

Humpback whale (*Megaptera novaeangliae*) entanglements in commercial fishing gear
on the U.S. West Coast: Implications for management and stock structure under the
Marine Mammal Protection Act

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Abstract

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In 2015, humpback whales (*Megaptera novaeangliae*) on the U.S. West Coast were separated into three Distinct Population Segments (DPSs) under the Endangered Species Act, but have remained one stock under the Marine Mammal Protection Act. The mismatch between stock structure and DPS structure under these two different laws has created several management challenges, particularly in terms of assessing allowable levels of human-caused mortalities. Entanglement in commercial fishing gear presents a significant source of mortality and injury for humpback whales, and entanglement reports on the West Coast have significantly increased since 2014. I address some of the implications of a future change in stock structure to match the DPS structure by assessing 1) which DPSs are most likely to be affected by entanglements, examining differential levels of mortality and serious injury, and 2) examining reductions in mortality needed to achieve management goals. I find that under a revised stock structure consistent with DPS designations, current entanglement rates exceed allowable mortality levels for the endangered Central America population.

1. Introduction

1.1 Overview of whale entanglements

Entanglements of large whales in commercial fishing gear present serious conservation challenges, and have become a significant source of mortality and injury for large whales, particularly humpback whales (*Megaptera novaeangliae*) (NOAA Fisheries, 2018a). Entanglements can occur when whales swim through fixed-gear fisheries or become entangled in nets. The resultant entanglements can cause lacerations, infection, or drowning. Entanglements around or in the mouth can inhibit feeding and lead to starvation, while entanglements around the fluke can create drag and require the whale to expend extra energy while swimming (Moore et al., 2012). Whales can travel long distances with gear still attached to them, sometimes for months or even years at a time (van der Hoop et al., 2017).

1.2 Humpback whale background

Humpback whales are found in all of the world's ocean basins, and generally migrate between low latitude breeding grounds in winter to high latitude feeding grounds in summer. The estimated humpback whale population in the North Pacific is 21,000 (Barlow et al., 2011). Abundance estimates of humpback whales off the U.S. West Coast vary, with abundance off California and Oregon in 2014 estimated to be between 1,400 and 2,400, depending on the model and sampling period used (Carretta et al., 2019a; Calambokidis et al., 2017); the best estimate for population size in California and Oregon waters is 2,374 for 2011-2014 (Carretta et al., 2019a). For northern Washington and South British Columbia waters, abundance is estimated at 526 animals, based on sampling from 2013-2014 (Calambokidis et al., 2017). Combining the estimates for these two groups results in 2,900 animals for the entire California/Oregon/Washington stock (Carretta et al., 2019a).

1.3 Endangered Species Act Status Review of humpback whales

In 1970, humpback whales were listed as endangered under the Endangered Species Conservation Act (ESCA). When the Endangered Species Act (ESA) replaced the ESCA in 1973, the listing of humpback whales as endangered continued (The Endangered Species Act of 1973). An endangered species is defined as one which “is in danger of extinction throughout all or a significant portion of its range” while a

threatened species is one which is “likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range” (The Endangered Species Act of 1973). The global populations remained listed as endangered until the National Marine Fisheries Service (NMFS) published a Status Review of the species in 2015. This Status Review separated the species into 14 distinct population segments (DPSs) and de-listed certain populations with healthy abundances and lower extinction risk (see Figure 1).

A species is defined under the ESA as “any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature” (The Endangered Species Act of 1973, Section 3(16)). Furthermore, to be considered a DPS, a population must be “significant” to the taxon to which it belongs, and “discrete” from the remainder of the taxon (The Endangered Species Act of 1973). Discreteness means that the population is separated from other populations due to physical, ecological, or behavioral factors. If a population meets the discrete criteria, it then must be considered significant, meaning that it is genetically different from other populations, a loss of the population would result in a significant gap in the range of the taxon, or the population is in a location that is ecologically unique for the taxon (The Endangered Species Act of 1973). Genetic information, as well as information on distribution, were used to assess significance and discreteness for the 2015 Status Review. The 14 DPSs were named for their primary breeding locations. Whales from three of the 14 DPSs feed along the West Coast of the U.S. The Hawaii DPS is found mostly off the coast of Alaska, with a small portion found off of Washington and British Columbia. The Mexico DPS is found all along the West Coast, and Central America DPSs is found mostly off of California and Oregon, with a smaller percentage found off of Washington. The Central America DPS is listed as endangered and the Mexico DPS is listed as threatened under the ESA, while the Hawaii DPS is not listed under the ESA.

1.4 The Marine Mammal Protection Act

While the ESA manages species at the level of DPSs, the Marine Mammal Protection Act (MMPA) manages species at the stock level. Stocks involve groups that are independent demographically. The MMPA defines stock as “a group of marine

mammals of the same species or smaller taxa in a common spatial arrangement that interbreed when mature” (The Marine Mammal Protection Act of 1972). Stocks are management units rather than biological units, and are managed similar to fish stocks. One stock of humpback whales is recognized on the U.S. West Coast, known as the CA/OR/WA stock. There are two other stocks in the North Pacific—the Central North Pacific stock, which winters around the Hawaiian Islands and migrates to Alaska and Northern British Columbia in the summer months, and the Western North Pacific stock, which winters off Asia and migrates to Russia and the Bering Sea (Muto et al., 2018). The distribution of the Central North Pacific stock may partially overlap with that of the CA/OR/WA stock off the coasts of Washington and British Columbia, but they are still considered two distinct stocks (Clapham, 2009).

The MMPA uses a metric known as Potential Biological Removal (PBR) to track and measure levels of human-caused mortality for each stock. The MMPA defines PBR as “the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population” (The Marine Mammal Protection Act of 1972). These human-caused mortalities are assessed by NMFS in marine mammal stock assessments and are documented as mortality, serious injury, or non-serious injury. NMFS defines serious injury as “any injury that will likely result in mortality” (Carretta et al., 2019b). Non-serious injuries and serious injuries are distinguished through data on animal condition and injury severity (NMFS, 2012). Some injuries are classified as a prorated serious injury based on previous data of similar injuries and the resultant status of the whale (Carretta et al., 2019b). Each entanglement is assigned a value based on this injury assessment, with mortality or serious injury designated as 1, prorated serious injury designated as 0.75, and not serious injury designated as 0.

