SC/66a/IA/16

Assessing the status and pre-exploitation abundance of North Pacific humpback whales

Yulia V. Ivashchenko, Alex N. Zerbini and Phillip J. Clapham

INTERNATIONAL
WHALING COMMISSION

Assessing the status and pre-exploitation abundance of North Pacific humpback whales

YULIA V. IVASHCHENKO, ALEX N. ZERBINI & PHILLIP J. CLAPHAM

[1]National Marine Mammal Laboratory
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115, USA

ABSTRACT

In part because of uncertainty in the catch record relating to illegal Soviet whaling, the IWC has not undertaken a Comprehensive Assessment of North Pacific humpback whales. With the recent correction of this catch record, such an assessment can now be considered. Here, we present a summary of existing data on catches, population structure, abundance, and trends of North Pacific humpback whales in order to generate a discussion about future approaches to assess the status of this population. We used a single-population logistic model that incorporates multiple intrinsic growth rate scenarios (ranging from 0% to 12% per annum), catch history and current abundance in an attempt to evaluate whether model output was consistent with observed estimates of population growth in the past 20-40 years. Not surprisingly given the simplistic approach, the model's predicted growth rates since the end of whaling to the present did not match observed growth rates for various periods and regions where humpback whales occur in the North Pacific. Explanations for this lack of consistency include: 1) the one-stock model does not incorporate the complicated structure of the population and is not appropriate for this population, 2) commercial catches were significantly under-reported; 3) *K* has changed (i.e. increased) since the beginning of whaling; 4) aboriginal catches prior to the commencement of commercial whaling were significantly larger than has been assumed; or 5) a combination of these factors. We make recommendations regarding approaches to the development of a more realistic assessment, and seek input from the Scientific Committee on future work.

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) are common in all oceans and conduct long seasonal migrations between winter breeding areas in the tropics and summer feeding grounds in high latitudes (Clapham & Mead 1996). In the North Pacific (NP) they are found along all coastal areas of Asia and North America (Mackintosh 1946). Currently, it is believed that NP humpback whales exist in at least five breeding sub-populations stretching from coastal Mexico to Asia; these are connected to various feeding areas in the northern NP, from the western coast of the United States through British Columbia and Alaskan waters to Russia in the east.

In part because the catch record has until recently been incomplete, NP humpback whales have never been the focus of a Comprehensive Assessment by the International Whaling Commission (IWC). Such assessments use recent estimates of abundance and trend together with a historical catch series to assess the pre-exploitation size of the population, and its current status relative to that benchmark. Recently, the catch record has been updated to include new information on extensive illegal takes by the USSR (Ivashchenko *et al.* 2013). In addition, there is now considerable new information on the current abundance and population structure of NP humpbacks, derived from the multi-national photo-identification and genetic study known as Structure Levels of Abundance and Status of Humpback Whales (SPLASH) (Calambokidis *et al.* 2008; Barlow *et al.* 2011; Baker *et al.* 2013). Using these new data, we here undertake a preliminary and simple first assessment of NP humpback whales, after providing some basic background information for this population. We highlight problems with both the single-population model and the data, and suggest approaches to the development of a more realistic assessment.

BACKGROUND

Whaling history

Whaling for humpback whales in the NP existed for centuries, with known hunting locations including Japan, North America, the Aleutian Islands and Chukotka (Reeves & Smith 2006). Three main periods are described based upon the methods and materials used in the hunt and the extent of the operations: aboriginal, historical and modern whaling.

Aboriginal whaling is characterized by a number of whaling methods used in the different regions throughout the NP. These include poison-tipped arrows, hand harpoon and lance, and nets (Reeves & Smith 2006). The most detailed whaling records from the aboriginal period exist in Japan. In this area, the hunt of large whales was recorded as early as the 10th century (Omura 1986). Starting in the 16th century, the use of nets revolutionized whaling in Japan and led to increased catches not only of humpbacks but other species as well; detailed records that survive from a few whaling areas provide an example of the extent and composition of catches (Omura 1986). In other regions of the NP no information exists on the number of whales killed, but there is occasionally reference to which species were hunted (Krupnik 1979, 1980; Stoker & Krupnik 1993). Concerning humpback whales, the only records of the actual number of whales killed come from Japanese coastal whaling operations; however, these records cover only a few areas out of many whaling locations around Japan and can only be considered as incomplete. Additionally, the almost complete lack of information concerning the number of humpbacks taken along the western coast of North America, Aleutian Islands and Chukotka makes assessing of the extent of aboriginal whaling very difficult. However, it is probably a reasonable assumption that the number of whales taken in the northern and eastern NP by these relatively primitive operations was not high, and thus likely had little impact on the populations concerned. The same may not be true of the historical Japanese hunts, which may have taken significant numbers of humpback whales around the coasts of Japan.

Studies of the Chukotka hunt for large whales show that bowhead (*Balaena mysticetus*) and gray whales (*Eschrichtius robustus*) were the primary target, with humpback whales only occasionally taken; this was the case even during the period 1910-1930 when bowhead whales were severely depleted. During this time, there was an increase in the number of gray whales in the catch records, but very few humpbacks were taken despite their abundance at that time (Krupnik 1987; Bogoslovskaya *et al.* 1982).

Historical whaling, involving sail-based vessels and hand-thrown harpoon technology, first appeared in the NP about 1780; at various times the main target species were sperm (*Physeter macrocephalus*), North Pacific right (*Eubalaena japonica*) and bowhead whales (Webb 1988). However, humpback whales were also killed, albeit in much smaller numbers. Townsend (1935), who analyzed logbooks and journals from American ("Yankee") whaling vessels for the period 1785 to 1912[1], gives the only known numbers for historical catches of humpback whales in the NP. During that period Townsend (1935) recorded large number of humpback whales killed in the Southern Hemisphere and North Atlantic; by contrast, the reported catch in the NP was very limited and totals only 208 whales caught in four main areas: the Mexican wintering grounds (147 animals), the Mariana Islands (51), California (5) and areas around Japan (5). The true extent of historical catches of humpback whales in the NP has not been assessed, and requires additional studies of whaling logbooks and journals.

The intermediate period, described by Reeves and Smith (2006) as American shore whaling, began during the second half of the 19th century and was characterized by the establishment of a number of shore whaling stations along the coasts of California and Baja California. These hunted gray and humpback whales using catcher boats, but with still rather inefficient equipment and processing methods. A detailed analysis of catches of both species was published by Reeves and Smith (2010); these data, as well as extrapolation for unknown catches, gave an estimate of humpback landings of 1,637 (SE=62), including struck and lost animals. This number inevitably has associated uncertainties, and additional work by local historians is required to fill the gaps. However, it currently represents the best estimate of humpback whale catches during this period.

Modern whaling spread throughout the NP beginning in 1889, when Russian whaling companies working around Japan used a floating factory and modern steam-powered catchers equipped with Føyn's harpoon guns (Webermann 1914;

[1] This period includes log books from whalers that worked all over the world and does not necessarily refers to the period of whaling in the NP.

Webb 1988). Over the next four decades, numerous coastal operations were established in Japan and along the western coast of North America (Webb 1988). At that period humpback whales became one of the primary target species for whalers in the eastern NP, and excessive catches drove some population into a significant decline which ultimately forced the closure of many whaling stations (Starks 1922; Webb 1988).

