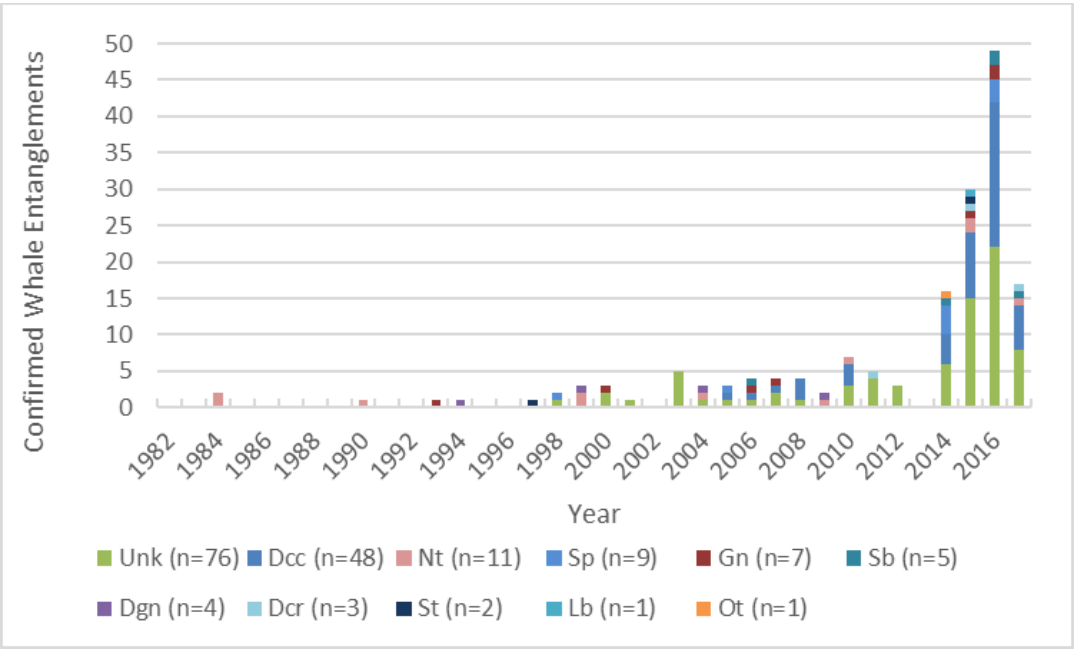

Figure 9 Confirmed humpback whale entanglement reports by entangling gear type and by year; 1982-2017 (n=167); Unk= Unknown, Dcc= Dungeness crab commercial, Nt= Netting,

Sp= Spot prawn, Gn= Gillnet, Sb= Sablefish pot, Dgn= Drift gillnet, Dcr= Dungeness crab recreational, St= Salmon troll, Lb= lobster, Ot= Other

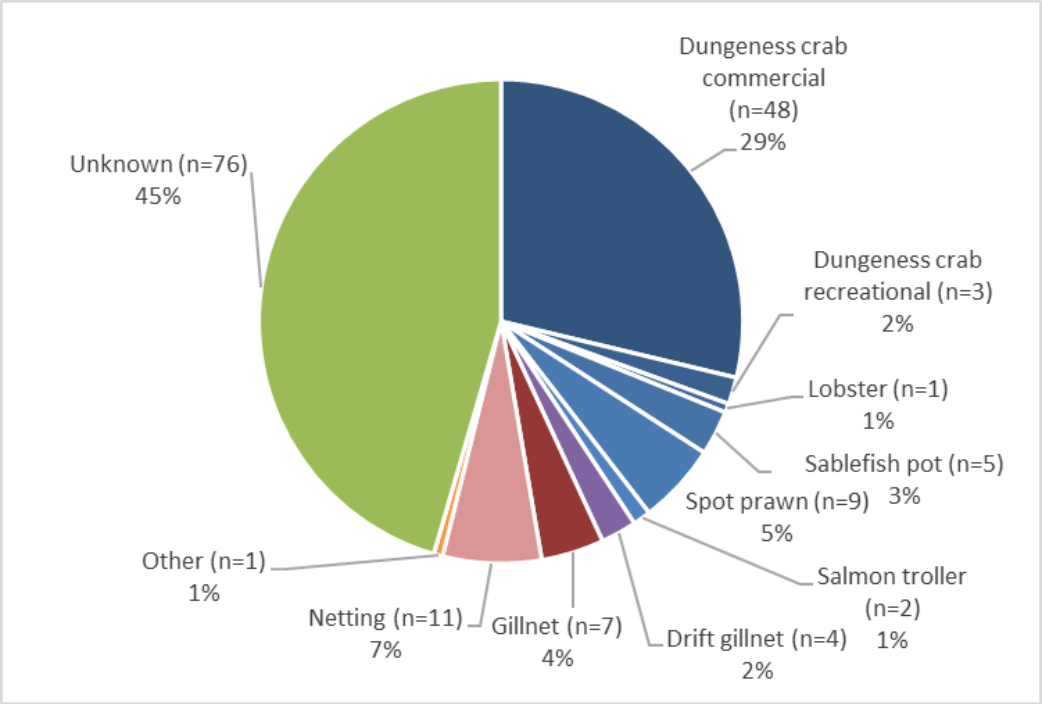

Figure 10 Confirmed humpback whale entanglement reports by entangling gear type; 1982-2017 (n=167)

Unidentified Whales

A total of 56 reports of entangled whales where the species was unidentified were received between 1982 and 2017, with 20 reports confirmed. Unidentified whales have been reported entangled throughout the U.S. West Coast during all months of the year except December (Appendix 2). The month with the highest total number of entangled unidentified whales reported has been May (10 total, 3 confirmed), and August (9 total, 4 confirmed). A recent paper by Carretta (2018) outlined a modeling approach to classify entanglements without species identification as a way to reduce the negative bias associated with ignoring unidentified entangled whales in species risk assessments. This paper indicated that the majority of unidentified entangled whales would likely be humpback and gray whales, based on three important predictor variables from his model: day of the year, entanglement type, and latitude; day of the year was the best predictor given the seasonality of whale presence off the U.S. West Coast.

Other Whale Species

Reports of several other species of whales as entangled were occasionally received by NMFS WCR, and are summarized below and in Appendix 2.

Blue whales (Bm) – Seven blue whale entanglements have been confirmed by the NMFS WCR and one other blue whale was reported as entangled but not confirmed due to lack of information. An entangled blue whale reported in September 2015 was the first confirmed entangled blue whale ever recorded off the U.S. West Coast. However, scars and wounds indicative of entanglements were found on blue whales prior to 2015 (Calambokidis, J., personal communication, August 8, 2012). This first case in 2015 was followed by four entangled blue whales in 2016 and three in 2017. Entangled blue whales have been reported during the summer, between June and September, and report locations have ranged from central California to southern California. Three of the confirmed blue whale cases were associated with commercial Dungeness crab fishing gear; the other five reports have an unknown entangling gear type.

Fin whale (Bp) – Seven fin whales were reported as entangled starting in 2009. All reports have unknown entangling gear types. Reports were received throughout the year and originated primarily from southern California, with one fin whale entanglement report coming from Washington.

Killer whales (Oo) - Two reported transient killer whale entanglements occurred in consecutive years in the month of April in 2015 and 2016, with one reported in northern California and one in central California. Both entanglements were associated with commercial Dungeness crab fishing gear.

Minke whales (Ba) – Seven minke whale entanglements were reported to the NMFS WCR, originating from southern California between April and December. Three of the confirmed minke whale entanglements are associated with drift gillnet, two were associated with netting, and two reports have an unknown entangling gear type.

Sperm whales (Pm) – Fourteen sperm whales were reported as entangled to the NMFS WCR. The reports originated from southern California, primarily between September and December. Ten entanglement reports were associated with drift gillnet and four entanglements were associated with gillnets.

Gear Associated with Whale Entanglements from the U.S. West Coast

NMFS strives to identify the type of gear that is reported or found entangled on whales. The difficulty of this task depends on the quality of information provided by documentation of the entanglement or in the best case, the gear that is removed, documented and analyzed by an entanglement response team. Often the entangling gear type gets classified as unknown in the absence of identifying information. In this section, we explore the information available in confirmed entanglement reports: gear type, fishery type, and their associated set locations. There is an inverse relationship between the number of reports and the information available about the

gear; few reports contain a high level of detail about the gear types, or their associated set locations (Figure 11).