Another important metric of the MMPA that relates to human-caused mortalities is the List of Fisheries (LOF). As mandated under the MMPA, all commercial fisheries are classified according to their level of incidental marine mammal mortality and serious injury. Within the LOF, Tier 1 considers the total impact of all fisheries on a stock, while Tier 2 considers an individual fishery’s impact on a stock (NOAA, 2018b). Under Tier 2, specific fisheries are placed into one of three categories. Category I fisheries are those

with annual mortality and serious injury at 50% or more of the stock's PBR level. Category II fisheries sustain annual mortality and serious injury between 1% and 50% of PBR, and Category III fisheries are at 1% or less of PBR. However, if a stock sustains annual mortality and serious injury from all fisheries (Tier 1) that is 10% or less of PBR, all fisheries that interact with that stock are automatically Category III fisheries. Fisheries that are Category I or II may be subject to certain rules, such as the requirement to accommodate observers aboard their vessels, or compliance with a take reduction plan, which aims to reduce serious injury and mortality in the fishery to below PBR levels within six months (Marine Mammal Protection Act of 1972, Section 118).

1.5 Units to Conserve

Species, sub-species, DPSs, and stocks can all collectively be referred to as Units to Conserve (UTCs) (Reynolds, 2005). Conservation often attempts to draw categorical boundaries around organisms in order to protect them, and UTCs provide levels at which to manage.

Advances in the field of genetics have provided new tools to understand UTCs (Boyd, 2010). Marine mammal taxonomy has lagged behind taxonomy of terrestrial species due to accessibility issues. In the case of humpback whales, genetic data has shown that they exhibit a strong preference for high latitude feeding grounds, which results in strong mitochondrial differentiation among feeding grounds. Despite successes using DNA, genetic information cannot yet conclusively assign a whale to a specific DPS due to overlapping haplotype occurrences in mitochondrial DNA (Baker et al., 2013). Photo-identification is the only conclusive way to determine whether a whale is part of a specific DPS.

1.6 Research questions

The re-classification of humpback whales into multiple DPSs, while simultaneously recognizing only one stock on the U.S. West Coast, has led to several management challenges. Despite review of the stock structure of humpback whales by NMFS, no changes to their management have been made. Separation of species into smaller UTCs has important management implications, particularly with regard to levels of human-caused mortality. The fact that these DPSs are considered discrete and significant indicates that losing one population would result in consequences to the

species as a whole, such as a loss in range of the species or the loss of a population with unique characteristics. It is therefore important to accurately assess how human-caused mortalities are affecting specific populations.

Because human-caused mortality has such a large bearing on management, I chose to assess humpback whale stock structure through the lens of mortality and serious injury caused by fishery entanglements. I assessed the changes to management that could occur under a three-stock structure that coincides with the DPS structure on the U.S. West Coast. I did this by (1) assessing which DPSs are likely to be impacted by entanglements in commercial fishing gear, (2) determining the PBR level for each new stock, (3) comparing levels of mortality and serious injury for each stock to these PBR levels, and (4) determining the reductions needed in entanglements to stay below certain management targets pursuant to the MMPA including PBR and LOF. In addition, I analyzed general data about entanglements including gear type, fishery type, report location, origin location, and disentanglement success. These data were used to explore implications of a new stock structure on management of the species. By assessing the implications of a stock structure change preemptively, the goal of this study is to provide clarity on how this shift would influence management of entanglements at current and future levels.

2. Methods

Data used in this study were collected by NMFS and included confirmed sightings of humpback whale entanglements from 2007 to 2016 off the coasts of Washington, Oregon, and California. This included six cases of entanglements reported off of Mexico and Canada that were determined to be gear from U.S. West Coast fisheries. There were a total of 136 individual entanglement cases during this ten-year period. These represent confirmed humpback whale entanglements, meaning that enough information was provided by the reporting party to positively identify the species and determine that the entanglement was a result of fishing gear. Every year, approximately 15% of entanglements on the U.S. West Coast are deemed “unidentified whales,” and it is highly likely that a large portion of these represent additional humpback whale entanglements (Carretta, 2018). Data included mortality and serious injury designations for each whale,

as determined by NMFS for the Stock Assessment Reports (SARs). The data also included the following information for each entanglement: report location, interaction type (fishery), date of report, and a serious injury value (0, 0.75, or 1).

The descriptions and notes for each entanglement report were used to determine additional information that was added to the dataset for analysis. This information included disentanglement success, gear type (single trap, multiple trap, net, etc.), the location of entanglement origin based on fishery (when known), and the corresponding feeding area group the whale belonged to based on both the location of the entanglement report and the location of entanglement origin. Entanglement origin location refers to the location where the whale first became entangled, which is usually only identified if the gear is retrieved or well-documented with clear photographs. Because whales can travel great distances with gear attached (e.g. from Washington to southern California), the location where the entanglement is reported is not necessarily the same as where it originated (van der Hoop et al., 2017).

In order to estimate sample PBRs for the three proposed stocks, I used the PBR formula from the SARs. This formula is the minimum population size *times* one half the estimated population growth rate *times* the recovery factor (Carretta et al., 2018). I first calculated the minimum population estimate for each DPS, following Wade & Angliss (1997):

$$N_{\text{MIN}} = N/\exp(0.842 \times [\ln(1 + [\text{CV}(N)]^2)]^{1/2})$$

where N is the abundance estimate and CV(N) is the coefficient of variation of the abundance estimate. The input values and resulting minimum population estimates are shown in Table 1.

Next I determined the population growth rate and recovery factor for each proposed stock. The population growth rate used for the Central America and Mexico stocks was 8%, which is the current maximum estimated net productivity rate of a small population (Carretta et al., 2018). 7% is the growth rate used for the Central North Pacific stock in the SARs, and because this stock consists of a strong majority of whales from the Hawaii DPS, a 7% growth rate was used to calculate PBR for the proposed Hawaii stock

(Muto et al., 2018). As described by Taylor et al. (2003), species are assigned a recovery factor based on their population abundance, with 0.1 for an endangered stock and 1.0 for a stock at its optimum sustainable population. The recovery factor used for the Central America stock was 0.1 due to its small abundance estimate while the recovery factor used for the Mexico and Hawaii stocks was 0.3. Because current PBR for the CA/OR/WA stock is divided by two since the stock spends approximately half its time outside of the U.S. EEZ (Carretta et al., 2018) (current PBR = $22/2 = 11$) this same method was followed in calculating PBR for the three new stocks. The resulting PBRs are provisional in that they are estimates provided for comparative purposes only. Current PBR was taken from the 2017 SAR, the most recently available at the time of analysis.

