Revised 2/15/2019

BLUE WHALE (*Balaenoptera musculus musculus*): Eastern North Pacific Stock

STOCK DEFINITION AND GEOGRAPHIC RANGE

North Pacific blue whales were once thought to belong to as many as five separate populations (Reeves *et al.* 1998), but acoustic evidence suggests only two populations, in the eastern and western North Pacific, respectively (Stafford *et al*. 2001, Stafford 2003, McDonald *et al*. 2006, Monnahan *et al*. 2014). North Pacific blue whales produce two distinct acoustic calls, referred to as “northwestern” and “northeastern” types. Stafford *et al.* 2001, Stafford 2003, and Monnahan *et al.* 2014 have proposed that these represent distinct populations with some degree of geographic overlap. The northeastern call predominates in the Gulf of Alaska, along the U.S. West Coast, and in the eastern tropical Pacific, and the northwestern call predominates from south of the Aleutian Islands to the Kamchatka Peninsula in Russia, though both call types have been recorded concurrently in the Gulf of Alaska (Stafford *et al*. 2001, Stafford 2003). Both call types occur in lower latitudes in the central North Pacific, but differ in their seasonal patterns (Stafford *et al*. 2001). Blue whales satellite-tagged off California in late summer have traveled to the eastern tropical Pacific and the Costa Rica Dome in winter (Mate *et al*. 1999, Bailey *et al.* 2009). Blue whales photographed off California have been matched to individuals photographed off the Queen Charlotte Islands in northern British Columbia and to one individual photographed in the northern Gulf of Alaska (Calambokidis *et al*. 2009a). Barlow (2010, 2016) noted there has been a northward shift in blue whale distribution within the California Current, based on a series of vessel-based line-transect surveys from 1991-2014. Gilpatrick and Perryman (2008) reported that blue whales from California to Central America (the Eastern North Pacific stock) are on average, two meters shorter than blue whales measured from historic whaling records in the central and western North Pacific.

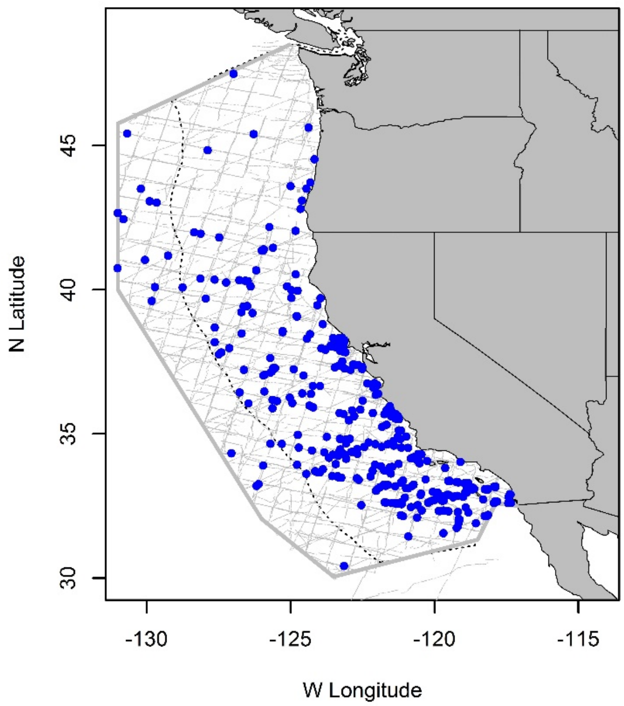

Figure 1. Blue whale sighting locations based on aerial and summer/autumn shipboard surveys off California, Oregon, and Washington, 1991-2014. Dashed line represents the U.S. EEZ; thin lines represent completed transect effort for all surveys combined.