From the beginning of the 20th century numerous companies hunted humpback whales and other balaenopterid species all over the NP. Webb (1988) and Tønnessen and Johnsen (1982) describe a common pattern of temporary success followed by declining whale abundance and the inevitable closure of many whaling stations. Most companies ran shore-based operations and were thus limited in their whaling range; consequently, when whale resources in the area were exhausted the station had to be closed or operations moved elsewhere (Webb 1988). On a few occasions whaling companies invested in factory ships which worked as a processing station instead of or together with a land station; this occurred in Alaskan waters (in the Shumagin Islands, Baranof Islands, and at Akutan) and also along the Mexican coast. However, some of these attempts proved unsuccessful due to the high cost of operating and the low catches (Tønnessen & Johnson 1982).

Catch statistics for humpback whales in the North Pacific are close to complete, although many do not include information regarding the positions, length, sex and maturity of individual animals. Overall, whaling production in the NP varied significantly between different companies and between years, but humpbacks were one of the most common species in the catch, and were sometimes taken in large numbers. For example, the American Pacific Whaling Company, operating from Gray's Harbor, Washington during the period 1911-1925 took 2,698 whales, of which 1,933 were humpbacks (Tønnessen & Johnson 1982). During a similar period (1919-26), the shore stations at Moss Landing and Trinidad in California killed 2,111 whales, of which the great majority (1,871) were humpbacks; this resulted in a population crash and the closure of both stations (Clapham *et al.* 1997).

Beginning in 1932, truly pelagic whaling operations, involving roaming factory ships and their associated fleets of catcher vessels, came to the NP. Once again the first operation was Russian: the first Soviet whaling fleet (the *Aleut*) began its work in 1932 with a "training" catch of 7 sei whales on the way to its home port of Vladivostok (Zenkovich 1954; Ivashchenko *et al.* 2011). In 1940, Japanese whaling factories went for the first time into the areas off Kamchatka and Chukotka (Terry 1950). All pelagic whaling fleets that worked in the NP belonged to only two countries: Japan and the Soviet Union.

Before the Second World War pelagic operations in the North Pacific were few, and annual catches of humpback whales were small, ranging from a few animals to 143 (Allison 2012). In 1946, nine countries signed the International Convention for the Regulation of Whaling (ICRW), among them the Soviet Union. From that point on each country was required to report to the Bureau of International Whaling Statistics (BIWS) detailed information on each whale taken, which resulted in a detailed database of catches for all species. For the catches of NP humpback whales the only limitation was a minimum size limit, set at 10.7m (35 feet), as well as a prohibition on the killing of lactating females and calves, and any pelagic operations in the area between 0 and 20-35 N latitude (IWC 1950). This remained the case until all catches of humpback whales in the NP were prohibited beginning from the 1966 season (IWC 1967). By that time, however, catches of humpback whales were already very low, and the situation was assumed to be a repeat of that in the Antarctic, where humpback populations had been greatly over-exploited. The IWC (1966) noted that the prohibition in the NP was necessary "in order for the population to rebuild to a level giving a substantial sustainable yield".

Until 1993, it was widely assumed that the modern whaling catch record was largely complete, especially for the period following creation of the IWC, with the exception of some years of missing data for specific shore whaling stations. The total catch of NP humpback whales during the period 1946-66 was believed to be 7,808, and 26,564 for the entire period of modern whaling (1900-66) (Allison 2012).

However, in 1993, it was revealed that Soviet whalers had conducted a global campaign of illegal whaling, with large unreported catches in both the Antarctic and the NP (Clapham & Ivashchenko 2009; Ivashchenko *et al.* 2011). Humpback whales were one of the main targets of the hunt, with more than 48,000 taken (mostly illegally) in the Antarctic (Clapham *et al.* 2009). An attempt to reconstruct Soviet catch totals for the NP was made by Doroshenko (2000a,b), but this was based upon incomplete data and lacked details on the timing and position of catches. More recently, Ivashchenko *et al.* (2013) have used previously unavailable Soviet whaling reports to give an updated total for all Soviet whaling catches in the NP. With these additional catches, the total number of humpbacks killed in the NP during the 20th century is now estimated to be 29,103 whales.

Population structure

Current understanding of humpback whale population structure in the NP developed through use of photo-identification, genetics and satellite tagging. The current most complete picture of humpback whale population structure in the NP comes from the multi-national photo-identification and genetic study known as Structure of Populations Levels of Abundance and Status of Humpback Whales (SPLASH) (Calambokidis *et al.* 2008; Barlow *et al.* 2011; Baker *et al.* 2013). The study showed a complicated mixing pattern between breeding and feeding grounds, with the majority of whales showing strong site fidelity to both specific feeding and breeding areas.

Currently four breeding populations have been identified: the Western NP (Okinawa and Philippines), Hawai'i, Mexico (mainland and the offshore waters of the Revillagigedo Islands), and Central America. Relatively low match rates between whales feeding in the Aleutian Islands and these four breeding areas indicate the likely existence of a fifth breeding population whose location is presently unknown; for the purpose of management, the U.S. National Marine Fisheries Service recently lumped this unidentified stock with the Western North Pacific.

The SPLASH results also highlighted six main feeding areas: California-Oregon (CA_OR), northern Washington-southern British Columbia (NWA_SBC), northern British Columbia-Southeast Alaska (NBC_SEAK), Aleutian Islands-Bering Sea (Al_BS) and the eastern coast of Kamchatka (Kam) (Barlow *et al.* 2011; Baker *et al.* 2013). The selection of the boundaries was based upon breaks in humpback whale distribution, observed exchange rates from photo-id matches, and genetic differentiation. Data from Russian waters were collected from three different areas: the Commander Islands, the eastern coast of Kamchatka, and the Gulf of Anadyr, although the Commander Islands and Gulf of Anadyr were subsequently placed together with the Aleutians-Bering Sea region.

Estimates of abundance

Rice (1978) estimated that before 1905 the population was around 15,000 whales based upon the catch history, which was then incomplete. To date, this is the only estimate of the population size in the NP prior to the advent of modern whaling. An estimate of 1,200-1,400 remaining humpbacks in the NP by the end of modern whaling on this species in 1966 was given by Gambell (1976) and Johnson and Wolman (1984). All of these estimates likely involve considerable uncertainty.

A number of local studies have provided estimates for different sub-populations on feeding or breeding grounds over the last 35 year. These include: Hawaii, Mexico, USA west coast/California-Oregon, Southeast Alaska and western Alaska, which includes the Alaska Peninsula and the eastern Aleutian Islands. The abundance estimates and calculated growth rates (r) are summarized in the Table 1. A few of these studies were able to establish a growth rate for a limited region or for the whole North Pacific, with reported rates between 6.6% and 10% (Table 2).

The most current estimate of the NP population as a whole comes from SPLASH, which used photo-identification mark-recapture to estimate total population size at 21,808 (CV= 0.027) (Barlow *et al.* 2011).

METHODS AND MATERIALS

Catches

Catch information was taken from different sources. The IWC database was used for humpback whale catches made by different countries for the period 1906-2006, except for Soviet catches from 1962 through 1972. Earlier catches (by Japan and land stations along the western coast of North America) were taken from the published literature. Soviet catches were reconstructed using formerly secret internal whaling industry reports (primarily those written by fleet scientists and whaling inspectors) that provided details of the distribution and number of catches (Ivashchenko *et al.* 2013). Using these reports together with geo-referencing of maps given by Doroshenko (2000b), we were able to assign positions to 3,271 Soviet humpback whale catches made after 1962 (Figure 1).