Humpback whales on the U.S. West Coast are considered to be part of one of two feeding area groups. One group feeds in an area off the coasts of California and Oregon (CA/OR), while the other feeds in an area off the coasts of Washington and South British Columbia (WA/BC). For the purposes of this analysis, each whale was assigned to one of these feeding areas based on where the whale was reported as entangled. For example, if an entangled whale was reported off the coast of Monterey, it was assigned to the CA/OR feeding area. Photo-identification work has demonstrated that humpback whales foraging off California and Oregon originate from both the Central America and Mexico DPSs, while the majority of whales foraging off Washington and southern British Columbia originate from the Hawaii and Mexico DPSs (Wade et al., 2016). Based on these data, NMFS created proportional estimates of each DPS that are applied to incidents of mortality and serious injury in waters off of California, Oregon, and Washington (see Table 2 for these proportions). Ultimately, NMFS considers any humpback whale migrating or foraging off the coast of California or Oregon to be an ESA-listed whale from either the Mexico or Central America DPSs, and any whale migrating or foraging off the coast or in inland waters of Washington to originate from the threatened Mexico DPS or the unlisted Hawaii DPS, plus a small proportion from the endangered Central America DPS (NMFS, 2016). In order to avoid underestimating levels of mortality to the endangered Central America DPS, NMFS chose the upper limit of the 95% confidence interval of the probability that individuals from this DPS will be found off of California

or Oregon. Therefore, the proportional estimates will equal more than 100% in order to be protective of the Central America DPS (NMFS, 2016).

3. Results

3.1 Overview of entanglements

The 136 entanglements considered in my analysis included 8 mortalities, 27 serious injuries, and 79 prorated serious injuries, for a total of 94.3 mortalities and serious injuries (9.4 per year). Twenty-two of the entanglements were deemed not serious injuries.

Of the 136 entanglements, the majority ($n = 72$) were of an unknown gear type, followed by single trap ($n = 45$), multiple trap ($n = 10$), and net ($n = 8$). The 45 single-trap entanglements resulted in 26.5 (59%) mortalities and serious injuries after disentanglement efforts. The 10 multiple trap entanglements resulted in 5 mortalities and serious injuries (50%); similarly, the 8 net entanglements also resulted in 5 mortalities and serious injuries (63%). The number of reported entanglements generally increased over time, with 2016 being the year with the highest number of reported entanglements ($n = 52$). The majority of entanglements were reported in California ($n = 113$) (see Figure 2). Seventy-two of the entanglements reported in California were of unknown origin, 38 originated in California, and 3 originated in Oregon. Ten entanglements were reported in Washington, with 7 of these being of unknown origin, 2 from Washington, and 1 from Oregon. Seven entanglements were reported in Oregon—4 of these were of unknown origin, 2 were from Oregon, and one was found with both Oregon and Washington gear. Additionally, 3 entanglements were reported in British Columbia that had U.S. gear—2 from Washington and 1 from California. Finally, 3 entanglements were reported in Mexico that all originated in California. Generally, entanglement origin locations, when known, did not differ significantly from entanglement report locations; however, there were some exceptions where whales traveled far from the location where they were entangled including one whale that was seen in British Columbia with California gear.

3.2 Assessment of mortality related to current PBR

The current PBR for the CA/OR/WA stock of humpback whales is 11 whales per year (Carretta et al., 2018). Entanglements in this dataset resulted in a total mortality and

serious injury rate of 94.3 over the entire ten-year period, or 9.4 annually. With more than 11 recorded mortalities and serious injuries per year from 2014-2016, PBR is being exceeded for this stock (see Figure 3). For example, in 2014, total mortalities and serious injuries from entanglements were 11.5 animals, while in 2015 and 2016 the total increased to 23.8 and 34.8, respectively. These numbers include entanglements alone and exclude other human-caused mortalities such as vessel strikes, and they alone exceed the PBR threshold of 11 human-related deaths per year for this stock.

3.3 PBR of proposed stocks

If the current stock was further divided into the three stocks proposed based on the DPSs, a new PBR would be calculated for each stock. I estimated the PBR allocation for U.S. waters for the endangered Central America stock to be 0.6 whales per year, 18.6 for the threatened Mexico stock, and 57.9 for the unlisted Hawaii stock (see Table 3).

3.4 Mortality of new stocks as compared to PBR

Using NOAA's proportional method to assign mortality to specific DPSs, I generated estimates of entanglement for each proposed stock using all the data from this time period. I used the report location of each entanglement to assign entanglements to either the CA/OR or WA/BC feeding groups. This led me to assign 123 entanglements to the CA/OR group and 13 to the WA/BC feeding group. Using the proportions from Table 2 for the CA/OR feeding group, this suggests that the incidence of entanglement was 24.6 whales from the Central America stock (2.5 per year) and 110.7 from the Mexico stock (11.1 per year). Applying proportional estimates to the WA/BC feeding group yields entanglement of an additional 2 whales from the Central America stock (0.2 per year), 5.5 from the Mexico stock (0.6 per year), and 5.6 from the Hawaii stock (0.6 per year). Combined estimates from both feeding groups indicate an entanglement rate of 2.7 whales per year from the Central America stock.

While these numbers represent all reported humpback whale entanglements during this time period, I also applied the proportional method to only those entanglements that were deemed mortalities and serious injuries and compared these to proposed PBR. I assigned 84 mortalities and serious injuries to the CA/OR feeding group and 10.5 to the WA/BC feeding group (based on report location). Total mortality and serious injury was 16.8 (1.7 per year) from the Central America stock and 75.6 (7.6 per

year) from the Mexico stock. For the WA/BC feeding group, there was an additional 1.6 (0.2 per year) mortalities and serious injuries from the Central America stock and 4.4 (0.4 per year) from the Mexico stock. Combined estimates from both feeding groups results in a total of 1.9 mortalities/serious injuries per year from the Central America stock and 8 from the Mexico stock. Provisional PBR for the Central America stock is therefore exceeded by these mortalities and serious injuries.