For the Marine Mammal Protection Act (MMPA) stock assessment reports, the Eastern North Pacific Stock of blue whales includes animals found in the eastern North Pacific from the northern Gulf of Alaska to the eastern tropical Pacific. This definition is consistent with the distribution of the northeastern call type, photogrammetric length determinations, and the known range of photographically-identified whales. Based on northeastern call type locations, some whales in this stock may range as far west as Wake Island and as far south as the Equator (Stafford *et al*. 1999, 2001). The U.S. West Coast is one of the most important feeding areas in summer and fall (Fig. 1), but, increasingly, blue whales from this stock are found feeding north and south of this area in summer and fall. Nine ‘biologically important areas’ (BIAs) for blue whale feeding are identified off the California coast (Calambokidis *et al*. 2015), including six areas in southern California and three in central California. Most of this stock is believed to migrate south to spend the winter and spring in high productivity areas off Baja California, the Gulf of California, and on the Costa Rica Dome. Given observations of feeding in these high productivity migratory destinations, blue whales are assumed to feed year-round. Some whales from this stock may be present year-round on the Costa Rica Dome (Reilly and Thayer 1990). However, it is also possible that some southern hemisphere blue whales occur north of the equator during the austral winter. One other stock of North Pacific blue whales (the Central North Pacific stock) is recognized in the Pacific Marine Mammal Protection Act (MMPA) Stock Assessment Reports.

POPULATION SIZE

The size of the feeding stock of blue whales off the U.S. West Coast has been estimated by line-transect and mark-recapture methods. Because some fraction of the population is always outside the survey area, the line-transect and mark recapture estimation methods provide different measures of abundance for this stock. Line transect estimates reflect the average density and abundance of blue whales in the study area during summer and autumn surveys, while mark-recapture estimates can provide an estimate of total population size if differences in capture heterogeneity are addressed.

Abundance estimates from line-transect surveys have been highly-variable and this variability is attributed to northward distributional shifts of blue whales out of U.S. waters linked to warming ocean temperatures (Barlow and Forney 2007, Calambokidis *et al.* 2009a, Barlow 2010, 2016). Mark-recapture estimates of abundance are considered the more reliable and precise of the two methods for this transboundary population of blue whales because not all animals are within the U.S. EEZ during summer and autumn line-transect surveys and mark-recapture estimates can be corrected for heterogeneity in sighting probabilities. Generally, the highest abundance estimates from line-transect surveys occurred in the mid-1990s, when ocean conditions were colder than present-day (Fig. 2). Since that time, line-transect abundance estimates within the California Current have declined, while estimates from mark-recapture studies have remained stable (Fig. 2). Evidence for a northward shift in blue whale distribution includes increasing numbers of blue whales found in Oregon and Washington waters during a 1996-2014 line-transect surveys (Barlow 2016) and satellite tracks of blue whales in Gulf of Alaska and Canadian waters between 1994 and 2007 (Bailey *et al.* 2009). An analysis of line-transect survey data from 1996-2014 provided a range of blue whale estimates from a high of approximately 2,900 whales in 1996 to a low of 900 whales in 2008 (Barlow 2016). The mean abundance estimate from the two most-recent line-transect surveys conducted in 2008 and 2014 is 1,146 (CV=0.33) whales.

Photographic mark-recapture estimates of abundance from 2005 to 2011 range from 1,000 to 2,300 whales, with the most consistent estimates represented by a 4-yr sampling period Chao model that incorporates individual capture heterogeneity (Calambokidis and Barlow 2013). The Chao model consistently yields estimates of approximately 1,500 whales (Fig. 2). The best estimate of blue whale abundance is taken from the Chao model of abundance for the period 2008 to 2011, or 1,647 (CV=0.07) whales (Calambokidis and Barlow 2013).

Minimum Population Estimate

The minimum population estimate of blue whales is taken as the lower 20th percentile of the log-normal distribution of abundance estimated from the mark-recapture estimate, or 1,551 whales.

Current Population Trend

Mark-recapture estimates provide the best gauge of population trends for this stock, because of recent northward shifts in blue whale distribution that negatively bias line-transect estimates. Based on mark-recapture estimates shown in Fig. 2, there is no evidence of a population size increase in this blue whale population since the early 1990s. While the Petersen mark-recapture estimates show an apparent increase in blue whale abundance since 1996, the estimation errors associated with these estimates are much higher than for the Chao estimates (Fig. 2). Monnahan *et al*. (2015) used a population dynamics model to estimate that the eastern Pacific blue whale population was at 97% of carrying capacity in 2013 and suggested that density dependence, and not vessel strike impacts, explains the observed lack of a population size increase since the early 1990s. Monnahan *et al.* (2015) also estimated that the eastern North Pacific population likely did not drop below 460 whales during the last century, despite being targeted by commercial whaling.