The model

We specified a deterministic generalized logistic model (Pella-Tomlinson), which has been previously used by the IWC in the assessment of Southern Hemisphere right and humpback whales (IWC 2001, 2002):

$$N_{t+1} = N_t + N_t \cdot r_{\max} \cdot \left[1 - \left(\frac{N_t}{K}\right)^z\right] - C_t$$

where:

- *N – is the population size, in numbers, at time 't' or 't+1', in years;*
- r_{max} *– is the maximum intrinsic growth rate;*
- *K – is the pre-exploitation population size;*
- *z – is the "shape" parameter (set here at 2.39, where MSYL = 0.6);*
- C_t *– is the catch, in numbers, in year 't'.*

The model started in the year for which the earliest catches were reported (1698) and was projected forward until 2015. We estimated the value of *K* required to obtain the most recent abundance (N_{2006}=21,800, Barlow *et al.* 2011) given the catch series for six different maximum intrinsic growth rate scenarios: 0, 2.5, 5, 7.5, 10 and 12% per annum (Table 2). We computed various quantities of interest (Table 2) and compared the model's predicted growth rate with those empirically estimated from survey data across the North Pacific Ocean (Tables 1 and 2).

RESULTS

Results from the population model are presented in Table 3 and illustrated in Figure 2. In none of the growth rate scenarios considered here did the maximum depletion rate fall below 37% of the original population size, and the population was never smaller than approximately 13,000 individuals. The original size of the population (*K*) given the intrinsic growth rates (r_{max}) varied from 29,621 to 54,357, with both extreme numbers coming from more unrealistic growth rate scenarios (0% and 12%). The recovery level in the year of the latest abundance estimate (2006) ranged from 40.1 to 73.6%, and the current (2015) recovery level ranged from 40.1 to 76.5% (Table 3 and Figure 2).

A comparison of the model's predicted rates of increase in all scenarios with empirical estimates computed in various regions across the North Pacific is presented in Table 2. It is clear that the model's predicted rates, irrespective of the r_{max} scenario, are inconsistent with the point estimates provided by most surveys, suggesting that the model fails to capture the population dynamics of humpback whales during and after whaling.

DISCUSSION

Not surprisingly, the modeling exercise conducted here produced results that were inconsistent with various empirical estimates of the rate of increase of North Pacific humpback whales between the end of whaling for this species and the present. There are several possible explanations for the failure of the model reproduce results from survey data: 1) the single stock model does not incorporate the complicated structure of North Pacific humpback whales and is not appropriate for this population, 2) commercial catches were significantly under-reported; 3) *K* has changed (i.e.

increased) since the beginning of whaling; and 4) aboriginal catches prior to the commencement of commercial whaling were significantly larger than has been assumed; or 5) a combination of these factors.

Given the number of known shore-based operations in the early days of whaling in Japan, it is possible that catches from this fishery were large enough to render the humpback whale population in the western NP depleted even before sail-based and modern commercial whaling began.

FUTURE WORK

As noted above, any model to assess and estimate the pre-exploitation population size of humpback whales in the North Pacific requires catches assigned to defined regions, recent estimates of abundance, and population growth rates based upon earlier estimates. Given that our simple one-population model failed to fit the data, we suggest that the following steps need to be taken to develop a more realistic model with which to assess this population:

- Feeding areas should be modeled separately. This assumes minimal exchange among them, which is reasonably consistent with SPLASH results.
- Sensitivity tests should be employed, assigning catches to different areas to examine whether it makes a difference to the outcome.
- *K* and initial population size should be treated as separate parameters rather than running the model with these two factors combined.

Below, we expand on these recommendations and provide details of the various factors involved.

Definitions of Breeding and Feeding areas

We have adopted the locations of humpback whale breeding and feeding areas from the SPLASH project. To define the boundaries of each region we at first drew a 100-m buffer from the 1000-m isobath (Figure 3) Many catches were distributed much further offshore of this designated buffer, and some of the regions were expanded offshore or additional regions were created (Figure 4) (see description below).

Breeding areas

Five breeding areas have being described for the North Pacific (Barlow *et al.* 2011). Since no pelagic catches were made on the breeding grounds, we describe the breeding area boundaries as wider ovals and include the Philippines and Okinawa, Hawaii, Mexico, Central America and the Unknown Breeding Area. Coastal whaling catches were made only in the Philippines/Okinawa and Mexico.

Feeding areas

Currently six different feeding regions are recognized in the NP:

- **Russia** (= eastern Kamchatka): an area which follows the contour of a 100-m buffer zone from the southern tip of Kamchatka to the northern end of Karaginskiy Gulf.
- **Aleutians/Bering Sea** (Al_BS). The Aleutian Islands chain includes the Commander Islands. This feeding area is defined as beginning halfway between the Kamchatka coast and the closest of the

Commanders, with an eastern extent at False Pass (Alaska Peninsula); the region extends north to include the Bering Sea and Chukchi Sea. The southern boundary initially follows the 100-m buffer zone, but we include the area below the Aleutian chain to 45° N to include catches that were distributed south of this region.

- **Gulf of Alaska** (GOA). During SPLASH data collection this region was separated into two areas: western and northern GOA. The southern boundary follows the 100-m buffer zone and the eastern end terminates at longitude 141° W.

- **Southeast Alaska** (SEAK) and **northern British Columbia** (NBC). This region is placed between the GOA and the northern part of British Columbia, with a southern boundary passing close to 50° N. Along the coast it follows the 100-m buffer line.

- **Southern British Columbia** (SBC) and **northern Washington** (WA). This region continues south to the southern boundary of Washington state at latitude 46° N, while to the west it follows the 100-m buffer zone.

- **California** (CA) and **Oregon** (OR). This region's boundaries follow the 100-m buffer line from the northern end of Oregon to the southern end of California, covering the coastal area from 46° N to 32° 30'N.

Additional areas were designated in order to assign catches, as follows:

- **Pelagic Gulf of Alaska** (pelagic GOA): this region includes offshore waters south of the GOA and SEAK regions with a southern boundary along latitude 52°N. It was created to incorporate pelagic catches in the GOA.

- **Pelagic North Pacific** (pelagic NP): this region covers the area south of the GOA and west of British Columbia, Washington and part of Oregon. The southern boundary follows latitude 43°N with the eastern margin at longitude 160°W.

- **Japan, Ogasawara** and **Baja**. These are considered migration routes, with Baja and Ogasawara possibly representing a mixing of whales from two or more feeding/breeding grounds.

Allocation of catches

After all the regions described above are defined in GIS, all modern catches with individual positions can be assigned to a particular region. Known coastal catches would be assigned based upon the locations of coastal whaling stations. The majority of catches were made on the feeding grounds, but a significant number of whales were killed on the breeding grounds (Mexico, Philippines, Okinawa) and on migration routes (notably the coast of Japan, as well as Ogasawara and Baja California). All catches from coastal Japan would be assigned to the Russian feeding region. We suggest that Ogasawara catches, based on the SPLASH photo-id exchange rates observed with the feeding regions, should be split 30%, 47% and 23% between Russia, Al_BS and GOA. Catches from the beginning of the 20th century off Baja are assumed to come from the breeding population in Mexico, although a small percentage were likely whales migrating from Central America. Mexico has been shown to have connections to all known feeding grounds.