This proportional method can also be used to assign entanglements of DPSs based on origin location. Although often unknown, entanglement origin location can be determined in cases where gear is recovered or there is photo documentation of the gear on the whale. Based on origin location, 48 whales were classified to be in the CA/OR feeding group, 4 in the WA/BC feeding group, one from both CA/OR and WA/BC (multiple gear sets on animal) and 83 were unknown. Applying the same proportional method as above to the CA/OR feeding group yields 9.6 whales from the Central America DPS and 43.2 from the Mexico DPS. The WA/BC feeding group yields an additional 0.6 whales from the Central America DPS, 1.7 from the Mexico DPS, and 1.7 from the Hawaii DPS. However, with 61% of the entanglements having an unknown origin, these numbers could be vastly underestimated. As discussed in Section 3.1, report location did not differ significantly from origin location (when known) in this dataset. For example, 41 entanglements had a known origin location of California, and 38 of these were also reported in California. I therefore re-categorized the unknown origin location entanglements to their report location and applied the same proportional method. There were 124 whales from the CA/OR feeding group, 11 from the WA/BC feeding group, and one from both. The CA/OR feeding group thereby included 24.8 whales from the Central America DPS (2.5 whales per year) and 111.6 from the Mexico DPS (11.2 whales per year). The WA/BC group included 1.7 whales from the Central America DPS (0.2 whales per year), 4.6 from the Mexico DPS (0.5 per year), and 4.7 from the Hawaii DPS (0.5 per year). Ultimately, this leads to 2.7 whales entangled per year from the Central America stock.

3.5 Reductions needed to achieve PBR

I next examined rates of mortalities and serious injuries that would be needed to stay below PBR for these new stocks. To stay at PBR for the Central America stock,

there would need to be less than 3.2 annual mortalities and serious injuries to the CA/OR feeding group, assuming through NOAA's proportional method that only 20% of those mortalities and serious injuries would be from the Central America population. Similarly, there could be 4.3 annual mortalities and serious injuries to the WA/BC feeding group, assuming 15% were from the Central America population. To stay at PBR for the Mexico stock, there could be 20.7 annual mortalities and serious injuries to the CA/OR feeding group or 44.3 to the WA/BC feeding group. If 90% of entanglements continue to be reported in CA/OR and 10% in WA/BC as was found in this dataset, there will need to be three or fewer mortalities and serious injuries on the entire West Coast to stay below Central America PBR of 0.6.

3.6 List of Fisheries and proposed PBR

In order to assess mortalities from specific fisheries, levels of mortality and serious injury from each fishery were compared to provisional PBR. Table 4 includes a list of the type of fishing gear observed on the whales in this dataset. Unidentified fisheries accounted for 74 of the entanglements. The next largest contributor was the California Dungeness crab fishery, with 29 confirmed entanglements (see Figure 4). These 29 entanglements resulted in 17.5 mortalities or serious injuries, or an entanglement rate of 1.8 per year. The second largest contributing fishery was the California spot prawn trap fishery, with 7 confirmed entanglements during this ten-year period, resulting in 2.5 mortalities and serious injuries, or an entanglement rate of 0.3 per year. I assigned these mortalities and serious injuries to each proposed stock (see Table 5), finding that mortalities and serious injuries from these fisheries were below provisional PBR for the Central America and Mexico stocks. However, the large number of entanglements that are unidentified suggest that the numbers for each fishery are likely underestimates, since a portion of the unidentified entanglements are probably attributable to these fisheries.

Using the List of Fisheries mortality guidelines established under the MMPA, I next assessed the mortalities caused by these fisheries under the new stock structure scenario. I examined the fisheries with the highest mortality and serious injury rates—California Dungeness crab and California spot prawn. In the 2016 LOF (the final year of this dataset) both California spot prawn and California Dungeness crab were listed as

Category II fisheries, meaning that (1) total mortality and serious injury from all commercial fisheries was greater than 10% of PBR for this stock (Tier 1) and (2) the annual mortality and serious injury rate from these specific fisheries was between 1 and 50 percent of current PBR (Tier 2). LOF is assessed using the most recent five-year period with available data, thus I used the period from 2012-2016 to assess LOF (see Table 6 for PBR categorization boundaries for new stocks). Moreover, whales that were disentangled often have an initial injury assessment of serious injury, which can be changed to not serious injury after disentanglement if the whale seems otherwise healthy. Because LOF is intended to assess entanglement risk from fisheries without subsequent human intervention to remove the entanglement, these serious injuries are added back into the analysis. With approximately 1.2 mortalities and serious injuries per year for the Mexico stock and 0.3 per year for the Central America stock from the CA spot prawn fishery, this fishery would remain a Category II fishery for both of these stocks. For the California Dungeness crab fishery, there were approximately 4.1 mortalities/serious injuries per year for the Mexico stock, and 0.9 per year for the Central America stock. This fishery would therefore remain in Category II for the Mexico stock, but would move to Category I for the Central America stock since the mortality/serious injury rate exceeds not only 50% of PBR, but also PBR itself.

In order for any CA/OR fisheries to avoid Category I fishery status, total mortalities and serious injuries must remain between 1% and 50% of PBR for each stock. To stay between 1% and 50% of PBR (Category II) for the Central America stock in CA/OR, total mortalities and serious injuries will need to be less than 1.6 per year. To become a Category III fishery with mortalities and serious injuries less than 1% of PBR, these fisheries would need to not exceed 0.03 mortalities and serious injuries per year in CA/OR. For the Mexico stock, fisheries would need to keep mortalities and serious injuries below 10.3 per year to remain a Category II fishery. Their mortalities and serious injuries would need to be less than 0.2 per year in order to become a Category III fishery.

Fisheries that impact the WA/BC feeding group must keep mortalities and serious injuries below 2.1 per year for the Central America stock in order to be a Category II fishery. For Category III status, total mortalities and serious injuries to the Central America stock must not exceed 0.04 per year. For the Mexico stock, fisheries must keep

mortalities and serious injuries at less than 22.2 per year to have Category II status, and less than 0.5 per year to have Category III status.

3.7 Disentanglement rates

Trained experts often respond to entangled whales and are sometimes able to fully or partially disentangle the whale. I examined how disentanglement rates differ based on gear type, location, and fishery, and how disentanglement influences mortality/serious injury rates.