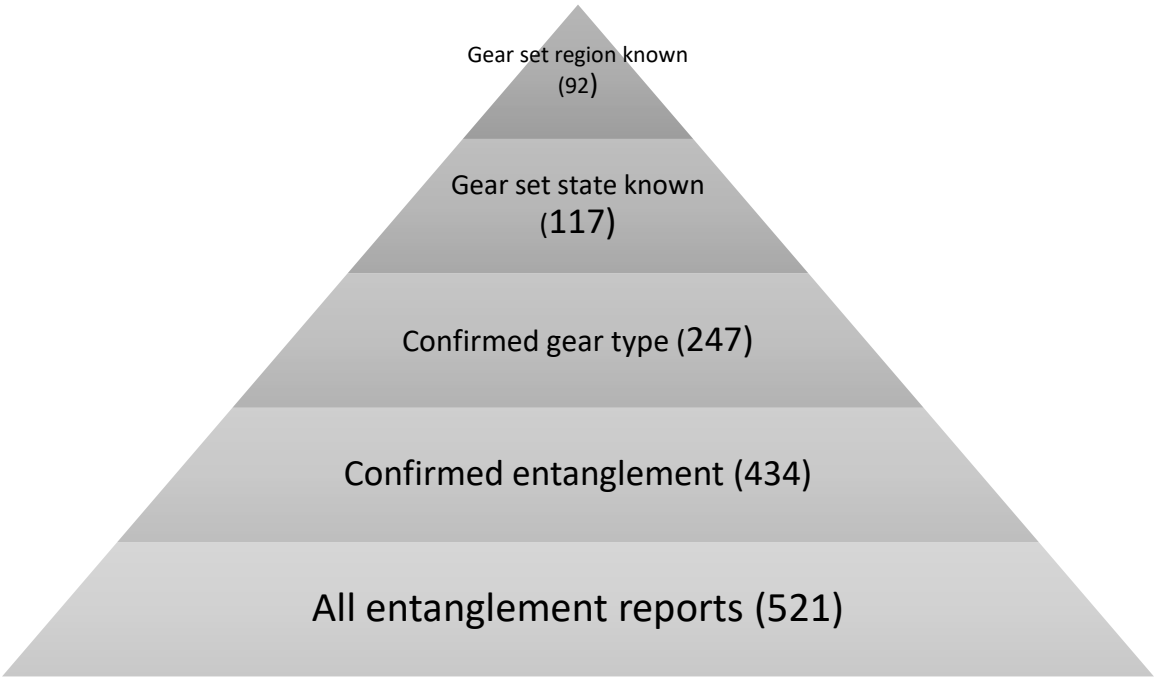

Figure 11 Data, Information, Knowledge, and Wisdom (DIKW) pyramid of the knowledge hierarchy for whale entanglements from the U.S. West Coast

The following gear types have been identified as involved in the entanglement of large whales off the U.S. West Coast between 1982 and 2017: netting, commercial and recreational fishing pots/traps, salmon troll line, steel cables, and a weather buoy. Most commonly across the entire historical record, gear from reported large whale entanglements cannot be identified and is attributed to gear from an unknown source (53%; 274). Unconfirmed entanglement reports do not have enough information to confirm a fishery therefor recorded as unknown entangling gear type. Entangling gear type was determined for 57% (247) of confirmed entanglement reports and gear source is unknown for 43% (187). Entanglement reports were comprised of the following confirmed gear types: various types of nets (34%; 148); pot/trap gear (22%; 95); hook and line gear (less than 1%; 2), and other types of gear (less than 1%; 2) (Figure 12). In general, there was a shift in the type of gear most commonly associated with large whale entanglements starting in 2000. From 1982-1999 (145 confirmed reports), nets were the type of gear primarily identified as associated with entanglement reports (71%; 103), with pot/trap gear rarely identified (2%; 3). Since 2000 (289 confirmed reports), pot/trap gear has become the most commonly identified gear type associated with entanglement reports (32%; 92), with entanglement reports associated with nets becoming rarer (16%; 45) (Figure 12). This change is likely due to a combination of gillnet fishing regulations changes and modified trap fishery gear marking, enabling easier identification. The percent of large whale entanglements reported with unknown gear has increased considerably from 26% (38) before the year 2000 to 52% (149) from 2000 to 2017 (Figure 12). This increase in reports of entanglements with unknown gear is likely related to changes in entangling gear types; netting is more easily identified as being “net” because of this

type of gear's distinguishing characteristics versus an entanglement in gear whose characteristics are less distinct, such as an entanglement where only line is visible.

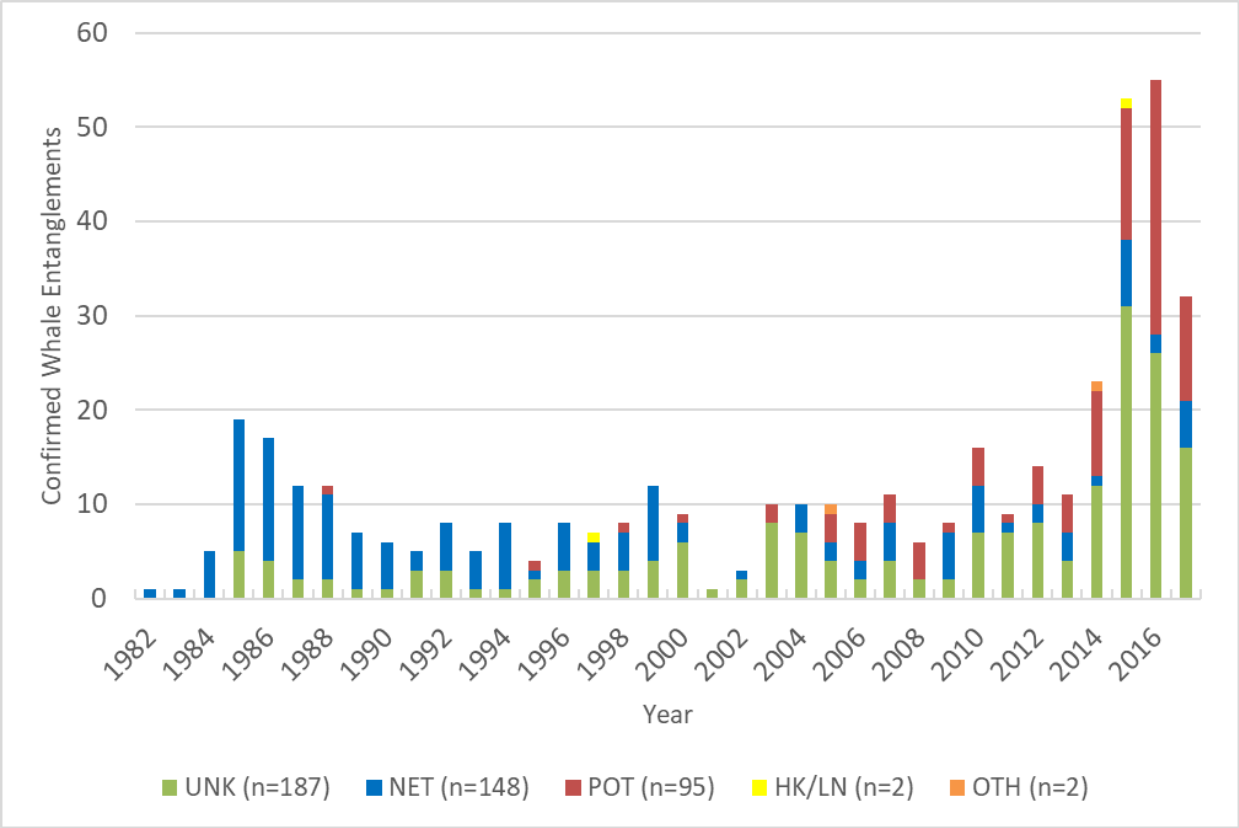

Figure 12 Confirmed entanglement reports from 1982-2017, by general gear type and year (n=434). Each bar represents a year; color coded sections represent the general gear type associated with the entanglement reports for that year. Unk= Unknown, NET= Netting, Gillnet, and Drift gillnet, POT= all trap/pot fisheries, HK/LN= Hook and line, OTH= Other

Identifying Gear to a Specific Fishery

From 1982-2017, NMFS was able to identify and confirm the specific fishery or gear in 57% of confirmed entanglement reports (247 of 434) (Figure 12; Table 3). Gillnet, typically not identified to a specific gillnet fishery, was confirmed in the highest number of reports (85). Netting, a more general category as identified by the reporting party or photos, was involved in 40 entanglement reports. Commercial large mesh drift gillnet was identified in 23 reports, primarily from commercial fishery observers. Of the entanglement reports confirmed to a specific fishery, the commercial Dungeness crab pot fishery had the highest number of reports (74) (Table 3). Other pot/trap fisheries confirmed to be involved with large whale entanglements are: commercial spot prawn (9), commercial sablefish (5), commercial lobster (3), recreational Dungeness crab (3) and commercial rock crab (1). For more information on U.S. West Coast fixed gear fisheries that may be involved with entanglements of whales, including some descriptions of spatial and temporal characteristics of these fisheries, see Saez et. al., 2013.

Table 3 Confirmed fishery type, by whale species, in confirmed entanglement records, 1982-2017 (n=247, 57% of confirmed records).