Catches from the pelagic regions were assign in different ways. Pelagic GOA catches were divided based on the boundary proportion of neighboring feeding regions: 75% to GOA and 25% to SEAK_NBC. Humpback whale catches made in the pelagic North Pacific region were split in equal parts (1/3 each) between AL_BS, GOA and SEAK_NBC. Very limited number of catches made around Kuril Is were assign as follows: 50% to Al_BS and 50% to Russian feeding region.

Two areas have major uncertainties in catch totals: California catches during the period 1856-1900, and Japanese coastal catches from 1656 through1900. We suggest three scenarios for each area, with values for minimum, median and maximum catch totals. For Japanese catches the minimum (base) can be represented by known (recorded) catches; however, given that catch data are available from only some of the stations that were known to have existed, we also recommend using values that are double and triple the base numbers. In total, there are nine recommended scenarios for use in a future model (Appendix 1). Humpback whale catch records from Japan before 1850s often came as a summary number for a period of years (10-50 years), and for the purpose of the yearly catch database the totals were evenly split between all years for the period covered (for example: during 1748-57 a total of 48 humpback whales were caught, so the catch database assigns 5 whales each year with two years of 4 whales). A final list of catches is shown in Table 4.

Estimates of abundance and rates of exchange

Estimates of abundance for feeding and breeding grounds have recently been calculated using multi-strata analysis (Wade *et al.* in progress). Current abundance estimates for feeding regions are[2]: Russia - 898; Al_BS - 7,914; GOA - 1,906; SEAK_NBC - 5,046; SBC_NWA - 301; CA_OR - 1,254 whales. Exchange rates among feeding and breeding areas are shown in Table 5 and Figure 5.

References

Allison, C. 2012. *International Whaling Committee summary database*, version 5.2. Available from the International Whaling Commission, Cambridge, UK.

Baker, C.S. & Herman, L.M. 1987. Alternative population estimates of humpback whales (Megaptera novaeangliae) in Hawaiian waters. *Canadian Journal of Zoology*, 65(11): 2818-2821.

Baker, C.S., Herman, L.M., Perry, A., Lawton, W.S., Straley, J.M., Wolman, A.A., Kaufman, G.D., Winn, H E., Hall, J.D., Reinke, J.M. & Ostman, J. 1986. Migratory movement and population structure of humpback whales (*Megaptera novaeangliae*) in the central and eastern North Pacific. *Marine Ecology Progress Series*, 31: 105-119.

Baker, C.S., Straley, J.M., & Perry, A. 1992. Population characteristics of individually identified humpback whales in southeastern Alaska: summer and fall 1986. *Fishery Bulletin*, 90(3): 429-437.

Baker, C.S., Straley, J.M., Perry, A. 1990. Population characteristics of humpback whales in Southeastern Alaska: summer and late season, 1986. Final report. v+23p.

Baker, S.C., Steel, D, Calambokidis, J., Falcone, E., González-Peral, U., Barlow, J., Burdin A., Clapham, P., Ford, J., Gabriele, C., Matilla, D., Rochas-Bracho, L., Straley, J., Taylor, B.,Urban, J., Wade, P., Weller, D., Witteveen, B. &Yamaguchi, M. 2013. Strong maternal fidelity and natal philopatry shape genetic structure in North Pacific humpback whales. *Marine Ecology Progress Series,* 494: 291–306

Barlow, J., Forney, K.A. 2007. Abundance and population density of cetaceans in the California current ecosystem. *Fishery Bulletin,* 105: 509-526.

Barlow, J., Calambokidis, J., Falcone, E.A., Baker, S.C., Burdin, A.M., Clapham, P., Ford, J.K.B., Gabriele, C.M., LeDuc, R., Mattila, D., Quoin II, T., Rojas Bracho, L., Straley, J., Taylor, B., Urban, J., Wade, P., Weller, D., Wittevenn, B. & Yamaguchi, M. 2011. Humpback whale abundance in the North Pacific estimated by photographic capture-recapture with bias correction from simulation studies. *Marine Mammal Science*, 27: 793-818.

Bogoslovskaya, L.S., Votrogov, L.M. & Krupnik, I.I. 1982. The bowhead whale off Chukotka: migrations and aboriginal whaling. *Reportsof the International Whaling Commission*, 32: 391-9.

[2] Current abundance numbers will be adjusted as the analysis is completed.

Calambokidis, J.C. 2009. Abundance estimates of humpback and blue whales off the US West Coast based on mark-recapture of photo-identified individuals through 2008. Unpublished report PSRG-2009-07. Cascadia Research, Olympia WA. 12 pp.

Calambokidis, J., J.C. Cubbage, G.H. Steiger, K.C. Balcomb, and P. Bloedel. 1988. Humpback whale (*Megaptera novaeangliae*) distribution and abundance in the Gulf of the Farallones, 1987. Report to the National Park Service and Gulf of the Farallones National Marine Sanctuary, San Francisco, California. 65pp.

Calambokidis, J., J.C. Cubbage, G.H. Steiger & K.C. Balcomb. 1990. Population estimates of humpback whales in the Gulf of the Farallones, California. In: Hammond, Philip S., Sally A. Mizroch and Gregory P. Donovan (editors), Individual recognition of cetaceans: use of photo-identification and other techniques to estimate population parameters. *Reports of the International Whaling Commission*, Special Issue 12: 325-333.

Calambokidis, J., Steiger, G.H., Straley, J.M., Quinn, T.J.I., Herman, L.M., Cerchio, S., Salden, D.R., Yamaguchi, M., Sato, F., Urbán, R.J., Jacobsen, J., von Ziegesar, O., Balcomb, K.C., Gabriele, C.M., Dahlheim, M.E., Higashi, N., Uchida, S., Ford, J.K.B., Miyamura, Y., Ladrón de Guevara, P.P., Mizroch, S.A., Schlender, L. & Rasmussen, K. 1997. Abundance and population structure of humpback whales in the North Pacific basin: final report, Vol. Cascadia Research Collective, Olympia, WA.

Calambokidis, J. & Barlow, J. 2004. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture recapture and line-transect methods. *Marine Mammal Science*, 20: 63-85.

Calambokidis, J., Falcone, E., Quinn II, T. J., Burdin, A. M., Clapham, P., Ford, J. K. B., Gabriele, C. M., Leduc, C. A., Mattila, D., Rojas-Bracho, L., Straley, J., Taylor, B. L., Urban, J., Weller, D., Witteveen, B. H., Yamaguchi, M., Bendlin, A., Camacho, D., Flynn, C., Havron, A., Huggins, J. & Maloney, N. 2008. *SPLASH: Structure of Populations, Levels of Abundance and Status of Humpback Whales in the North Pacific*. Final report. Cascadia research, Olympia WA. 57 pp.

Clapham, P.J. & Mead, J.G. 1999. *Megaptera novaeangliae*. *Mammalian Species,* 604: 1-9.

Clapham, P.J., Leatherwood, S., Szczepaniak, I. & Brownell, R.L. Jr. 1997. Catches of humpback and other whales from shore stations at Moss Landing and Trinidad, California, 1919-1926. *Marine Mammal Science,* 13: 368-394.