Table 7 shows disentanglement success (fully, partially, or not disentangled) for the three most common gear types: multiple-trap, single-trap, and net. Multiple-trap gear had a 40% full disentanglement rate, while single-trap gear had a 33% full disentanglement rate. Including partial disentanglements results in a disentanglement rate of 70% for multiple-trap entanglements and 44% for single-trap entanglements. There was a 0% full disentanglement rate and a 13% partial disentanglement rate for net entanglements.

Disentanglement rates also differ by report location because each state has varying capacity for entanglement response. California had both the largest number of fully disentangled whales and whales that were not disentangled (see Table 8 for numbers of disentanglements for each state). The difference in disentanglement numbers between states is dependent on many factors including entanglement response capacity, location of the animal, weather conditions, and timely reporting. Whales can also sometimes release themselves from the gear, and therefore all disentanglements may not be attributable to human efforts.

Finally, I examined the influence of fishery type on disentanglement success by looking at disentanglement rates for fisheries with the highest number of entanglements (see Table 9). There was a 34% full disentanglement success rate for the California Dungeness crab fishery, while the Oregon Dungeness crab fishery had a 75% full disentanglement rate and the California spot prawn fishery had a 57% disentanglement rate. It is worth noting that some of these disentanglements occurred in a different state than where the entanglement originated (i.e. disentanglement of Oregon Dungeness crab gear in California).

Disentanglements can sometimes impact the mortality/serious injury designations given to the animal if the gear is successfully removed and there are no severe injuries. In these data, I identified 15 entanglements that were initially classified as serious injury or prorated serious injury and were changed to not serious injury after disentanglement. An additional 6 animals were fully disentangled, but their designations remained unchanged, with 3 remaining as not serious injuries and 3 remaining as serious injuries. There were 10 partial disentanglements, 8 of which were designated as prorated serious injuries and remained as such after partial disentanglement. One was changed from a serious injury to a prorated serious injury after disentanglement, and one was a serious injury that remained a serious injury after partial disentanglement. Partial disentanglements, therefore, do not often fully alleviate the animal of a serious injury designation, as it can be difficult to determine that the remaining gear will not pose a threat to the life of the whale.

4. Discussion

4.1 Entanglement reports

The increasing number of entanglement reports in recent years could be due to increasing numbers of entanglements, or a variety of other factors. These factors include increased public awareness of the issue and therefore more reports, more people on the water that observe entangled whales, movement of whales into previously unoccupied areas (such as the Salish Sea), or an increase in whale abundance. Preliminary data show a sharp increase in humpback whale abundance estimates in CA/OR since 2014 (Calambokidis, 2019). However, it is currently unknown if this increase is due to an influx of whales into this area, increases in reports of sightings, or the use of automated matching algorithms (Calambokidis, 2019). It is also possible that these levels of entanglements have been happening all along, but they have only been observed with increasing human populations and presence on the water. Feist et al. (in prep) has been analyzing whale watch cruise ship activity in Monterey Bay, finding that the number of half-day whale watching trips from one of the most active whale watching operators showed a marked increase starting in 2015. However, the increase in entanglement reports began in 2014, and the number of whale watch cruises operating out of Monterey

did not increase at all that year. Changing environmental conditions may also have played a role, with warmer ocean temperatures altering prey distribution and creating a larger overlap between gear and humpback whales. Another factor that may have created a large co-occurrence between whales and gear was the occurrence of a toxic algal bloom off the West Coast in 2014, which delayed the opening of the Dungeness crab season and stretched it further into spring, during which time the whales were more likely to encounter the gear. Any or all of these factors may have contributed to the increased number of entanglement reports in recent years.

An important area of concern remains the high number of entanglements that cannot be attributed to a certain fishery or species. Although NMFS's ability to identify gear has increased with better documentation and increased response, unidentified entanglements still represent the largest category of entanglements. Proper identification of gear, while difficult to obtain, is necessary to accurately assess impacts to whales from specific fisheries. An additional consideration is the fact that some gear is more easily identifiable, such as Dungeness crab gear, which could bias the reporting. Species identification can also be difficult to obtain due to a lack of cetacean identification experience, rough ocean conditions, or distance from the whale (Carretta et al., 2019a). Unidentified whales represent approximately 15% of entanglement cases on the U.S. West Coast (Carretta et al., 2019a). Prior to 2018, these entanglements were not assigned to specific species. Using a new species identification model based on variables such as gear type, season, location, depth, and sea surface temperature, Carretta (2018) estimated unidentified whale entanglements represented an additional 14.4 humpback whale entanglements from 2012 to 2016. These unidentified entanglements will be important to consider in the future when assessing impacts to specific populations and fisheries.

4.2 Implications for management and stock structure

The management of humpback whales on the U.S. West Coast has been made increasingly complex by the separation of the species into three DPSs under the ESA while simultaneously maintaining one stock under the MMPA. Because it appears increasingly likely that stock structure under the MMPA will be changed to match the three DPSs, I sought to preemptively examine some of the implications of this potential change in regards to management of human-caused mortality. The section that follows

compares current management practices with potential changes under a revised stock structure.

Under the current one stock/three DPS structure, high levels of entanglements in recent years have made it difficult to ensure that each DPS is receiving adequate protection. The current PBR of 11 has been greatly exceeded by entanglement mortalities since 2014, peaking in 2016 with annual mortalities and serious injuries triple the rate of PBR. The addition of ship strikes in 2016 increases this number significantly as well, from 34.75 to 49 mortalities and serious injuries. While this analysis utilized ten years of available data, stock assessment reports use the most recent five-year period to assess annual mortalities and serious injuries in relation to PBR. With significant increases in entanglement reports in the last five years, analysis of annual mortality and serious injury will be elevated the next several years due to assessment of a five-year period rather than a ten-year period. As previously discussed, these observed mortalities should be considered the minimum number of true human-caused mortalities. The existing designation as only one stock under the MMPA means that there is only one PBR, and it is therefore difficult to assess how entanglement mortalities are affecting each DPS. This is particularly important with regard to the endangered Central America DPS because their abundance is so low.