	Blue	Fin	Gray	Humpback	Killer	Minke	Sperm	Unidentified	**Total**
HK/LN- Salmon troll	0	0	0	2	0	0	0	0	**2**
NET- Drift gillnet	0	1	4	4	0	4	10	0	**23**
NET- Gillnet	0	0	72	7	0	0	4	2	**85**
NET- Netting	0	0	24	11	0	2	0	3	**40**
OTH- Weather buoy	0	0	0	1	0	0	0	0	**1**
OTH- Salmon cables	0	0	1	0	0	0	0	0	**1**
POT- Dungeness crab commercial	3	0	19	48	2	0	0	2	**74**
POT- Dungeness crab recreational	0	0	0	3	0	0	0	0	**3**
POT-Lobster	0	0	2	1	0	0	0	0	**3**
POT-Sablefish	0	0	0	5	0	0	0	0	**5**
POT-Spot prawn	0	0	0	9	0	0	0	0	**9**
POT-Rock crab	0	0	1	0	0	0	0	0	**1**
Total	3	1	123	91	2	6	14	7	**247**

Net fisheries

Netting (Nt): Netting was confirmed as the entangling gear type in 40 reports, involving 24 gray whales, 11 humpback whales, 2 minke whales, and 3 unidentified whales over the reporting period (1982-2017). The majority of the entanglement reports involving netting were reported prior to 2000 (70%; 28). Of these 40 entanglement reports involving netting, most of the whales were observed in (reported from) southern California (63%; 25), however the gear set location is unknown for all 40 reports.

Gillnets (Gn): Gillnet was confirmed as the entangling gear type in 85 reports. Gillnet entanglements were most commonly associated with gray whales (72), and have also entangled 7 humpback whales, 4 sperm whales, and 2 whales where the species was unidentified. Although gillnet entanglements were reported in recent years, 69% (59) were reported prior to the year 2000 (Figure 13). Three of the gillnet entanglements originated from Washington and two originated from southern California and one originated from Oregon. The majority (93%; 79) are from an unknown set region.

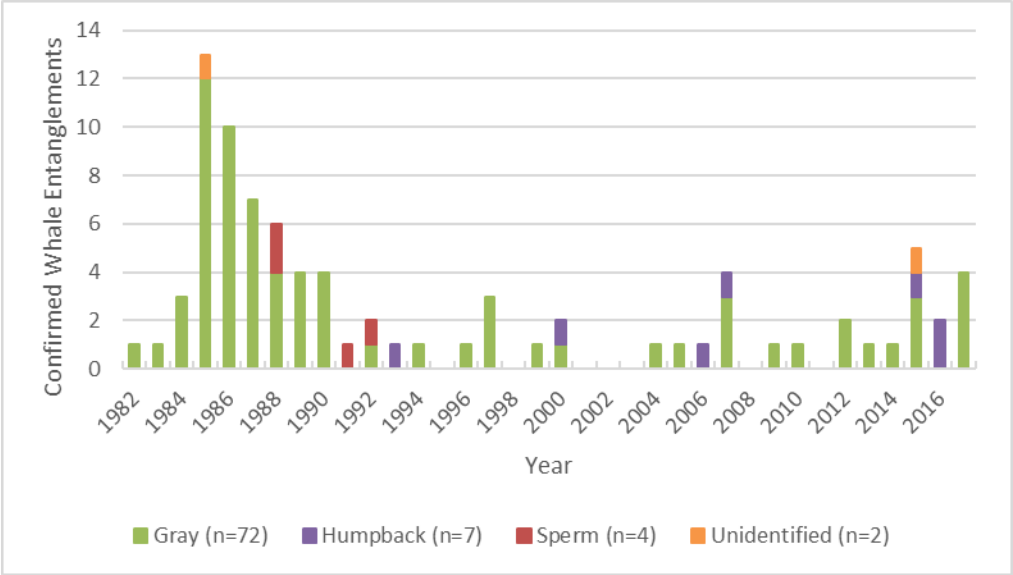

Figure 13 Confirmed gillnet whale entanglements by whale species and by year; 1982-2017 (n=85)

Drift gillnet (Dgn): Drift gillnet was confirmed as the entanglement source in 23 reports: 1 fin whale, 4 gray whales, 4 humpback whales, 4 minke whales, and 10 sperm whales. Drift gillnets were more frequently reported prior to the year 2000 (70%; 16). Drift gillnet entanglements occurred in southern California in 15 reports, central California in 7 reports, and an unknown location in one report. These reports are from commercial fishery observers, primarily, and fishermen self-reports.

Pot fisheries

Commercial Dungeness crab (Dcc): Commercially fished Dungeness crab gear was confirmed as the entanglement source in 74 whale entanglement reports from 1928 to 2017. Humpback whales are the whale species most frequently entangled with commercial Dungeness crab gear, 48 (65%). Three blue whales (4%), 19 gray whales (26%), 2 killer whales (3%), and 2 unidentified whales (3%) have also been reported as entangled (Figure 14). All but one commercial Dungeness crab entanglement occurred after the year 2000, with 64% (47) of entanglements reported from 2014-2017. Entanglement reports associated with commercial Dungeness crab have been recorded in every month of the year, with a peak between April through August (74%; 55) (Figure 15). The majority of commercial Dungeness crab entanglements occurred with gear set in California, 46 (62%), with 7 (10%) set in Oregon, 12 (16%) set in Washington, 1 (1%) with gear sets from both Oregon and Washington, 1 (1%) with gear sets from California and Oregon, and 7 (10%) from unknown set region (Table 4). Of the 46 California commercial Dungeness crab entanglements, 22 (48%) entanglements involved gear set in central California, CCa, and 24 (52%) had a California Dungeness crab trap tag but the set region is unknown, UCa (although the gear is only set in CCa or NCa based on the biological distribution of Dungeness crab). Commercial Dungeness crab season in California is open typically from mid-November to mid-August, depending on the management area.

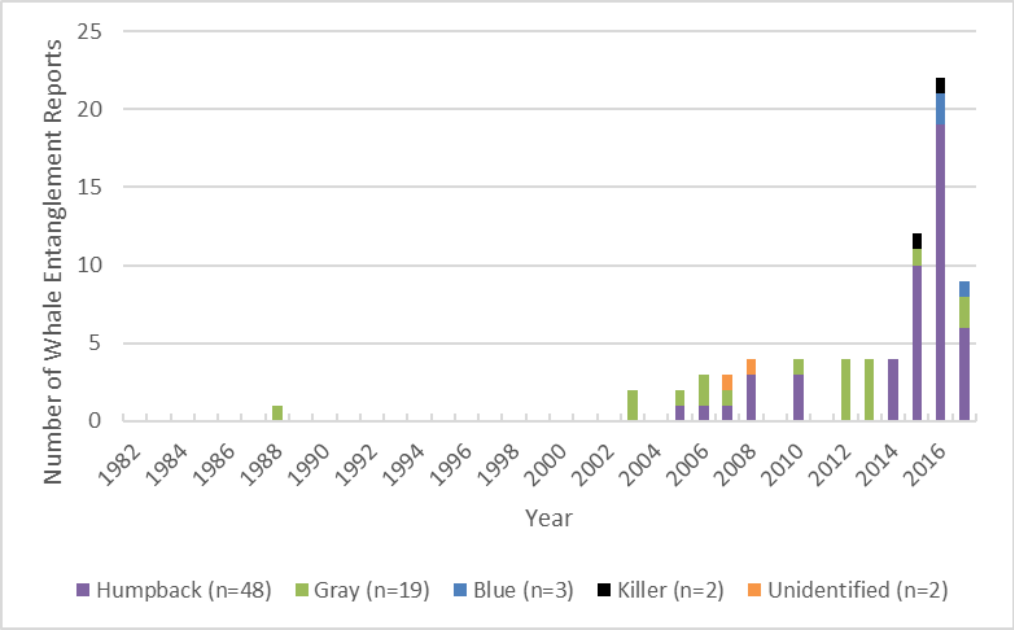

Figure 14 Confirmed whale entanglements in commercial Dungeness crab gear by whale species by year; 1982-2017 (n=74)

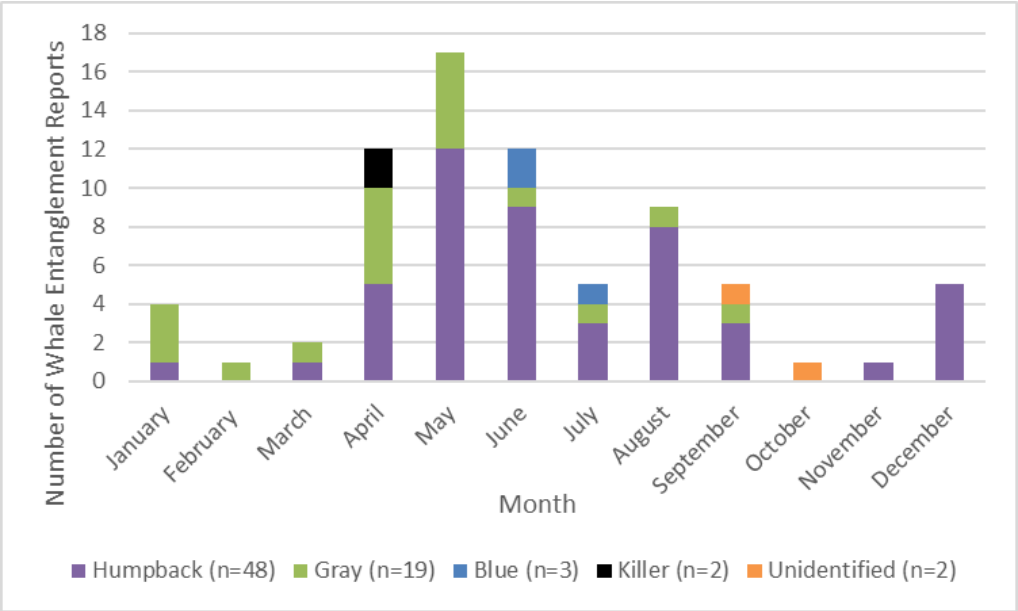

Figure 15 Confirmed whale entanglement reports in commercial Dungeness crab gear by month of the year and whale species; 1982-2017 (n=74)

Recreational Dungeness crab (Dcr): There have been three confirmed entanglements involving recreational Dungeness crab gear, all involving humpback whales. One entanglement was reported in August 2011 in Washington with Washington recreational gear. Another humpback whale was reported in February 2015 in CCa with recreational gear set in the same region within the same week. The third humpback whale was reported in

January 2017 in Mexico (Mx) with recreational crab gear originally set in CCa in November 2016 (Table 5).