Clapham, P.J. & Ivashchenko, Y.V. 2009. A whale of a deception. *Marine Fisheries Review*, 71(1): 44-52.

Clapham, P., Mikhalev, Y., Franklin, W., Paton, D., Baker, C. S., Ivashchenko, Y. & Brownell, R. L. Jr. 2009. Catches of humpback whales, *Megaptera novaeangliae*, by the Soviet Union and other nations in the Southern Ocean, 1947-1973. *Marine Fisheries Review*, 71(1): 39-43.

Darling, J.D. 1983. Migrations, abundance and behavior of Hawaiian humpback whales, *Megaptera novaeangliae* (Borowski). Ph.D. dissertation, University of California at Santa Cruz, Santa Cruz, CA.

Doroshenko, N.V. 2000a. Sovetskiy promisel blyuvalov, serikh i gladkikh (grenladskikh i yuzgnikh yaponskikh) kitov v Severnoy Patsifike v 1961-1979 gg. [Soviet whaling for blue, gray, bowhead and right whales in the North Pacific Ocean, 1961-1979.] In: *Soviet whaling data (1949-1979)*, eds A. V. Yablokov & V. A. Zemskiy, Center for Russian Environmental Policy, Moscow, pp. 96-104.

Doroshenko, N.V. 2000b. Sovetskiy promisel gorbachey (Megaptera novaeangliae) v Severnoy Patsifike. [Soviet catches of humpback whales (*Megaptera novaeangliae*) in the North Pacific.]. In: *Soviet whaling data*, eds A. Yablokov & V. A. Zemskiy, Moscow, pp. 48-95.

Gambell, R. 1976. World whale stocks. *Mammal Review*, 6: 41–53.

Ivashchenko, Y. V., Clapham, P. & Brownell, R. L. Jr. 2011. Soviet illegal whaling: the Devil and the details. *Marine Fisheries Review*, 73:1-19.

Ivashchenko, Y.V., Clapham, P.J. & Brownell, R.L. Jr. 2013. Soviet catches of whales in the North Pacific: revised totals', *Journal of Cetacean Research and Management,* 13: 59-71.

IWC. 1950. Report of the International Whaling Commission, Appendix I, International Convention for the Regulation of Whaling, London, pp. 9-19.

IWC. 1966. Report of the International Whaling Commission, Appendix III, Chairman's report of the sixteenth meetting, London, pp. 15-22.

IWC. 1967. Report of the International Whaling Commission, Appendix III, Chairman's report of the Seventeenth Meeting, London, pp. 17-24.

IWC. 2001. Right whales: worldwide status. *Journal of Cetacean Research and Management*, Special Issue 2.

IWC. 2002. Report of the International Whaling Commission, Annex H,, London, pp. 188-209.

Johnson, J.H. & Wolman, A.A. 1984. The humpback whale, *Megaptera novaeangliae*. *Marine Fisheries Review*, 46(4): 30-37.

Krupnik, I.I. 1979. Aboriginal Asiatic Eskimo Whaling in the 1920-1930's. XIV Pacific Science Congress USSR, Khabarovsk, August 1979. Committee F, Section F III, Abstracts. Moscow, 1979.

Krupnik, I.I. 1980. Morskoy zveroboyniy promisel asiatskikh eskimosov v 1920-1930 gg. [Marine mammal hunting of Asian Eskimos in 1920-1930.]. In: *Morskie Mlekopitayushchie [Marine Mammals]*, ed. V. A. Zemskiy, Moscow, pp. 66-79.

Krupnik, I.I. 1987. The bowhead vs. the gray whale in Chukotkan aboriginal whaling. *Arctic*, 46: 16-32.

Mackintosh, N.A. 1946. The natural history of whalebone whales. *Biological Reviews*, 21:60-74.

Mizroch, S.A., Herman, L.M., Straley, J.M., Glockner-Ferrari, D.A., Jurasz, C., Darling, J. & Von Ziegesar, O. 2004. Estimating the adult survival rate of central North Pacific humpback whales (*Megaptera novaeangliae*). *Journal of Mammalogy*, 85: 963-972.

Omura, H. 1986. History of right whale catches in the waters around Japan. *Reports of the International Whaling Commission,* Special Issue 10: 35-41.

Reeves, R.R. & Smith, T.D. 2006. A taxonomy of world whaling operations and eras. In *Whales, whaling and ocean ecosystems*, eds J.A. Estes, D.P. DeMaster, D.F. Doak, T.M. Williams & Brownell, R.L. Jr. University of California Press, Berkeley, CA, pp. 82-101.

Reeves, R.R. & Smith, T.D. 2010. Commercial whaling, especially for gray whales, *Eschrichtius robustus*, and humpback whales, *Megaptera novaeangliae*,at California and Baja California shore stations in the 19th century (1854-1899). *Marine Fisheries Review*, 72(1):1-25.

Rice, D.W. 1978. *The humpback whale in the North Pacific: distribution, exploitation and numbers*. U.S. Department of Commerce, NTIS PB 280-794.

Rice, D.W. & Wolman, A.A. 1979. Humpback whales census in Hawaiian waters, February 1977. In: K.S. Norris and R.S. Reeves (eds). Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. Report to the U.S. Marine Mammal Commission, Washington, DC, pp. 45-53.

Starks, E.C. 1922. A history of Calfornia shore whaling. *Fishery Bulletin*, l: 1-36.

Stoker, S.W. & Krupnik, I.I. 1993. Subsistence whaling. In *The bowhead whale*, eds J.J. Burns, J.J. Montague & C.J. Cowles, Society for Marine Mammalogy, Lawrence, KS, pp. 579-629.

Straley, J.M., Quinn, T.J.I. & Gabriele, C.M. 2009. Assessment of mark-recapture models to estimate the abundance of a humpback whale feeding aggregation in southeast Alaska. *Journal of Biogeography,* 36:427-438.

Terry, W.M. 1950. *Japanese whaling industry prior to 1946*. General Headquarters Supreme Commander for the Allied Powers, Natural Resources Section, Tokyo.

Tønnessen, J.N. & Johnsen, A.O. (eds) 1982. *The history of modern whaling*. University of California Press, Berkeley, CA.

Townsend, C.H. 1935. The distribution of certain whales as shown by logbooks records of American whaleships. *Zoologica*, 19: 1-50.

Urban, R.J, Alvarez, F.C, Salinas, Z.M, Jacobsen, J., Balcomb, K.C.I., Jaramillo, L.A., Ladron De Guevara, P.P. & Aguayo, L.A. 1999. Population size of humpback whale, *Megaptera novaeangliae*, in waters off the Pacific coast of Mexico. *Fishery Bulletin,* 97: 1017-1024.

Webb, R.L. 1988. *On the Northwest: commercial whaling in the Pacific Northwest*. University of British Columbia Press Pacific Maritime Studies No. 6, University of British Columbia Press, Vancouver, BC.

Webermann, E. 1914. *Kitobiyniy promisel v Rossii [Whaling in Russia]*. Izvestiya Moskovskogo Komercheskogo Instituta, Moscow. [In Russian]

Zenkovich, B.A. 1954. *Vokrug sveta za kitami. [Around the world after whales]*. Geographgiz, Moscow. [In Russian]

Zerbini, A.N., Waite, J.M., Laake, J.L. & Wade, P.R. 2006. Abundance, trends and distribution of baleen whales off western Alaska and the central Aleutian Islands. *Deep-Sea Research* Part I - Oceanographic Research Papers 53: 1772-1790.