The separation of the species into three stocks allows for more targeted management that helps provide protection to each population. A PBR rate for each stock based on the abundance level of that stock allows for certain management actions to be triggered when PBR is exceeded. With such a low PBR for the Central America stock, it is likely that PBR would be exceeded often. In terms of LOF, if the Central America stock sustained mortalities from all commercial fisheries exceeding 10% of PBR and therefore moved from Tier 1 to Tier 2, any individual fishery would have a difficult time reaching Category III status. This could result in increased restrictions on these fisheries or the requirement of more observers on these vessels to document mortalities (or lack thereof). Moreover, PBR could be exceeded for the Central America stock without being exceeded for the Mexico stock, allowing for management to be targeted to a specific stock. Emergency measures could be implemented under the MMPA to prevent further

mortalities from commercial fisheries, which could potentially provide the Central America population the time it needs to recover.

4.3 Mitigation

Because entanglements can have a strong influence on mortality and serious injury rates and considering that whale entanglements will be a difficult problem to eliminate completely, it is important to consider possible ways to make entanglements less lethal. Using less vertical line is one gear configuration that is being explored to reduce the amount of gear whales can become entangled in, and therefore potentially reducing the likelihood of serious injury. However, reducing the number of vertical lines would require increasing the number of traps, which could increase the severity of the injury. By examining mortalities and serious injuries by gear type, as well as disentanglement rates, I hoped to determine whether one gear type was less likely to cause mortality or was easier to disentangle. However, the three gear types with the highest number of reported entanglements (multiple trap, single trap, and net) imposed similar rates of mortality and serious injury, ranging between 50 and 63% mortality/serious injury post-disentanglement. Multiple-trap entanglements, therefore, were not found to be more lethal than single trap entanglements. However, multiple-trap entanglements had a higher disentanglement rate (70% including partial disentanglements) than single-trap entanglements (44% including partial disentanglements). Multiple-trap entanglements may be more likely to trap the whale in place, allowing responders to locate the whale and disentangle it. Whales can often travel with single-trap entanglements, however, making it difficult for responders to locate and disentangle them. Multiple-trap entanglements were not found to cause more mortality or serious injury than other types of entanglements, and the disentanglement rate is much higher for these entanglements. Because single-trap entanglements represent the majority of humpback whale entanglements and are less able to be successfully disentangled, mitigation efforts will need to be focused on this gear in the future if mortality and serious injury rates from commercial fisheries are to be reduced.

California, Oregon, and Washington have all convened working groups with stakeholders from the fishing industry, NGOs, and state and federal agencies to work toward mitigating whale entanglements. The California Working Group has also created

a Risk Assessment and Mitigation Program (RAMP) to assess conditions when entanglement risk in the California Dungeness crab fishery might be elevated and implement management measures if needed (California Ocean Protection Council, 2019). This program assesses risk factors such as ocean conditions, whale concentrations, and fishing dynamics to get a better picture of entanglement risk. This type of adaptive management that is responsive to changing environmental conditions will be necessary going forward, because it allows management measures to be put in place when conditions show the highest level of risk to whales. Because the endangered Central America DPS is found largely off of California, and this analysis found that entanglement levels will need to be significantly reduced under a new stock structure, small and incremental gear alterations may not be enough to reduce entanglements to levels needed in the future.

4.4 Conclusion

Entanglement in commercial fishing gear presents risk of increasing mortality and serious injury for humpback whales on the U.S. West Coast. These mortalities and serious injuries have exceeded PBR for the CA/OR/WA stock for the last several years. With whales from three DPSs of varying abundance levels overlapping in the same feeding areas, it has become difficult to assess how entanglement mortalities are impacting individual DPSs. The designation of three stocks under the MMPA that match DPS designations under the ESA could allow for more targeted management that better assesses impacts to each population through revised PBR rates. This study demonstrates that under a new stock structure scenario, mortalities and serious injuries from entanglements are greatly exceeding PBR for the Central America population. Moreover, because of the overlap between the Central America population and the California Dungeness crab fishery, this fishery would potentially move into Category I status under a revised stock structure based on current entanglement levels. Because disentanglement rates are generally low for pot/trap fisheries like the Dungeness crab fishery, mitigation efforts should be focused on preventing entanglements from occurring, rather than addressing them after the fact. This analysis has outlined several factors related to human-caused mortality that NMFS may need to consider when undertaking a change in stock structure for humpback whales.

Table 1: Metrics used to calculate PBR for each stock

	Central America DPS	Mexico DPS	Hawaii DPS
Abundance estimate	411	3,264	11,398
CV	0.30	0.06	0.04
Growth rate	8%	8%	7%
Recovery Factor	0.10	0.30	0.30
Minimum population estimate	320	3,103	11,020

Table 2: Proportional estimates used by NMFS to assign mortalities to each DPS based on feeding area location

Feeding Areas	Central America DPS	Mexico DPS
California/Oregon	20%	90%
Washington/SBC	15%	42%

Table 3: PBR for each proposed stock

Central America	Mexico	Hawaii
0.6	18.6	57.9

Table 4: Number of humpback whale entanglements per fishery, 2007-2016

Fishery	Number of entanglements
CA halibut and white seabass set gillnet fishery	1
CA swordfish drift gillnet fishery	1
CA spot prawn trap fishery	7
Dungeness crab pot fishery	5

CA Dungeness crab pot fishery	29
OR and WA Dungeness crab pot fishery	1
OR Dungeness crab pot fishery	4
Recreational Dungeness crab pot fishery	2
WA Dungeness crab pot fishery	3
Gillnet fishery	4
Lobster trap entanglement	1
Marine debris	1
Unidentified fishery interaction	53
Unidentified net fishery	2
Unidentified pot/trap fishery entanglement	19
WA/OR/CA sablefish pot fishery	3

Table 5: Levels of mortality and serious injury from specific fisheries and assigned to proposed stocks

Fishery	Annual mortalities/serious injuries	Annual mortalities/serious injuries assigned to proposed stocks
CA Dungeness Crab	1.94	<i>Central America</i> 0.39
		<i>Mexico</i> 1.75
CA Spot Prawn	0.28	<i>Central America</i> 0.06
		<i>Mexico</i> 0.25

Table 6: List of Fisheries PBR categorizations for proposed stocks

	Central America stock	Mexico stock
1% of PBR	0.006	0.19
50% of PBR	0.32	9.31

Table 7: Disentanglement success for most common gear types

	Multiple-trap	Single-trap	Net
Fully disentangled	4	15	0
Partially disentangled	3	5	1
Not disentangled	3	25	7
Total	10	45	8