CURRENT AND MAXIMUM NET PRODUCTIVITY RATES

Based on mark-recapture estimates from the U.S. West Coast and Baja California, Mexico, Calambokidis *et al*. (2009b) estimated an approximate rate of increase of 3% per year, but this estimate excludes the effects of anthropogenic mortality and serious injury on the population. Thus, the observed rate of population increase from mark-recapture estimates likely represents an underestimate of the maximum net productivity rate. For this reason and because an estimate of maximum net productivity is lacking for any blue whale population, the default rate of 4% is used for all blue whale stocks, based on NMFS guidelines for preparing stock assessments (NMFS 2016).

POTENTIAL BIOLOGICAL REMOVAL

The potential biological removal (PBR) level for this stock is calculated as the minimum population size (1,551) times one half the default maximum net growth rate for cetaceans (½ of 4%) times a recovery factor of 0.3 (for an endangered species which has a minimum abundance greater than 1,500 and a CV_{Nmin}<0.5), resulting in a PBR of 9.3. Because whales in this stock spends approximately three quarters of their time outside the U.S. EEZ, the PBR for U.S. waters is one-quarter of this total, or 2.3 whales per year.

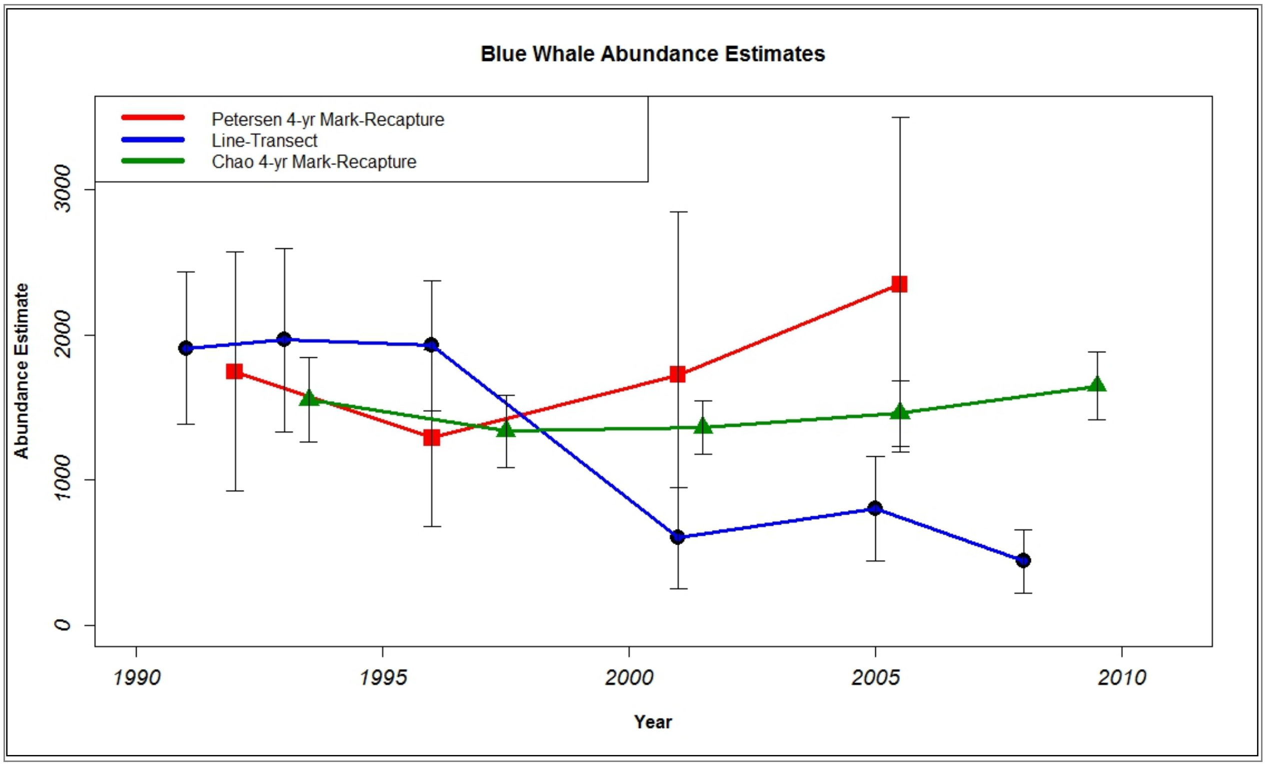

Figure 2. Estimates of blue whale abundance from line-transect and photographic mark-recapture surveys, 1991 to 2011 (Barlow and Forney 2007, Barlow 2010, Calambokidis and Barlow 2013). Vertical bars indicate ±2 standard errors of each abundance estimate.