Table 1. List of abundance estimates for the whole North Pacific, and regions therein.

Stock	Years	N	SD	SV	Source
Mexico	1965	100+	?		Rice 1978
Mexico	1990-1993	1600			Calambokidis *et al.* 1997
Mexico	1991-92	2,700			Urban *et al.* 1999
Hawaii	1976-77	500	± 90		Rice 1978
Hawaii	1976-79	650	550-790		Rice and Wolman 1979
Hawaii	1978-79	895	592-1837		Darling *et al.* 1983
Hawaii	1980-83	1,407	1,113-1,703		Baker and Herman 1987
Hawaii	1990-1993	4,000			Calambokidis *et al.* 1997
SEAK	1983	374	327-421		Baker *et al.* 1986
SEAK	1986	547	504-590		Baker *et al.* 1990
SEAK	2000	961	657-1,076		Straley *et al.* 2009
western Alaska	1987	830	458-1502	0.31	Zerbini *et al.* 2006
western Alaska	2001	2191	1145-4189	0.34	Zerbini *et al.* 2006
western Alaska	2002	2137	1343-3398	0.24	Zerbini *et al.* 2006
western Alaska	2003	2425	1845-3186	0.14	Zerbini *et al.* 2006
CA (Gulf of the Farallones)	1986-88	188-253			Calambokidis *et al.* 1990
CA (central)	1986-87	230	200-260		Calambokidis *et al.* 1988
CA_OR, WA	1991-96	570	569 to 837		Calambokidis & Barlow 2004
CA_OR, WA	1996-97	840			Barlow *et al.* 2011
CA_OR, WA	2005	1,145			Barlow & Forney 2007
western Alaska	2004?	2,544	1,899-3,680		Zerbini *et al.* 2006
Asia	1990-1993	400			Calambokidis *et al.* 1997
all NP	1990-1993	8,000 (6010)	± 474		Calambokidis *et al.* 1997
all NP	2004-06	21,808		0.04	Barlow *et al.* 2011

Table 2. A comparison of observed and model predicted rates of increase (ROI, in %/year) for humpback whales in four different periods and regions in the North Pacific.

Region	**Period**	**Reference**	**Observed ROI**	**95% CI**	**Model predicted ROI (%) for each r_{max} scenario**					
					0	2.5	5	7.5	10	12
North Pacific Ocean	1966-2005	Calambokidis *et al.* (2008)	6.8	-	0.0	0.6	1.0	1.2	1.3	1.3
Western North Pacific	1980-1996	Mizroch *et al.* (2004)	10.0	3.0-16.0	0.0	0.6	0.9	1.1	1.0	1.0
Northern Gulf of Alaska/central and eastern Aleutians	1987-2003	Zerbini *et al.* (2006)	6.6	5.2-8.6	0.0	0.5	0.8	0.8	0.8	0.7
West coast of the USA	1990-2008	Calambokidis (2009)	8.0	-	0.0	0.5	0.7	0.8	0.7	0.6

Table 3. – Estimates of model parameters and quantities of interest for the single North Pacific humpback whale population logistic model.

	Scenario					
r_{max}	0%	3%	5%	8%	10%	12%
K	54357	44782	38156	33845	31100	29621
Nmin	21800	17029	14375	13241	12935	12970
Nmin/K	40.1%	38.0%	37.7%	39.1%	41.6%	43.8%
N2006/K	40.1%	48.7%	57.1%	64.4%	70.1%	73.6%
N2015/K	40.1%	50.8%	60.3%	67.8%	73.3%	76.6%

Table 4. List of catches of humpback whales in the North Pacific, by year and area.

Year	Asia min	Asia med	Asia max	Ogasawara	Russia	Al_BS	GOA	SEAK_NBC	NWA_SBC	CA-OR med	CA-OR min	CA-OR max	Baja-MX
Total	5573	8216	10859	822	259	7192	4529	4527	3987	4622	3850.8	5401.6	2236
1656	1	2	2										
1657													
1658	2	4	6										
1659													
1660	1	2	3										
1661													
1662	2	4	6										
1663	1	2	3										
1664	1	2	3										
1665	1	2	3										
1666	1	2	3										
1667	1	2	3										
1668													
1669	2	4	6										
1670													
1671	2	4	6										
1672													
1673	2	4	6										
1674	1	2	3										
1675	1	2	3										
1676	1	2	3										
1677	2	4	6										
1678													
1679	1	2	3										
1680	2	4	6										
1681	2	4	6										
1682	1	2	3										
1683													
1684	1	2	3										
1685	1	2	3										
1686	1	2	3										
1687													
1688	2	4	6										
1689	1	2	3										
1690	1	2	3										
1691	1	2	3										
1692													
1693	2	4	6										
1694													
1695	2	4	6										
1696	1	2	3										
1697	1	2	3										
1698	10	20	30										
1699	10	20	30										
1700	11	22	33										

Year	Asia min	Asia med	Asia max	Ogasawara	Russia	AI_BS	GOA	SEAK_NBC	NWA_SBC	CA-OR med	CA-OR min	CA-OR max	Baja-MX
1701	10	20	30										
1702	9	18	27										
1703	12	24	36										
1704	9	18	27										
1705	10	20	30										
1706	11	22	33										
1707	11	22	33										
1708	10	20	30										
1709	11	22	33										
1710	11	22	33										
1711	11	22	33										
1712	10	20	30										
1713	12	24	36										
1714	10	20	30										
1715	11	22	33										
1716	11	22	33										
1717	11	22	33										
1718	10	20	30										
1719	12	24	36										
1720	11	22	33										
1721	11	22	33										
1722	11	22	33										
1723	12	24	36										
1724	10	20	30										
1725	11	22	33										
1726	11	22	33										
1727	11	22	33										
1728	9	18	27										
1729	10	20	30										
1730	10	20	30										
1731	11	22	33										
1732	10	20	30										
1733	10	20	30										
1734	10	20	30										
1735	10	20	30										
1736	10	20	30										
1737	12	24	36										
1738	9	18	27										
1739	10	20	30										
1740	10	20	30										
1741	10	20	30										
1742	9	18	27										
1743	11	22	33										
1744	9	18	27										
1745	11	22	33										
1746	10	20	30										
1747	10	20	30										
1748	6	12	18										

Year	Asia min	Asia med	Asia max	Ogasawara	Russia	AI_BS	GOA	SEAK_NBC	NWA_SBC	CA-OR med	CA-OR min	CA-OR max	Baja-MX
1749	6	12	18										
1750	4	8	12										
1751	7	14	21										
1752	5	10	15										
1753	6	12	18										
1754	5	10	15										
1755	6	12	18										
1756	4	8	12										
1757	5	10	15										
1758	5	10	15										
1759	6	12	18										
1760	7	14	21										
1761	6	12	18										
1762	7	14	21										
1763	8	16	24										
1764	5	10	15										
1765	6	12	18										
1766	6	12	18										
1767	8	16	24										
1768		0	0										
1769	1	2	3										
1770		0	0										
1771	1	2	3										
1772		0	0										
1773	2	4	6										
1774		0	0										
1775	1	2	3										
1776	1	2	3										
1777	1	2	3										
1778		0	0										
1779	1	2	3										
1780		0	0										
1781	2	4	6										
1782		0	0										
1783	1	2	3										
1784		0	0										
1785	1	2	3										
1786	1	2	3										
1787	1	2	3										
1788		0	0										
1789	1	2	3										
1790		0	0										
1791	1	2	3										
1792		0	0										
1793	1	2	3										
1794		0	0										
1795	1	2	3										
1796		0	0										