Table 8: Disentanglement success and entanglement report location

	California	Oregon	Washington
Fully disentangled	18	0	1
Partially disentangled	5	2	1
Not disentangled	90	5	8
Total	113	7	10

Table 9: Disentanglement success for specific fisheries

	CA Dungeness Crab	OR Dungeness Crab	CA Spot Prawn
Fully disentangled	10	3	4
Partially disentangled	2	0	1
Not disentangled	17	1	2
Total	29	4	7

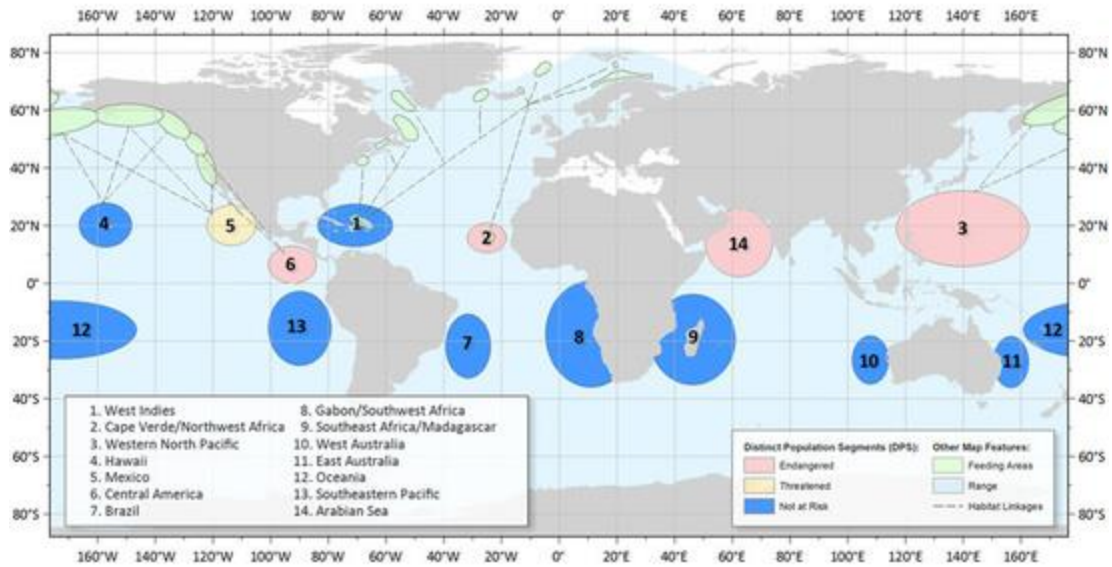


Figure 1: Global Distinct Population Segments (DPSs) of humpback whales. Reprinted from NOAA Fisheries, retrieved from <https://www.fisheries.noaa.gov/species/humpback-whale>

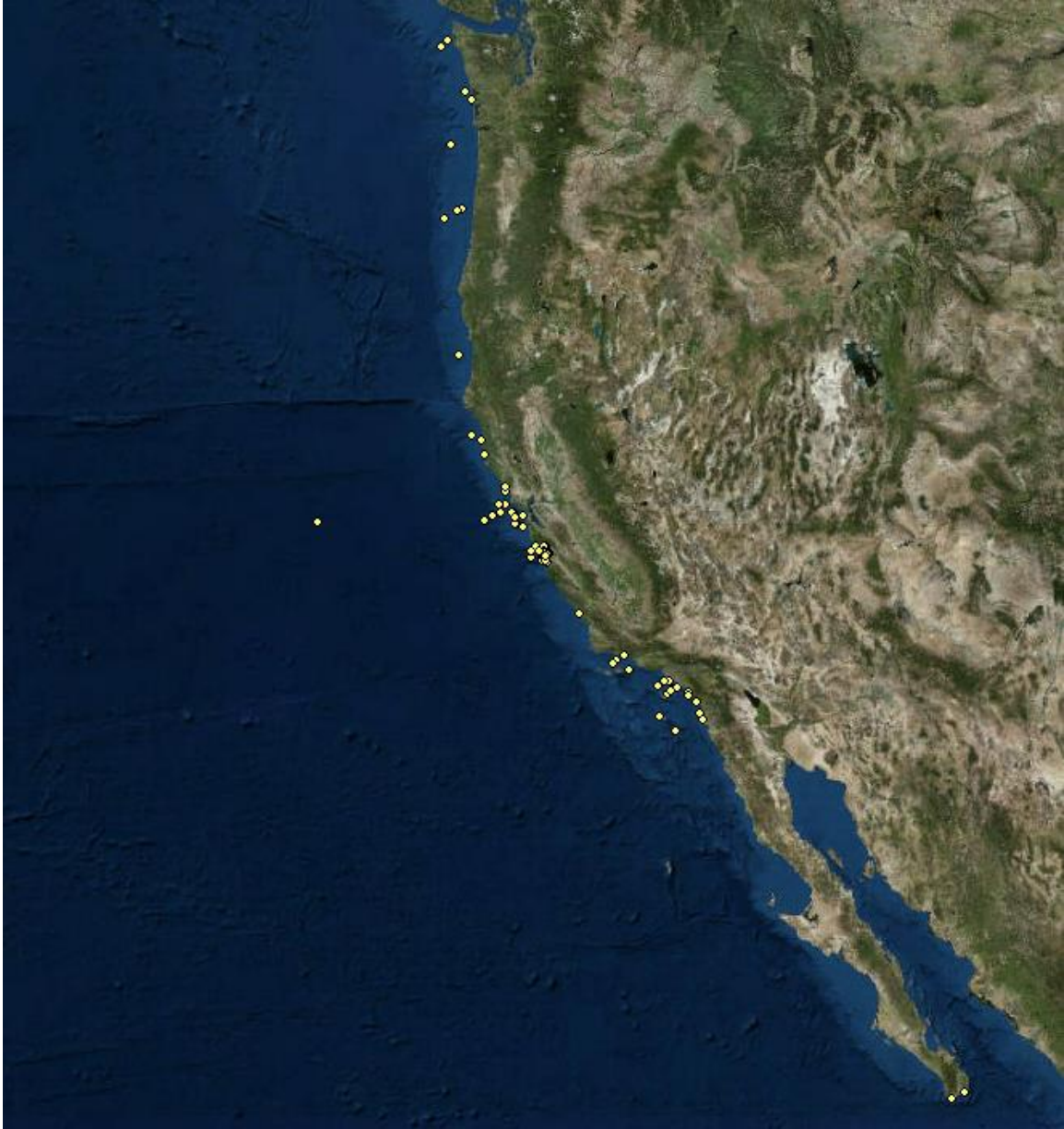


Figure 2: Locations of reported humpback whale entanglements for which coordinates were available, 2007-2016