HUMAN-CAUSED MORTALITY AND SERIOUS INJURY

Fisheries Information

Two blue whales were seriously-injured in California Dungeness crab pot gear and a third whale was seriously-injured in an unidentified pot/trap fishery during the most recent 5-year period of 2012-2016 (Carretta *et al*. 2018a). Two additional prorated serious injuries were observed in unidentified fishing gear during the same period (Table 1). There have been no observed entanglements of blue whales in the California swordfish drift gillnet fishery during a 27-year observer program that includes 8,845 observed fishing sets from 1990-2016 (Julian and Beeson 1998, Carretta *et al*. 2004, Carretta *et al.* 2018b). However, some gillnet mortality of large whales may go unobserved because whales swim away with a portion of the net. The total observed serious injury and mortality due to commercial fisheries from 2012-2016 is 4.5 whales, or 0.9 whales annually. This represents a negatively-biased accounting of the serious injury and mortality of blue whales in the region, because not all cases are detected and there is no correction factor available to account for undetected events.

Unidentified whales represent approximately 15% of entanglement cases along the U.S. West Coast, (Carretta 2018). Observed entanglements may lack species IDs due to rough seas, distance from whales, or a lack of cetacean identification expertise in some cases. In previous stock assessments, these unidentified entanglements were not assigned to species, which results in underestimation of entanglement risk, especially for commonly-entangled species. To remedy this negative bias, a cross-validated species identification model was developed from known-species entanglements ('model data'). The model is based on several variables (location + depth + season + gear type + sea surface temperature) collectively found to be statistically-significant predictors of known-species entanglement cases (Carretta 2018). The species model was used to assign species ID probabilities for 21 unidentified whale entanglement cases (‘novel data’) from 2012-2016. Species probability assignments resulted in an additional 0.3 additional blue whale entanglements for 2012-2016, or 0.06 blue whales annually.

Annual entanglement rates of blue whales (observed) during 2012-2016 is the sum of observed annual entanglements (0.9/yr), plus species probability assignments from unidentified whales (0.06/yr), or 0.96 blue whales annually.

Table 1. Summary of available information on observed incidental mortality and injury of blue whales (Eastern North Pacific stock) from commercial fisheries (Carretta *et al.* 2018a, 2018b). Values in this table represent observed deaths and serious injuries and totals are negatively-biased because not all cases are detected.

Fishery Name	Year(s)	Data Type	Percent Observer Coverage	Observed Mortality (and serious injury)	Estimated mortality and/or serious injury (CV in parentheses)	Mean Annual Mortality and Serious Injury (CV in parentheses)
CA Dungeness crab pot	2012-2016	Strandings and sightings	n/a	0 (2)	n/a	≥ 0.4
Unidentified pot/trap fishery	2012-2016	Strandings and sightings	n/a	0 (1)	n/a	≥ 0.2
Unidentified fishery	2012-2016	Strandings and sightings	n/a	0 (1.5)	n/a	≥ 0.3
CA/OR thresher shark/swordfish drift gillnet fishery	2012-2016	observer	23%	0	0	0 (n/a)
Total Annual Takes						≥ 0.9