Lobster (Lb): Three whales have been confirmed as entangled with lobster gear: 2 gray whales and 1 humpback whale. All entanglements involved gear set in SCa, based on the operational area of the fishery (Table 4). One gray whale entanglement was reported in March 1995 and another in January 2009. The humpback whale entanglement was reported in October 2015. Commercial lobster season in California is open from October to March. The timing and location of reported lobster entanglements align with "in-season" fishing, meaning the whale likely became entangled during the fishing season.

Sablefish (Sb): There have been five confirmed humpback whale entanglements involving sablefish pot gear. One of the entanglements was reported in August 2006. There were additional entanglements, one in October 2014, two in 2016 in April and May, and one in July 2017. In the 2014 report and one of the entanglements in 2016, the gear was originally set in Oregon, while the set location for the other entanglements are unknown (Table 4). The 2017 humpback whale entanglement involved a mooring line set during the operation of sablefish trap fishing, and the whale subsequently became entangled with multiple sets of coonstripe shrimp traps as well. Sablefish pot fishing is open year round, with a portion of the fishery limited to April 1 to October 31.

Spot prawn (Sp): There have been 9 confirmed humpback whale entanglements involving spot prawn trap gear. The first entanglement was reported in October 1998, then one in September 2005, four in 2014 - one in June and three in September, and three in 2016 - February, March and September. Five of the entanglements involved gear set in CCa, two from SCa, and the set location is unknown for the remaining two reports (Table 4). Commercial fishing for spot prawn is open from February to October in SCa and August to April in CCa. The timing and location of the entanglement reports align with "in-season" fishing for spot prawn meaning the whale likely became entangled during the fishing season.

Rock crab (Rc): One gray whale was confirmed as entangled with commercial rock crab trap gear set in SCa in April 2000 (Table 4).

Other entanglement types

Salmon troll (St): Two humpback whales have been entangled with salmon troll (hook/line) gear, one in central California in 1997 and one in southern California in 2015 (Table 4).

Weather buoy (Ot): In 2014, a humpback whale was confirmed as entangled with a Scripps Institute of Oceanography Coastal Data Information Program Waverider weather buoy off

central California.

Salmon cables (Ot): In 2005, a gray whale was reported as entangled with cables used with salmon fishing off Washington.

Table 4 Confirmed whale entanglement report where the fishery is confirmed, shown by set location and whale species; 1982-2017 (n=245)

Fishery	Set Region	Total Whales	Whale Species
Dcc (n=74)	CCa	22	2 blue whales, 1 gray whale, 1 killer whale, 18 humpback whales
	UCa	24	1 blue whale, 7 gray whale, 1 killer whale, 15 humpback whales
	UCa/Or	1	1 gray whale
	Or	7	4 gray whales, 3 humpback whales
	Or/Wa	1	1 humpback whale
	Wa	12	5 gray whales, 7 humpback whales
	Un	7	1 gray whale, 4 humpback whales, 2 unidentified whales
Dcr (n=3)	CCa	2	2 humpback whales
	Wa	1	1 humpback whale
Dgn (n=23)	CCa	7	1 minke whale, 6 sperm whales
	SCa	15	1 fin whales, 4 gray whales, 4 humpback whales, 2 minke whales, 4 sperm whales
	Un	1	1 minke whale
Gn (n=85)	SCa	2	2 gray whales
	Wa	3	3 gray whales
	Or	1	1 gray whale
	Un	79	66 gray whales, 7 humpback whales, 4 sperm whales, 2 unidentified whales
Lb (n=3)	SCa	3	2 gray whales, 1 humpback whale
Nt (n=40)	SCa	1	1 gray whale
	Un	39	23 gray whales, 11 humpback whales, 2 minke whales, 2 unidentified whale
Rc (n=1)	SCa	1	1 gray whale
Sb (n=5)	Or	2	2 humpback whales
	NCa	1	1 humpback whale
	Un	2	2 humpback whales
Sp (n=9)	CCa	4	4 humpback whales
	SCa	2	2 humpback whales
	UCa	1	1 humpback whale
	Un	2	2 humpback whale
St (n=2)	CCa	1	1 humpback whale
	Un	1	1 humpback whale

There were 117 records where we know the State where the gear was set and assume that is where the whale became entangled; 88 from California, 1 from California and Oregon (1 whale entangled with 2 sets of gear), 10 from Oregon, 1 from Oregon and Washington (1 whale entangled with 2 sets of gear), and 17 from Washington (Figure 9). Within California, 38 were from central California (CCa), 24 were from southern California (SCa), 1 was from northern California (NCa) and 25 were from an unknown location within California (UCa). The unknown locations were all associated with the California commercial Dungeness crab fishery and were likely set in either central or northern California based on where the fishery operates.

There were 2 "other" entanglements where entanglement locations were known. The first confirmed entanglement was a humpback whale entangled with a weather buoy in central California. The initial location was confirmed as the same as the gear set/entanglement location since the whale was anchored in place to the weather buoy. The other confirmed entanglement was a gray whale entangled with cables associated with salmon fishing in Washington. Again, the entanglement was confirmed to have occurred in the same place it was reported from since the whale was anchored in place. The whale subsequently self-released from the cables.

There were 92 records where the gear set region was known (Figure 11, top of pyramid). Specific set information may be available, but fishermen can set gear in a range of areas and it is difficult to identify specific location of gear, therefore for the purposes of the paper, these were coded to the regional level (Figure 1). Of the 92 records were gear set region was known, there were 73 records where the gear set region (and presumably the location of the entanglement) was the same as the region where the whale entanglement was reported (Table 5). Central California region had the highest number of these types of entanglement reports (31) of which 16 were associated with CA commercial Dungeness crab entanglements. There were 24 entanglement reports where the gear set location and entanglement report both occurred in southern California, of which 15 were associated with drift gillnet fisheries.

Table 5 Whale entanglement reports where the whale entanglement location and report location were the same; 1982-2017 (n=73)

Region	Fishery	Total Whales	Whale Species
SCa (n=24)	Dgn	15	1 fin whale, 4 gray whales, 4 humpback whales, 2 minke whales, 4 sperm whales
	Gn	2	2 gray whales
	Lb	3	2 gray whales, 1 humpback whale
	Nt	1	1 gray whale
	Rc	1	1 gray whale
	Sp	2	2 humpback whales
CCa (n= 31)	Dcc	16	1 gray whale, 14 humpback whale, 1 killer whale
	Dcr	1	1 humpback whale
	Dgn	7	1 minke whale, 6 sperm whales
	Sp	5	5 humpback whales
	St	1	1 humpback whale
	Ot	1	1 humpback whale
NCa (n=1)	Sb	1	1 humpback whale
Or (n=7)	Dcc	4	3 gray whales, 1 humpback whale *(gear from Or and Wa)
	Gn	1	1 gray whale
	Sb	2	2 humpback whales
Wa (n=10)	Dcc	5	3 gray whales, 2 humpback whales
	Dcr	1	1 humpback whale
	Gn	3	3 gray whales
	Ot	1	1 gray whale

There were 19 whale entanglement reports where the gear set region (presumably where the entanglement occurred) was different from the region where the entanglement was reported, indicating that the whale carried the gear into another region (Table 6). In addition, there were 25 whale entanglement reports where the gear was set in an unknown region in California (UCa), of which, one whale was reported as entangled in another state and two were reported in another country. These three records are included in Table 6 with an asterisk*. The longest distances between confirmed gear set location and reporting location was associated with commercial Dungeness crab gear and carried by humpback whales from California south to Mexico, and north to British Columbia, Canada. Dungeness crab traps are the only gear type that have been confirmed on a whale first reported entangled in a different location than where the gear was originally set.