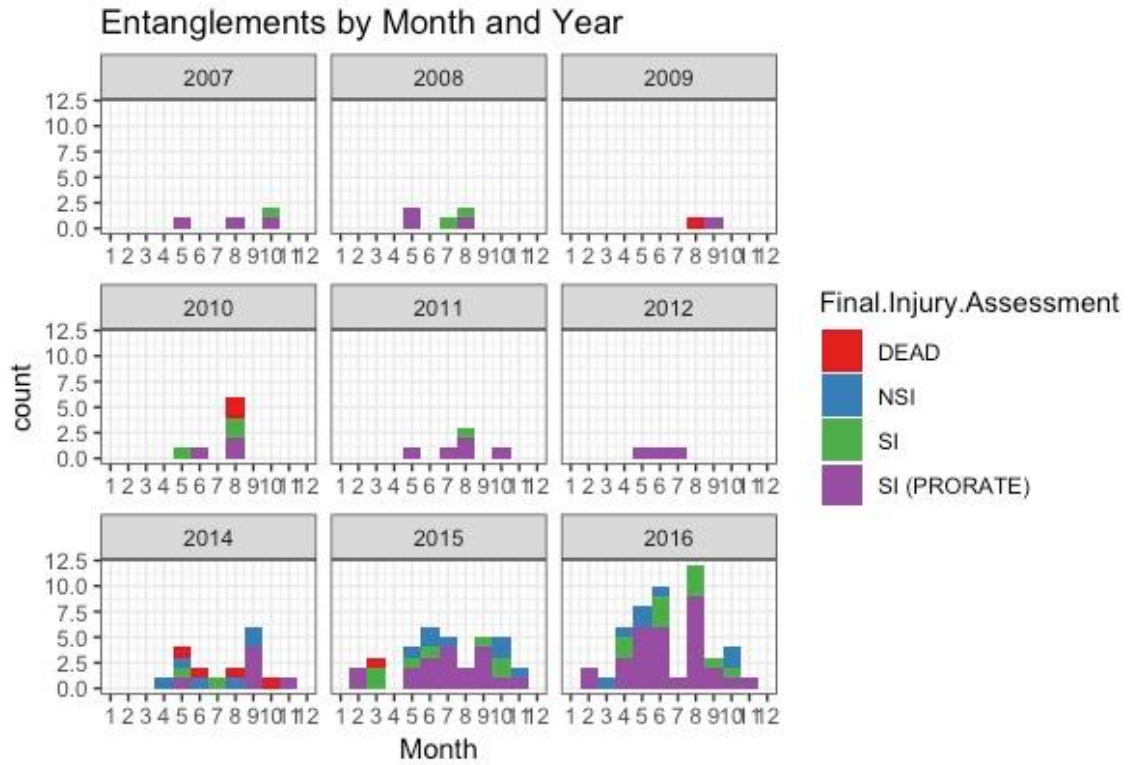


Figure 3: Reported humpback whale entanglements and injury assessments per month, 2007-2016

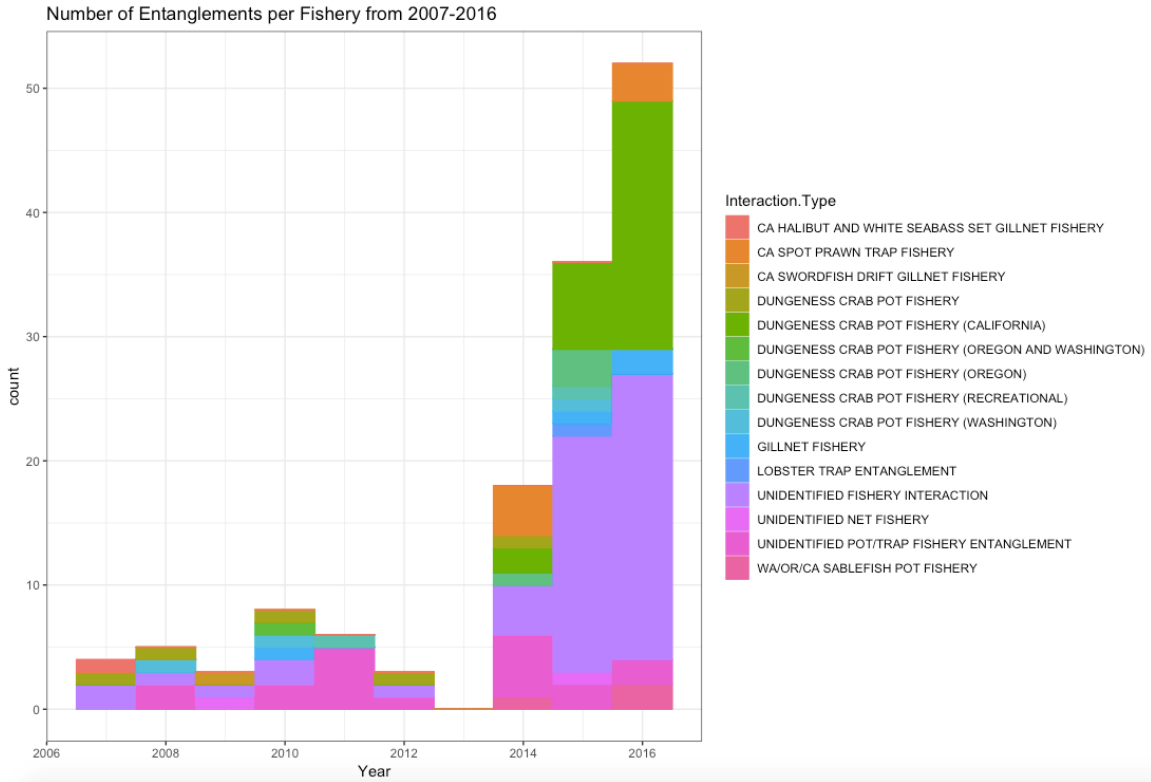


Figure 4: Reported humpback whale entanglements in commercial fisheries

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