Ship Strikes

One blue whale ship strike death was observed during the most recent 5-year period of 2012-2016 (Carretta *et al*. 2018a), resulting in an observed annual average of 0.2 ship strike deaths. Observations of blue whale ship strikes have been highly-variable in previous 5-year periods, with as many as 10 observed (9 deaths + 1 serious injury) during 2007-2011 (Carretta *et al*. 2013). The highest number of blue whale ship strikes observed in a single year (2007) was 5 whales (Carretta *et al*. 2013). Over the 10-year period 2007-2016, 11 blue whale ship strikes were observed (Carretta *et al*. 2013, 2018a). In addition, 4 unidentified whales were also observed struck by ships during the same 10-year period. No methods have been developed to prorate the number of unidentified whale ship strike cases to species, because of small observed sample sizes and identified cases are likely biased towards species that are large, easy to identify, and more likely to be detected, such as blue and fin whales. Most observed blue whale ship strikes have been in southern California, where large container ship ports overlap seasonally with blue whale distribution (Berman-Kowalewski *et al*. 2010). Including ship strike records identified to species and prorated serious injuries, blue whale mortality and injuries attributed to ship strikes in California waters was one whale during 2012-2016 (Carretta *et al*. 2018a). Documented ship strike deaths and serious injuries are derived from observed whale carcasses and at-sea sightings and are considered minimum values. Where evaluated, estimates of detection rates of cetacean carcasses are consistently quite low across different regions and species (<1% to 17%), highlighting that observed numbers are unrepresentative of true impacts (Kraus *et al*. 2005, Perrin *et al*. 2011, Williams *et al*. 2011, Prado *et al*. 2013). Due to this negative bias, Redfern *et al*. (2013) first noted that the number of observed ship strike deaths of blue whales in the U.S. West Coast EEZ likely exceeds PBR.

Ship strike mortality was recently estimated for blue whales in the U.S. West Coast EEZ (Rockwood *et al*. 2017), using an encounter theory model (Martin *et al.* 2016) that combined species distribution models of whale density (Becker *et al*. 2016), vessel traffic characteristics (size + speed + spatial use), along with whale movement patterns obtained from satellite-tagged whales in the region to estimate encounters that would result in mortality. The estimated number of annual ship strike deaths was 18 blue whales, though this includes only the period July – November when whales are most likely to be present in the U.S. West Coast EEZ and the season that overlaps with cetacean habitat models generated from line-transect surveys (Becker *et al*. 2016, Rockwood *et al*. 2017). This estimate was based on an assumption of a moderate level of vessel avoidance (55%) by blue whales, as measured by the behavior of satellite-tagged whales in the presence of vessels (McKenna *et al*. 2015). The estimated mortality of 18 blue whales annually due to ship strikes represents approximately 1% of the estimated population size of the stock

(18 deaths / 1,647 whales). The results of Rockwood *et al*. (2017) also include a no-avoidance encounter model that results in a worst-case estimate of 40 annual blue whale ship strike deaths, which represents 2.4% of the estimated population size. Using the moderate level of avoidance model from Rockwood *et al*. (2017), estimated ship strike deaths of blue whales are 18 annually. A comparison of average annual ship strikes observed over the period 2012-2016 (0.2/yr) versus estimated ship strikes (18/yr) indicates that the rate of detection for blue whale vessel strikes is approximately 1%. Comparing the highest number of ship strikes observed in a single year (5 in 2007) with the estimated annual number (18) implies that ship strike detection rates have not exceeded 27% (5/18) in any single year.

Impacts of ship strikes on population recovery of the eastern North Pacific blue whale population were assessed by Monnahan *et al*. (2015). Their population dynamics model incorporated data on historic whaling removals, levels of ship strikes, and projected numbers of vessels using the region through 2050. The authors concluded (based on 10 ship strike deaths per year) that this stock was at 97% of carrying capacity in 2013 and that current ship strike levels do not pose a threat to the status of this stock. These authors also analyzed the status of the blue whale stock based on a 'high case' of annual ship strike deaths (35/yr) and concluded that under that scenario, the stock would have been at approximately 91% of carrying capacity in 2013. Caveats to the carrying capacity analysis include the assumption that the population was already at carrying capacity prior to commercial whaling of this stock in the early 20th century and that carrying capacity has not changed appreciably since that time (Monnahan *et al*. 2015).

Vessel traffic within the U.S. West Coast EEZ continues to be a ship strike threat to all large whale populations (Redfern *et al*. 2013, Moore *et al.* 2018). However, a complex of vessel types, speeds, and destination ports all contribute to variability in ship traffic, and these factors may be influenced by economic and regulatory changes. For example, Moore *et al*. (*in press*) found that primary vessel travel routes changed when emission control areas (ECAs) were established off the U.S. West Coast. They also found that large vessels typically reduced their speed by 3-6 kts in ECAs between 2008 and 2015. The speed reductions are thought to be a strategy to reduce operating costs associated with more expensive, cleaner burning fuels required within the ECAs. In contrast, Moore *et al*. (2018) noted that some vessels increased their speed when they transited longer routes to avoid the ECAs. Further research is necessary to understand how variability in vessel traffic affects ship strike risk and mitigation strategies.