Table 6 Whale entanglement reports where the whale entanglement location and report location were different; 1982-2017 (n=21)

Report Region	Set Region	Fishery	Total Whales	Whale Species
Mx (n=5)	Wa	Dcc	1	1 humpback whale
	CCa	Dcc	1	1 humpback whale
	UCa*	Dcc	2	2 humpback whales
	CCa	Dcr	1	1 humpback whale
SCa (n=7)	Wa	Dcc	2	1 gray whale, 1 humpback whale
	Or	Dcc	1	1 humpback whale
	CCa	Dcc	4	2 blue whales, 2 humpback whales
CCa (n=2)	Or	Dcc	1	1 humpback whale
	UCa/Or	Dcc	1	1 gray whale
NCa (n=1)	Or	Dcc	1	1 gray whale
Or (n=1)	Or/Wa	Dcc	1	1 humpback whale
	UCa*	Dcc	1	1 gray whale
	Wa	Dcc	1	1 gray whale
Wa (n=1)	Or	Dcc	1	1 humpback whale
Bc (n=4)	CCa	Dcc	1	1 humpback whale
	Wa	Dcc	3	3 humpback whales

*Unknown California set region. One reported as entangled in another state and two reported in another country.

Entanglement Response

From 1982 to 2017, a total of 442 live free-swimming or anchored entangled whales from the U.S. West Coast were reported to NMFS MMHSRP. In addition, 79 dead whales were reported as entangled, 77 confirmed, which did not warrant an entanglement response team. All entanglement reports, confirmed and unconfirmed are included in the entanglement response section because entanglement response is often an important part of confirming an entanglement. Dead whales are documented by MMHSN partners and necropsied if feasible.

The entanglement response network's goals during responses are to:

1) ensure human safety;
2) ensure whale safety;
3) remove all or portions of the life-threatening portions of entangling gear if possible;
4) document the configuration of the entanglement on the whale, entangling gear, marks or pigmentation unique to the individual whale, the body condition of the whale, the whale's behavior, and the actions of the response team for debrief and training (Mattila et. al., 2007).

Entanglement response was initiated for 39% (172) of the entangled live whales that were reported. Many responses ended with either full (29%; 49) or partial (10%; 32) disentanglement. Entangled whales were not successfully located/relocated by the disentanglement team or the team was unsuccessful in removing any gear in 47% (81) of the response efforts to whale

entanglement reports (Table 7). Self-releases, where the animal was able to free itself with no human intervention, were observed and reported in 20 of all of the entanglement cases, of which 10 self-releases were recorded without a formal entanglement response. The ultimate fate of reported entangled whales, whether completely or partially disentangled or released from gear, or not disentangled at all, is not known in most of the entanglement cases reported. However, in 2015, the NMFS WCR office received photos where a fully disentangled whale was resighted and photographed three weeks later, healing from the entanglement injuries. In another case, a gray whale was fully disentangled from the entangling gear in August 2012, but later died and washed ashore (80 FR 50599; Carretta et. al., 2014). There are likely more cases where entangled whales have been sighted pre- and post- entanglement, but review of the many photo databases in the area is not complete.

Every effort is made to respond to whales that are reported as entangled. Whale entanglement responses have been initiated for all seven whale species reported as entangled off the U.S. West Coast. The knowledge gained from entanglement response efforts contributes to a greater understanding of whale entanglements off the U.S. West Coast. Entangling gear has been either fully or partially removed from gray whales (48), humpback whales (30), and one minke whale (Table 7). Self-releases were documented with 1 blue whale, 6 gray whales, 9 humpback whales, 1 killer whale, and 3 unidentified whales. Out of the 172 responses initiated for entanglement reports, the success rate of fishery identification was 63% (109 cases), compared to entanglement reports without a response (n=349 cases), where the success rate of fishery ID was only 40% (138 cases). The documentation collected during entanglement response is invaluable in gaining an understanding of entanglements towards preventative solutions.

Table 7 Outcome of entanglement, response, and number of dead sightings by whale species; 1982-2017 (n=521, all entanglements reported to NMFS)

Species	Full	Partial	Self-release	Response, No gear removed	No response, no gear removed	Dead	Total
Blue whale	0	1	1	1	5	0	**8**
Fin whale	0	0	0	1	4	2	**7**
Gray whale	29	19	6	33	99	54	**240**
Humpback whale	19	12	9	40	99	9	**188**
Killer whale	0	0	1	0	0	1	**2**
Minke whale	1	0	0	0	3	2	**6**
Sperm whale	0	0	0	0	7	7	**14**
Unidentified whale	0	0	3	6	43	4	**56**
Total	**49**	**32**	**20**	**81**	**260**	**79**	**521**

Dead entangled gray whales account for 22% (54) of all gray whale entanglement reports, and were most often associated with net fisheries 11% (27), and 3% attributed to commercial Dungeness crab gear (6). There was one dead entangled gray whale that was unconfirmed. Dead humpback whales accounted for 5% (9) of all humpback whale entanglement reports and were most often associated with commercial Dungeness crab gear 3% (5), and netting 1% (2). There

was also a humpback whale death attributed to the sablefish pot fishery. All fin whale, minke whale, and sperm whale entanglement deaths were attributed to net fisheries. There was one dead entangled whale where the species could not be identified.

Entanglement outcomes, as documented by the original reporting party or through an entanglement response, have varied according to fishery or gear type. Of the 247 reports where entangling gear or fishery was confirmed, commercial Dungeness crab gear was associated with entanglements that had the highest number of releases (full, partial, and self-releases) with 36, representing a 49% success rate for responses to entanglements with this gear (Table 8). The majority (21) of the 35 commercial Dungeness crab gear releases were associated with humpback whales. The next highest number of releases was associated with gillnet, 23, representing an 27% success rate with all releases involving gray whales. Netting (Dgn, Gn, and Nt) had the highest number of deaths attributed or associated with entanglements, with gillnet identified with 20 dead entangled whales, netting associated with 11 dead whales, and drift gillnet associated with 9 dead whales. There were 25 dead whales entangled with an unknown gear type.

Table 8 Outcome of entanglement response and number of dead sightings (no response) by fishery; 1982-2017 (n=521)

Fishery	Full	Partial	Self-release	% release	Response, no gear removed	No response, no gear removed	Dead	Total
Dcc	17	9	10	49%	16	10	12	74
Dcr	1	0	0	33%	0	2	0	3
Dgn	1	0	0	4%	13	0	9	23
Gn	8	12	3	27%	16	26	20	85
Lb	3	0	0	100%	0	0	0	3
Nt	0	3	0	8%	1	25	11	40
Ot	1	0	1	100%	0	0	0	2
Rc	0	0	0	0%	0	0	1	1
Sb	3	1	0	80%	0	0	1	5
Sp	3	2	1	67%	2	1	0	9
St	0	0	0	0%	0	2	0	2
Un	12	5	5	8%	44	183	25	274
Total	**49**	**31**	**19**		**81**	**260**	**79**	**521**

Discussion

This report represents the first comprehensive review of U.S West Coast large whale entanglement records collected from 1982-2017. This review has provided a summary of the whale entanglements by region, by gear type and fishery, and the outcomes of entanglement responses. This information was collected by a variety of reporting parties and entanglement response network members and which was subsequently synthesized and organized into a single database by NMFS.

Data

Before analyzing these historic records, we determined that it would be necessary to normalize the data into a common format. A key step was to identify criteria to evaluate the information provided in the entanglement reports, so that it could be standardized and organized accurately into a database format. With standardization of the information, future entanglement reports can also be included in this same format and any user can be informed of the sources, accuracy, and completeness of the data.

Significant changes to the quality and quantity of entanglement reporting have occurred over time, which likely has influenced the accuracy and overall integrity of the information available from reports over the years. In addition, changes to the reporting process have made it easier to report entanglements, such as the introduction of a 24-hour reporting hotline, which likely has increased the number of reports received per year. Advances in technology and the ease of collecting photographic and video documentation of entanglements, along with the convenience of electronic communications to share information, has dramatically increased the extent of documentation that is ultimately provided to NMFS. The development of stranding programs, including an entanglement response network, along with increased awareness by the public of the issue and how to report entangled whales, has improved the consistency and quality of documentation over the years. Over time, the organization and evaluation of entanglement data received by NMFS also evolved, primarily in response to the increasing numbers of reported entanglements, leading to increased concern and priority of the entanglement issue on the U.S. West Coast in recent years. As a result, we urge users of this data to exercise careful consideration when comparing data across the entire time period, and to place increased confidence and emphasis on the reporting and evaluation of this information from more recent years, particularly over the last decade.