Year	Asia min	Asia med	Asia max	Ogasawara	Russia	AI_BS	GOA	SEAK_NBC	NWA_SBC	CA-OR med	CA-OR min	CA-OR max	Baja-MX
1797	1	2	3										
1798		0	0										
1799	1	2	3										
1800	5	10	15										
1801	5	10	15										
1802	11	22	33										
1803	20	40	60										
1804	32	64	96										
1805	22	44	66										
1806	26	52	78										
1807	29	58	87										
1808	33	66	99										
1809	15	30	45										
1810	14	28	42										
1811	22	44	66										
1812	27	54	81										
1813	23	46	69										
1814	9	18	27										
1815	43	86	129										
1816	10	20	30										
1817	16	32	48										
1818	23	46	69										
1819	19	38	57										
1820	15	30	45										
1821	16	32	48										
1822	11	22	33										
1823	28	56	84										
1824	28	56	84										
1825	34	68	102										
1826	16	32	48										
1827	25	50	75										
1828	18	36	54										
1829	20	40	60										
1830	29	58	87										
1831	26	52	78										
1832	20	40	60										
1833	16	32	48										
1834	8	16	24										
1835	15	30	45										
1836	7	14	21										
1837	6	12	18										
1838	5	10	15										
1839	7	14	21										
1840	0	0	0										
1841	8	16	24										
1842	9	18	27										
1843	9	18	27										
1844	8	16	24										

Year	Asia min	Asia med	Asia max	Ogasawara	Russia	AI_BS	GOA	SEAK_NBC	NWA_SBC	CA-OR med	CA-OR min	CA-OR max	Baja-MX
1845	8	16	24										
1846	9	18	27										
1847	8	16	24										
1848	10	20	30										
1849	21	42	63										
1850	25	50	75										
1851	34	68	102										
1852	20	40	60										
1853	33	66	99										
1854	19	38	57							23	13	33	
1855	19	38	57							36	16	56	
1856	17	34	51							29	18	40	
1857	23	46	69							34	20	48	
1858	16	32	48							46	32	60	
1859	14	28	42							48	33	63	
1860	27	54	81							48	33	63	
1861	9	18	27							71	44	98	
1862	20	40	60							60	38	82	
1863	12	24	36							67	45	89	
1864	25	50	75							59	29	89	
1865	12	24	36							48	27	69	
1866	8	16	24							50	28	72	
1867	5	10	15							49	28	70	
1868	4	8	12							51	29	73	
1869	3	6	9							55	33	77	
1870	5	10	15							45	22	68	
1871	3	6	9							45	22	68	
1872	4	8	12							45	22	68	
1873	3	6	9							42	21	63	
1874	9	18	27							44	22	66	
1875	10	20	30							44	22	66	
1876	17	34	51							43	21	65	
1877	28	56	84							48	23	73	
1878	22	44	66							47	22	72	
1879	26	52	78							51	26	76	
1880	27	54	81							42	21	63	
1881	21	42	63							43	21	65	
1882	52	104	156							44	22	66	
1883	49	98	147							38	21	55	
1884	38	76	114							39	22	56	
1885	38	76	114							27	16	38	
1886	44	88	132							22	11	33	
1887	51	102	153							24	11	37	
1888	58	116	174							24	11	37	
1889	32	64	96							24	11	37	
1890	24	48	72							11	2	20	
1891	22	44	66							11	2	20	
1892	4	8	12							11	2	20	

Year	Asia min	Asia med	Asia max	Ogasawara	Russia	AI_BS	GOA	SEAK_NBC	NWA_SBC	CA-OR med	CA-OR min	CA-OR max	Baja-MX
1893	14	28	42							11	2	20	
1894	24	48	72							11	2	20	
1895	41	82	123							11	2	20	
1896	61	122	183							5	0	13	
1897	34	68	102							5	0	13	
1898	4	8	12							5	0	13	
1899	2	4	6							2	2	2	
1900	1	1	1										
1901	12	12	12										
1902													
1903													
1904													
1905													
1906									139				
1907								231					
1908								242	201				
1909								262	335				
1910	29	29	29					352	389				
1911	60	60	60					619	576				
1912	68	68	68			148		469	422				
1913	138	138	138					222	397				
1914	165	165	165			109		122	160				476
1915	105	105	105			117		115	252				
1916	92	92	92			82		143	137				
1917	31	31	31			23		81	205				
1918	24	24	24			58		98	129				
1919	55	55	55		2	126		70	122	225	225	225	
1920	83	83	83			67		8	106	380	380	380	
1921	100	100	100		1			72	15	157	157	157	35
1922	82	82	82		1	87		57	124	502	502	502	
1923	68	68	68		1	156		78	99	376	376	376	
1924	69	69	69	86	2	72		47	98	197	197	197	150
1925	72	72	72	86	2	266		40	21	43	43	43	403
1926	57	57	57	53		150	236	24		21	21	21	499
1927	80	80	80	14	1	98	455	21					472
1928	65	65	65	25	1	42	178	21		10	10	10	179
1929	69	69	69	5		45	169	10		7	7	7	16
1930	60	60	60	2		13	178	12					
1931	42	42	42	27	1								
1932	53	53	53	34		2	128						
1933	44	44	44	48		26	114			65	65	65	
1934	29	29	29	28	6	72	139	13					
1935	42	42	42	34	1	246	37	1		1	1	1	6
1936	26	26	26	53	23	57	95	14					
1937	21	21	21	50	20	102	43	7		3	3	3	
1938	22	22	22	44	16	40		4					
1939	20	20	20	60	15	54				59	59	59	
1940	33	33	33		12	129		2		19	19	19	

Year	Asia min	Asia med	Asia max	Ogasawara	Russia	AI_BS	GOA	SEAK_NBC	NWA_SBC	CA-OR med	CA-OR min	CA-OR max	Baja-MX
1941	16	16	16	22	5	8		11		16	16	16	
1942	14	14	14	14	5	9		16		12	12	12	
1943	10	10	10	57	10	19		7		5	5	5	
1944	5	5	5	59						1	1	1	
1945	11	11	11		1								
1946	8	8	8	12	3	6							
1947	8	8	8	1	3	7				13	13	13	
1948	8	8	8	3	6	7		115		16	16	16	
1949	0	0	0	4	3	4		76		11	11	11	
1950	5	5	5		10	12		95					
1951	4	4	4		4	5		51		4	4	4	
1952	2	2	2	1	14	51		61					
1953	9	9	9		4	55		47					
1954	12	12	12		14	151		106					
1955	20	20	20		14	136		37					
1956	14	14	14		8	70		28		133	133	133	
1957	32	32	32		18	34		49		199	199	199	
1958	294	294	294		8	29		40		115	115	115	
1959	238	238	238		4	75		27		140	140	140	
1960	170	170	170		4	56				67	67	67	
1961	95	95	95		11	333				62	62	62	
1962	25	25	25		1	1181	657	16		39	39	39	
1963	3	3	3		3	1098	1532	147	5	55	55	55	
1964	1	1	1		1	1025	320	10	26	27	27	27	
1965	4	4	4			300	210	79	9	4	4	4	
1966	5	5	5			52	6	13					
1967						65	14	22	5				
1968						8	15	14	9				
1969						2			3				
1970						3	3	3	3				
1971													
1972						4							

Table 5. Exchange rates between feeding areas (top) and breeding regions.