Habitat Issues

Increasing levels of anthropogenic sound in the world's oceans is a habitat concern for blue whales (Reeves *et al*. 1998, Andrew *et al*. 2002). Tagged blue whales exposed to simulated mid-frequency sonar and pseudo-random noise demonstrated a variety of behavioral responses, including no change in behavior, termination of deep dives, directed travel away from sound sources, and cessation of feeding (Goldbogen *et al*. 2013). Behavioral responses were highly dependent upon the type of sound source and the behavioral state of the animal at the time of exposure. Deep-feeding and non-feeding whales reacted more strongly to experimental sound sources than surface-feeding whales that typically showed no change in behavior. The authors stated that behavioral responses to such sounds are influenced by a complex interaction of behavioral state, environmental context, and prior exposure of individuals to such sound sources. One concern expressed by the authors is if blue whales did not habituate to such sounds near feeding areas that "repeated exposures could negatively impact individual feeding performance, body condition and ultimately fitness and potentially population health." Currently, no evidence indicates that such reduced population health exists, but such evidence would be difficult to differentiate from natural sources of reduced fitness or mortality in the population. Nine blue whale feeding areas identified off the California coast by Calambokidis *et al*. (2015) represent a diversity of nearshore and offshore habitats that overlap with a variety of anthropogenic activities, including shipping, oil and gas extraction, and military activities.

STATUS OF STOCK

The reported take of North Pacific blue whales by commercial whalers totaled 9,500 between 1910 and 1965 (Ohsumi and Wada 1972). Approximately 3,000 of these were taken along the west coast of North America from Baja California, Mexico to British Columbia, Canada (Tonnessen and Johnsen 1982; Rice 1992; Clapham *et al*. 1997; Rice 1974). Recently, Monnahan *et al*. (2014) estimated that 3,411 blue whales (95% range 2,593–4,114) were removed from the eastern North Pacific populations between 1905 and 1971. Blue whales in the North Pacific were given protected status by the IWC in 1966, but Doroshenko (2000) reported that a small number of blue whales were taken illegally by Soviet whalers after that date. As a result of commercial whaling, blue whales were listed as "endangered" under the Endangered Species Conservation Act of 1969. This protection was transferred to the Endangered Species Act in 1973. Despite a current analysis suggesting that the Eastern North Pacific population is at 97% of carrying capacity (Monnahan *et al*. 2015), blue whales are listed as "endangered", and consequently the Eastern North Pacific stock is automatically considered a "depleted" and "strategic" stock under the MMPA. Conclusions about the population's current status relative to carrying capacity depend upon assumptions that the population was already at carrying capacity before commercial whaling impacted the population in the early 1900s, and that carrying capacity has remained relatively constant since that time (Monnahan *et al*. 2015). If carrying capacity has changed significantly in the last century, conclusions regarding the status of this population would necessarily change (Monnahan *et al*. 2015).

The observed annual incidental mortality and injury rate from ship strikes (0.2/yr) and commercial fisheries (≥ 0.9/yr), totals 1.1 whales annually from 2012-2016. While this does not exceed the calculated PBR of 2.3 for this stock of blue whales, observations alone are not representative of impacts due to incomplete detection of vessel strikes and fishery entanglements. However, *estimated* vessel strike mortality (18/yr) exceeds the calculated PBR of 2.3 for this stock of blue whales and does not include vessel strikes outside of the U.S. EEZ. Monnahan *et al*. (2015) proposed that estimated ship strike levels of 10 – 35 whales annually did not pose a threat to the status of this stock, but estimates of carrying capacity of this blue whale stock differed depending on the level of ship strikes: 97% of K with 10 annual strikes and 91% of K with 35 annual strikes. The highest estimates of blue whale ship strike mortality (35/yr; Monnahan *et al*. (2015) and 40/yr; Rockwood *et al*. (2017) are similar, and annually represent approximately 2% of the estimated population size. Observed and assigned levels of serious injury and mortality due to commercial fisheries (≥ 0.96) for this stock are not less than 10% of the stock's PBR (2.3), thus, commercial fishery take levels are not approaching zero mortality and serious injury rate.

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