Trends in Reporting

Our results show increasing trends in the reporting of large whale entanglements in fishing gear (lost and active), marine debris, and other entangling sources off the U.S. West Coast. We have identified a number of factors likely contributing to the increasing trend in entanglement reports and any changes in underlying entanglement rates that may be occurring. These factors include changes in fishing effort and compliance with evolving fishery regulations, fluctuations in population sizes and distributions of large whales, e.g., humpback whales (Calambokidis and Barlow, 2017, Calambokidis et. al., 2017), changes in the oceanographic environment and ecosystem that may be influencing fishing activity and whale distribution closer to shore

(Santora, 2018), and changes in public awareness and stranding response capacity. To date, we have not developed a complete or specific understanding of exactly how these factors may be contributing individually or in concert with each other to overall entanglement reports, although recent investigations are beginning to provide insight into the relative contribution of certain factors (Feist et al., *in review*; Santora et al., 2020). Of particular interest to us are potential relationships between the dynamics of environmental conditions (e.g., water temperatures, prey availability) and the influence on whale distribution, in combination with corresponding dynamics of fishing effort, and the resulting dynamics of entanglement risks, which if better understood, could be used by managers or industry to predict entanglement risk and take proactive measures to mitigate those risks in a selective and focused manner. As a result, we urge the scientific community to continue to investigate these factors and develop tools and strategies that such information could inform, and for managers or members of the fishing industry to be flexible and open to using these tools and strategies, if successfully developed.

Underlying any assessment of entanglement data, we must acknowledge these results represent a minimum estimate of entanglement events. Whale entanglement reports are opportunistic and are likely biased towards areas of higher human populations and areas where whale species are closer to shore. Despite significant efforts to increase awareness, collaboration, and allocation of resources to document the outcomes of entanglements, an unknown number of entanglements, have not been documented or otherwise accounted for, particularly those resulting in mortality given the predominance of reports of live animals and that dead animals may be more likely to sink undetected rather than wash ashore or float. A minimum entanglement rate for humpback whales of 45% in California and Oregon and 33% in Washington and British Columbia was estimated based on a scar study conducted during the SPLASH (Structure of Populations, Levels of Abundance and Status of Humpback Whales in the North Pacific) cruise (Calambokidis et. al., 2008). Our results do not provide a determination on whether the number of entanglements have population level consequences, because the number of actual versus reported entanglements is unknown. However, the current level of entanglements observed and reported on the U.S. West Coast is similar to trends observed globally, indicating that serious injury and mortality from entanglements is a chronic problem facing whales worldwide (Read 2008; International Whaling Commission 2010; Clapham et. al., 1999; Fowler 1987; Read et. al., 2006; Wegner and Cartamil, 2012).

Any large whale along the U.S. West Coast whose spatial and temporal distribution overlaps with entangling gear is at risk of becoming entangled, as is evident in our records of confirmed entangled blue, fin, gray, humpback, minke, sperm, and killer whales. Confirmed entanglements have been reported in all months, suggesting that risks of entanglement remain persistent to some degree throughout the year, despite the varying distributions and migration patterns of different whales and varying fishing seasons. Baleen whales, in particular gray and humpback whales, are the most commonly reported entangled whale species along the U.S. West Coast, which is likely influenced by their proximity to shore (e.g., higher chance of detection), overlap with entangling gear for relatively long periods of time during their annual migrations, and increased population numbers, afforded to them by current legal protections against whaling.

Recognizing Bias

These data in this review may reflect some bias on confirmation of certain entangled whale species because of the animal's proximity to observers and areas where higher human populations exist, especially those with active waterfronts and good weather. For example, sperm whales are typically found farther offshore in deeper waters, when compared to migrating gray whales, which are typically observed closer to shore. The likelihood that there would be an opportunistic sighting of a sperm whale is low compared to a gray whale. There are likely other species of large whales that are not in our database that have been entangled, but have not been observed. For example, blue whales had never been observed entangled until 2015. Now, several blue whales have been observed as entangled each year between 2015 and 2017. Prior to 2015, it had been suspected that blue whales had been entangled based on the type of scars observed on individual animals, but it had never been confirmed and was therefore absent from the entanglement record up to that point.

Some of the challenges we encountered with our dataset included the range of information that was provided in initial reports. The NMFS observer program trains fishery observers in the identification of whale species that may be unintentionally caught in fishing gear. Reports of entangled animals from a fishery observer provides confirmation of the fishing gear, set location and timing, and the species. For example, the majority of sperm whale entanglements with the drift gillnet fishery in the historical record were collected through the NMFS observer program. Most trap fisheries are not observed or have very low percent coverage by the NMFS observer program, such as the sablefish fishery. The public, on the other hand, is often not trained as well in species identification and is typically not familiar with gear identification; therefore, the opportunistic reports from the public often require more time to follow-up to confirm the information provided in their report. We note, however, that these opportunistic reports constitute the majority of the historical record, demonstrating the value of increased outreach and awareness of entangled whale reporting to aid in evaluating entanglements along the U.S. West Coast.

Gray Whales

Gray whales and humpback whales were the two most common species reported entangled, which may be due to their foraging, social, and migratory behaviors. Gray whales likely feed and mate opportunistically along their migration, which may also make them susceptible to entanglement. When exploiting prey or bottom-feeding, gray whales typically dive down and roll to one side before they surface. During courtship behavior, they also roll, turning on their sides, and surfacing. This rolling behavior may increase their chances of getting a flipper or tail entangled if they pass through fishing gear. Gray whale entanglements were reported primarily in the winter and spring months, which generally reflects the annual migration of this species to and from breeding in Baja California and foraging grounds off the U.S. West Coast and Alaska[9]. The location of nearly half of the gray whale entanglements reported during the summer months in the geographic area of this analysis (CA/OR/WA) align with the areas identified as feeding

[9] Whale entanglement records from Alaska are not included in this report.

grounds for PCFG gray whales. PCFG gray whales are individuals that do not complete the typical gray whale migration, occupying waters between northern California and British Columbia during the summer months (IWC 2011). Comparison of whale entanglement photos, when available, to the catalog of PCFG photos held by Cascadia Research Institute, has confirmed these gray whales as belonging to the PCFG. PCFG gray whales may be more susceptible to entanglement due to their proximity to entangling gear and the duration that they are exposed to entangling gear (e.g., they are not transiting through, but instead are exploiting food resources near fishing areas) when compared to migrating gray whales.

From the mid-1980s to the early 1990s, the majority of reports were entangled gray whales in gillnets. The gillnet fishery operations overlapped with migration routes during this time, and also likely reflects a general increased awareness at that time about gray whales, so that the reporting party was able to provide an accurate species identification. However, it would be inaccurate to review the entanglement reports and state that *only* gray whales were entangled in netting, specifically gillnet, from the mid-1980s to early 1990s. It is very likely that other species could have become entangled in netting and whales could have been entangled in other types of gear, but were not observed or reported accurately. There has been a shift since 2000, where the number of gray whales entangled in netting has decreased. This is likely due to a decrease in fisheries using netting due to changes in fisheries regulations over this time. For example, the fishing effort in the CA large mesh drift gillnet fishery has declined significantly beginning in 2001 when a large time-area closure was put into place off central California and southern Oregon to protect leatherback sea turtles. It is also possible that the overlap of gray whale migratory routes with trap/pot fishing gear has increased to some degree, although this has not been confirmed. Gray whales migrate within a consistent distance from shore (DeAngelis et. al., 2013), and commercial Dungeness crab fishery managers (Juhasz, C., personal communication, August 1, 2018) indicate that there has been an increase in depth ranges utilized during fishing operations over time which could increase co-occurrence of gray whales and other whale species with crab gear to some degree. However, analyses are suggesting there has not been any dramatic changes in the overall spatio-temporal patterns of Dungeness crab fishing effort over the last decade beyond specific season openings changes in response to certain conditions such as domoic acid concerns (Feist et al., *in review*).

Humpback Whales

Humpback whales are especially prone to entanglement due to their morphology, including long pectoral flippers and the presence of rigid structures on their head and pectoral flippers, which can snag on entangling gear. In addition, foraging behavior, such as lunge or bubble net feeding (Wiley et. al., 2011), may also make humpback whales more susceptible to entanglement, as they may bottom side-roll and twist during foraging events as they pass through entangling gear in the water column. Humpback whales, especially younger animals have been observed playing in kelp, so there may be a natural curiosity in investigating lines, which may contribute to entanglements. When the entangling gear is identified, humpback whales are most often reported entangled in pot gear, primarily in Dungeness crab gear. In general, the Dungeness crab fishery's first and last day of the season is mid-November or early December, through the end of June, July or mid-September (depending on location along the coast), respectively. Higher numbers of humpback whale entanglements were reported during the spring through the fall, with most

reports recorded in the months of May and August. This time period overlaps with the Dungeness crab fishing season during the spring into the summer months (depending on location). Reports of entangled humpback whales have occurred throughout their range, but some of the highest numbers of entangled animals were observed in Central California (CCa), which includes areas where Dungeness crab gear and other fixed gear fisheries are fished relatively intensely. Humpback whales are also known to forage in areas closer to shore, in areas that overlap with a variety of fixed gear fisheries, and not just Dungeness crab gear.

Increasing abundance of humpback whales off the U.S. West Coast cannot solely explain the sharp increase in entanglements (Caretta et. al., 2018). Variability in humpback whale entanglement reports may also be explained by environmental changes that have shifted whale distributions resulting in an increase in the number of animals foraging in a specific area for longer durations (Santora et. al*.,* 2020.) Our results also show that reports were frequently made in Monterey Bay, CA, which is an area where large aggregations of humpback whales have been observed exploiting anchovies and sardines in recent years, bringing them very close to shore. In 2015-2016, there was a spike in the number of humpback whale entanglements in CCa, which coincided with a warm-water "blob" in the Pacific Ocean that led to lower levels of krill available for baleen whales and pushed other prey species, like sardines and anchovies, nearshore (Santora et. al., 2020). There was also a change in the fishing effort in CCa due to a domoic acid bloom that created a human health concern. This caused a delay in commercial and recreational Dungeness crab fishery openings that shifted large concentrations of fishing effort into the spring months that normally occur in the winter. This was coincident with the arrival of large numbers of humpback whales in the area, and likely contributed to relatively high rates of reporting of entangled whales during that year.

Reporting Location vs Entanglement Location

One of most challenging aspects of interpreting entanglement data is the fact that the location of where an entangled animal is observed and reported, does not necessarily reflect where and when the entanglement originated. For example, in 2017, an entangled humpback whale first reported off Mexico was entangled with gear associated with California Dungeness crab recreational gear. In addition, Dungeness crab gear set off Washington state was removed from another humpback whale in southern California in 2017. A similar relationship with the timing of the report and when the entanglement occurred also exists. We know that animals can remain entangled for many weeks, months, or even years, and still remain capable of traveling great distances (Van der Hoop et. al., 2017, Lyman et. al., 2007). This makes it difficult to assess when the entanglement actually occurred. Because of this, and since many of these species range across international borders, improving collaboration with countries like Mexico and Canada will aid in the tracking and evaluation of entanglements. However, our review of the historical record indicates that when known, approximately 79% of the gear involved in entanglements is set in a location that is within the same regional area where the report is made. This suggests that there is some relationship between the patterns of entanglement reporting and the origins of entanglements, at least at the regional level, in areas where entanglements are commonly reported. This could also suggest that entanglements may be detected and reported rather quickly or that the whales remain in the same location for a while, increasing their chances of getting entangled and reported from the same spot because they haven't moved.

In assessing the extent of entanglements along the U.S. West Coast, there is an unexpected absence of reports in the historical record in Northern California (NCa) for entanglements in Dungeness crab gear, particularly since the California Dungeness crab fishery only sets gear in CCa and NCa. Whales would certainly overlap with this gear in Del Norte, Humboldt, and Mendocino counties, so some level of entanglement risk exists. However, there are multiple factors that may explain why there is an absence in the historical record. These include some relative separation between the area of fishing effort compared to the distribution of whales and the location itself, as the coastline off of NCa typically has fewer "eyes on the water" compared to other areas, leading to fewer whale entanglement observations. Other likely potential explanations for lower reporting may include a lack of general awareness and knowledge of how or where to report entanglements, or the willingness to do so. These factors to some degree also contribute to the relatively lower rates of entanglement reports from Oregon and Washington.

Entanglement Timing and Fisheries Management

It is clear that using the seasonal patterns for whale presence and fishery effort, along with information that can be gleaned from entanglement reports regarding the origins of entanglements, would aid in any decision-making process to address this conservation concern. We do note that entanglements are occasionally reported with fishing gear during time periods outside of that fishery's fishing season. For example, the majority of entanglements in Dungeness crab gear (74%) were reported in April through August within or immediately adjacent to the fishing season but have been reported every month of the year outside of Dungeness crab fishing seasons. There are legitimate concerns about the entanglement risks posed by lost or derelict gear, although the ability to attribute entanglements to them is difficult to assess knowing that whales are capable of remaining entangled with gear for long periods of time. The first "official lost gear" entanglement was confirmed from a humpback whale reported in California in 2015 that was entangled in two different sets of Dungeness crab gear from Oregon from the 2011-2012 and 2012-2013 fishing seasons. In addition, there continues to be a large number of entanglements reported where the gear is unknown, and thus whether it was actively fished or lost at the time of entanglement is also unknown. All of these factors pose challenges when evaluating options to reduce the number of entanglements.

Fishery management regulations implemented during the time frame of this study have likely affected the patterns of gear types associated with entanglements, such as the decreasing use of gillnets in places like California. However, specific or overall trends in fishery effort have not been analyzed within this data review; therefore, we draw no specific conclusions on the causal effects that fishery management changes may have had on entanglement occurrence rates. However, we note that recent efforts are beginning to provide insight into how the recent dynamics of fishing effort may be related to current trends in entanglements (e.g., Feist et al., *in review*). Ultimately, we encourage the scientific community, managers, and the fishing industry to thoroughly investigate the patterns of fishing effort in recent years, including the distribution and intensity of that effort and any gear loss, in comparison to entanglement data and information on whale distributions and activity, to better understand how the dynamics of fishing effort may be influencing entanglement risks.

Identifying Unknowns in Entanglement Data

This review of our whale entanglement database highlights several categories of unknowns for large numbers of entanglements, particularly confirmation of gear type and the origins of entangling gear. Although there have been advancements in the collection, review, and analysis of entanglement data through the incorporation of digital images, improvements in gear marking are still needed in order to improve the ability to identify the origins of entanglements. For example, implementation of buoy tags in U.S. West Coast crab fisheries (Washington began in 2005, Oregon in 2006, and California in 2013) has been valuable in the review process to confirm gear type, but they are not used among all fixed gear fisheries on the U.S. West Coast. Any improved or enhanced marking of fixed fishing gear along the U.S. West Coast that may be developed should not impede fishing activities, but should be easily identifiable with the gear in hand or upon visual inspection of documentation so that in the event of an entanglement report, managers are provided with as much information as possible. Ideally, the gear (line, buoys, netting) would be marked in a manner that would indicate the state of origin and fishery type. The ultimate marking would allow for identification of the gear owner, enabling conversations with the fisherman to better understand how the gear was set up, where it was set, and timing of the entanglement. In response to this need, initiatives are underway in U.S. West Coast State-managed fisheries that include new requirements for improved and/or standardized marking of buoys (e.g., in California), registration of buoy color/patterns (e.g., Oregon), along with some initial line marking proposals (e.g., in Washington). In concert with improved gear marking, improved descriptions of the gear and how the animal is entangled (which may help rule out certain types of gear) are needed to accompany entanglement reports. Increased and dedicated outreach to people most likely to observe and report entanglements is needed as well as increased awareness and willingness to stand-by with an entangled whale to better support entanglement response teams who can document more effectively is needed.

Periodic reviews of entanglement data should be conducted to assess any changes in entanglement trends and/or in response to changes in fishing patterns, especially following fishery management changes that could affect spatial and temporal distributions of fishing gear. As a supplement to tracking entanglements reported, efforts to connect whale ID photo databases should be made to better track pre- and post-entanglement sightings of whales. This will lead to a better understanding of timing of entanglement (if the whale was seen gear-free before the entanglement report), long-term survivability/health of the animal post-entanglement response and potential population effects.

Within this review, we have aimed to present information crucial to evaluating future conservation recommendations to reduce risk to large whales and any decisions that can provide managers with some direction for modifying current management methods. During our review of the historical record, we explicitly defined protocols to provide a conservative assessment of large whale entanglements from 1982-2017. Even as the documentation and evaluation of entanglement reports continues to advance, a considerable amount of uncertainty remains and we have identified some of the key components, like identification of gear and related fishery, where there were unknowns and opportunities for improved data collection and analyses. We caution that the use of numerical results for management purposes should include consideration of the possible bias associated with these uncertainties discussed in this review. As data collection

continues to improve and new modeling methods becomes available, a temporally and spatially-explicit evaluation of entanglement risk, including incorporation of environmental and social-economic variables, should have significant management value by identifying the shortcomings of current management approaches, and priorities for implementing effective measures to reduce the occurrence of large whale entanglements.

Conclusion/Looking Forward

We have assessed 35 years of whale entanglement data on the U.S. West Coast, but we still do not have a solution to reduce entanglements. A collaborative effort between scientists, managers, fishermen, large whale entanglement response teams, and other stakeholders will be crucial to develop strategies to reduce entanglements. We hope that the data we have provided in this review will help inform those strategies.

To build on the foundation of work laid out in this review, future work is needed in the following areas:

1) Improve reporting to NMFS: increasing public awareness and understanding of the need for early and accurate reporting, expanding geographic reporting party coverage, support large whale entanglement response network to gain better documentation (e.g. photo identification, gear identification, injuries) and quality of information collected from each entanglement report;
2) Improve understanding of the ecological drivers affecting the distribution of whales and their risks of interaction with U.S. West Coast gear, and develop tools to assist with predicting distributions based on those drivers;
3) Improve understanding of the dynamics of the West Coast fixed gear fisheries, and develop tools to assist with monitoring/predicting those distributions;
4) Enhance understanding of how behavior of whales and different gear configurations may interact to increase/decrease chances of entanglements occurring;
5) Continue gear research and development of innovative ideas in collaboration with fishermen to reduce the number and/or severity of future entanglements, specifically for the U.S. West Coast; and
6) Continue and expand fishery gear marking initiatives based on evaluations of whale entanglement report data and success/failure of current marking schemes to identify the origins of entanglements.

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Appendix

Appendix 1 Definitions of key data fields summarized in the historical entanglement record review and used to assess patterns or trends in whale entanglement over time

Data Field	Description
CaseID Number	The initial identification number assigned to the case. The Case ID Number should be assigned by a NMFS Regional Stranding Coordinator. The format is as follows YYYYMMDDGs. Four digit year, two digit month, two digit day, followed by a two letter code for the scientific name, Genus species. Scientific name codes are: Ba=Minke, Bb=Sei, Bm=Blue, Bp=Fin, Er=Gray, Mn=Humpback, Oo=Killer, and Pm=Sperm and Uk=Unknown whale.
Species ID	Species identification (ID) initially relies on information provided by the reporting party. When the reporting party is able to provide photos or videos, this increases the Review Team's ability to confirm or later modify the initial species ID, as appropriate. For those reports where the entangled whale cannot be identified to species or the initial report is considered unreliable, it is recorded as unidentified in the database. In some cases, when the species ID was initially considered an "unidentified" whale by the reporting party, the Review Team was able to confirm the whale species from photos or videos associated with the report, or from a resight. The Review Team's decision-making process to confirm species ID is included in the record.
Date	The date of the first reported observation of the entangled whale. Any subsequent sightings or dates that actions took place (e.g., a disentanglement response) are also included in the database and listed by corresponding date. All information is recorded, but linked to the original Date of the first observation
Report Confirmation	A *confirmed* (C) entanglement report is an observation of a whale with human-made materials[10] (including rope, net, monofilament line, buoys, traps, hooks, or debris) attached to it. This observation is reported ultimately to NMFS WCR. A confirmed report does not need to contain all of the possible details that may be relevant to describing the entanglement (e.g., exact species of whale, location, type of gear, etc.). Criteria used to deem a report "confirmed", listed in increasing order of certainty (needs to meet at least one to qualify as "confirmed"): • Photos or video of the gear on the whale • NOAA staff has direct visual observation • The report came from a trusted source (trained or professional observer) • An experienced response entanglement network member or NMFS expert interviewed the reporting party, using non-leading questions. The information provided is detailed and specific enough to confirm entanglement. • Corroborated, independent, and multiple sources providing reports with detailed descriptions of the animal and the entanglement.
	An *unconfirmed* (U) entanglement report is an observation of a whale that may have been or is believed to have been entangled. This observation is reported ultimately to NMFS WCR; however, the information is insufficient to confirm the entanglement based on the evidence and documentation obtained from the reporting party. Criteria used to deem a report "unconfirmed": • No photos or video to provide evidence of gear entangling a whale (including only having photos of a whale that do not show any gear) • Report is from non-trusted source (untrained observer, general public) • Information could not be confirmed during follow-up interview or corroborated by subsequent reports • Presence of gear in the vicinity, but unable to determine if gear was actually attached to animal (e.g., whale logging near buoys, whale swimming/thrashing near fishing gear) • Vague, uncertain, or limited descriptions

[10] NMFS West Coast Regional office received reports of alive and dead whales with scars indicating previous entanglements; however, if no entangling gear was present, the reports were not included in this analysis.

Data Field	Description
	• 2nd- or 3rd- hand report and unable to conduct follow-up interviews
Reporting Source	Organization (for example, U.S. Coast Guard), Business (for example, XYZ Whale Watch), Public, Fishing Vessel (for example, XYZ Charters) or Other. This is used to evaluate level of confidence in the report.
Report Region Code	The location where the reporting party initially sighted the entangled whale. Location information includes a general location description; county; state; and, latitude/longitude, if provided. Colloquial names provided by the reporting parties were standardized by providing a known geographic designation in addition to the colloquial nomenclature. Codes for location are: Bc= Canada, Wa=Washington , Or= Oregon, NCa= Northern California (Del Norte, Humboldt, Mendocino counties), CCa= Central California (Sonoma to San Luis Obispo counties), SCa=Southern California (Santa Barbara to San Diego counties), UCa= Unknown California, Mx=Mexico, Uu= Unknown
County	County nearest the position where the entangled animal was first sighted. If offshore the county is determined by nearest landfall due east
State	State nearest the position where the entangled animal was first sighted.
Alive or Dead	This records if the entangled whale is initially reported as being alive or dead.
Entanglement Type	The identification of the entangling gear or the determination that the entangling gear came from a specific fishery relies on information and any documentation provided by the reporting party and/or responders to the NMFW WCR. This includes photographs, video, or the gear retrieved off the animal. Along the U.S. West Coast, certain fisheries have gear marking requirements that are put forth under State and Federal regulations, as well as other characteristics that may be identifiable (see Fixed Gear Guide; appendix in Saez et. al., 2013). NMFS works with State, Federal, tribal fishery managers, and other experts to identify and verify that the entangling gear is accurately assigned to a specific fishery. Because NMFS fishery observers are assigned to a specific fishery, any reports provided by them is assigned to that specific fishery. If a fisherman self-reports an entangled marine mammal, typically reported as bycatch, that report is assigned to the fisherman's specific fishery. Fishermen are required to self-report within 48 hours of returning to port, only if the marine mammal was injured or killed. If the entangling gear could not be identified or assigned to a specific fishery, it was assigned as unknown. For example, when the reporting party used only the term "line" to describe the entangling gear, the Review Team used a conservative approach and assigned the entangling gear as unknown, because it could be from a pot/trap, net, or other fishing source (e.g., mooring line). When netting was described/documented on a confirmed entanglement report, it was coded in general as a "Net" entanglement in the database. The Review Team determined that the likelihood for a reporting party to accurately identify netting as the correct entangling gear is higher due to its appearance than other types of gear. Reporting party gear type identification is often speculative (e.g. based solely on visible floats and/or line) and is categorized as unconfirmed unless there is additional conclusive information. All reports are ultimately categorized on a case-by-case basis when making these assessments.
Entanglement Fishery Code	The entangling material has been identified or described with enough information to characterize as fishery origin. Fisheries were coded as: Dcc= Dungeness crab commercial, Dcr= Dungeness crab recreational, Dgn= Drift gillnet, Gn= Gillnet, Lb= Lobster, Nt= Netting, Rc=Rock crab, Sb= Sablefish pot, St= Salmon troll, Sp= Spot prawn, Un= Unknown, Ot= Other (e.g.., cables, weather buoys)
Gear Set Location Code	The location where the gear was originally set. Specific locations typically require confirmation by either the fisherman who set the gear or from a NMFS Fishery Observer. General geographic information (e.g., state) can also be occasionally inferred using other available information such as the shape and color of any buoy tags (e.g., gear marking associated with a trap limit program, Saez et. al., 2013) observed on entangling gear. Gear set location information is often obtained during follow-up interviews with the owner of the entangling gear once it is identified. Gear set locations were coded as: Codes for gear set location are the same as report region codes.

Data Field	Description
Entanglement Response	Code for entanglement response are: Yes (Y), or No (N). Any attempt at intervention, including measures attempted by a trained disentanglement team[11], and includes searching for the entangled whale, even if the whale is not found. Entanglement reports of live free-swimming and/or anchored entangled whales are classified by the level of entanglement response effort. Classifications include: • whale not found after initial sighting; • whale is re-sighted (no additional entanglement evaluation is possible, so disentanglement efforts are not initiated); • stand-down (entanglement evaluated, but disentanglement efforts are not initiated for a variety of reasons); • partial release from gear (disentanglement effort is conducted by a trained team, some gear is removed, but some gear remains on animal after team's release efforts; gear can be removed either directly by trained response team or by animal itself or a combination); • full release from gear (disentanglement effort is conducted by trained team and all gear is removed from the animal); and whale self-release (entanglement response team is on-the-water and there is no intervention, but animal self-releases or trained observer reports the animal "throwing" the gear and self-releasing).
Entanglement Removed	Codes for entanglement removed are: F, SR-F, P, SR-P, N, Dead: The intervention resulted in successful entanglement removal (F), partial removal (P), or removal was unsuccessful (N). This could also include self-release cases (SR-F, self-release full; SR-P, self-release partial). If the animal was reported as dead, entanglement response was not necessary and was coded as dead.
Paper Code	Whale entanglement reports were coded and combined across key data fields: report location, entangling gear type/fishery, gear set location, and whale species. The first letter of each coded piece of information begins with a capital letter.

Appendix 2

See attached spreadsheet for NMFS WCR whale entanglement data

List of field names included:

CaseID, Common Name, Observation Date, Entanglement Confirmation, Reporting Source, Report Region Code, Report County, Report State, Alive or Dead, Entanglement Type, Entanglement Fishery Code, Gear Set Location Code, Entanglement Response, and Entanglement Removed.

[11] Due to the dangerous nature of responding to entangled large whales, responders go through extensive training to learn the proper techniques and protocols to ensure their safety and that of the animals. A permit held by NOAA's Marine Mammal Health and Stranding Response Program provides authorization for entanglement responders.