	Russia	Aleutians-Bering	GOA	SEAK	NWA-SBC	CA-OR
Asia	83%	8%	1%	0%	0%	0%
Hawaii	13%	55%	57%	89%	36%	0%
Mexico	3%	37%	42%	11%	58%	82%
Central America	0%	0%	0%	0%	5%	18%

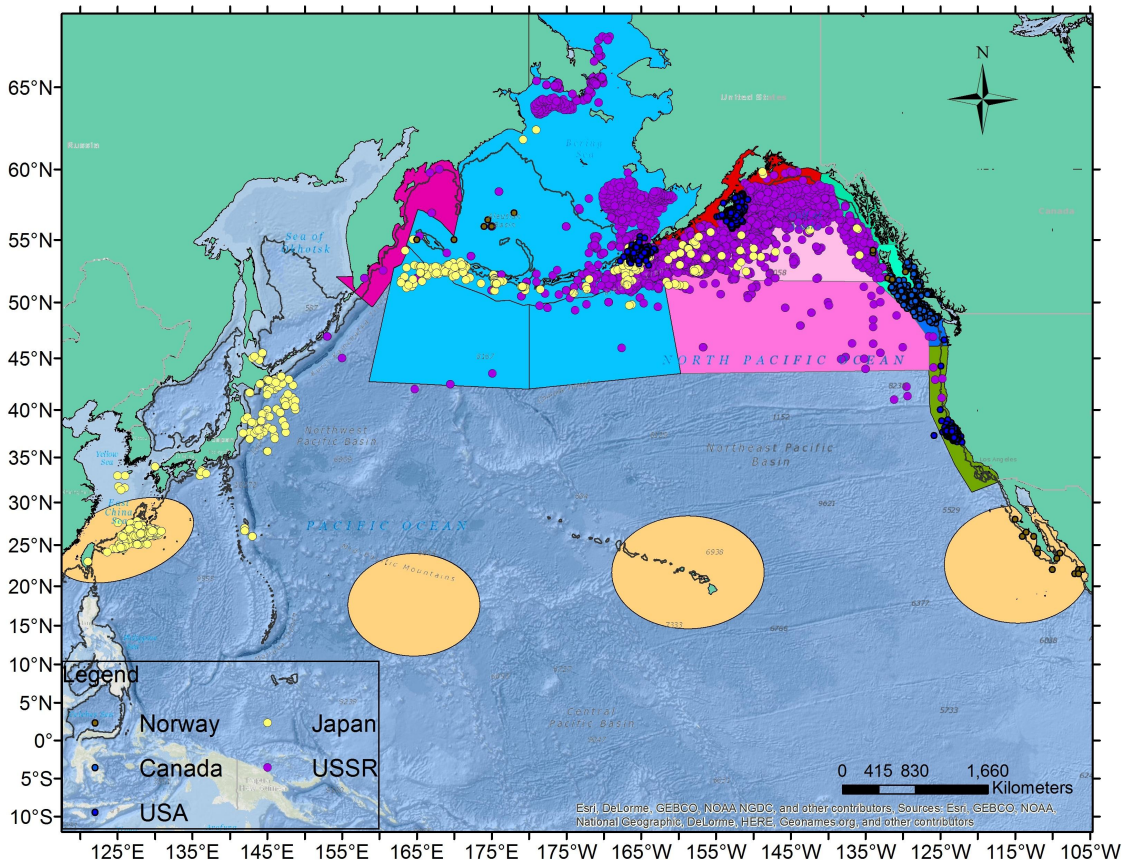

Figure 1. Distribution of 20th century humpback whale catches by all countries.

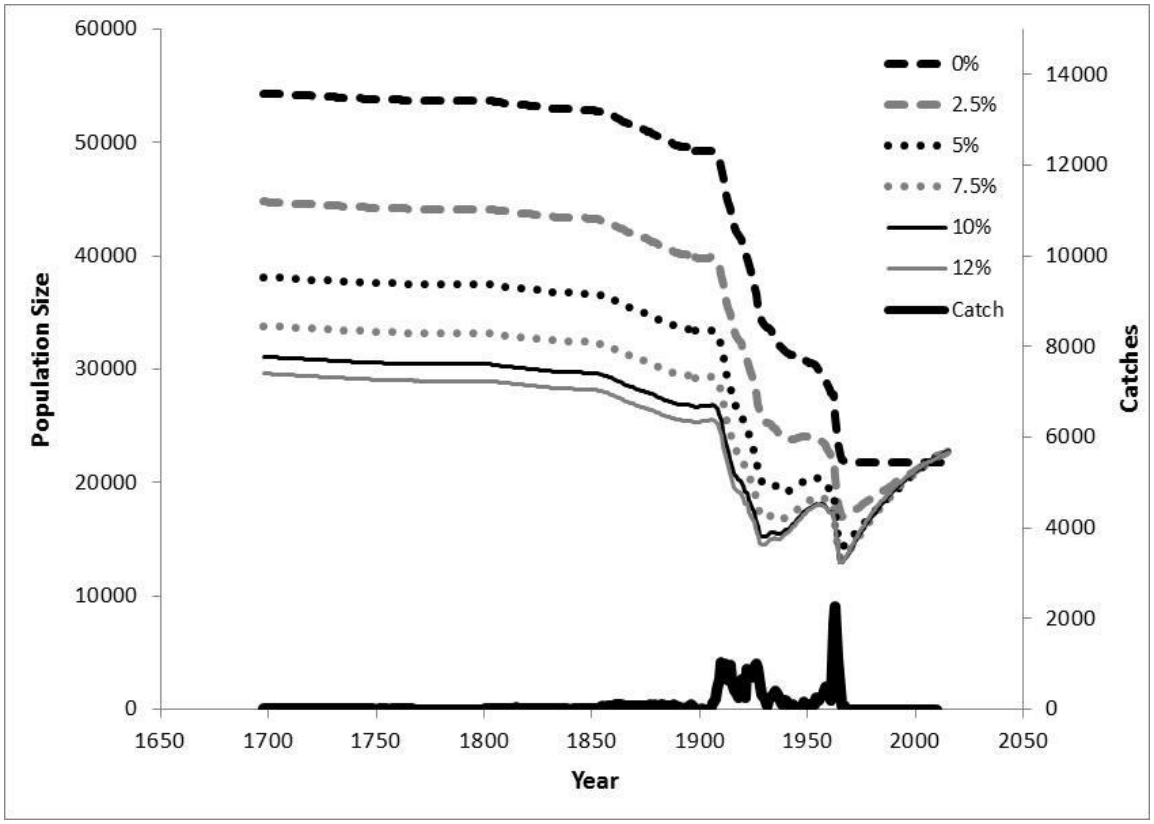

Figure 2. Population trajectories predicted by the logistic model for six r_{max} scenarios (0-12%/year) and catch series of North Pacific humpback whales.

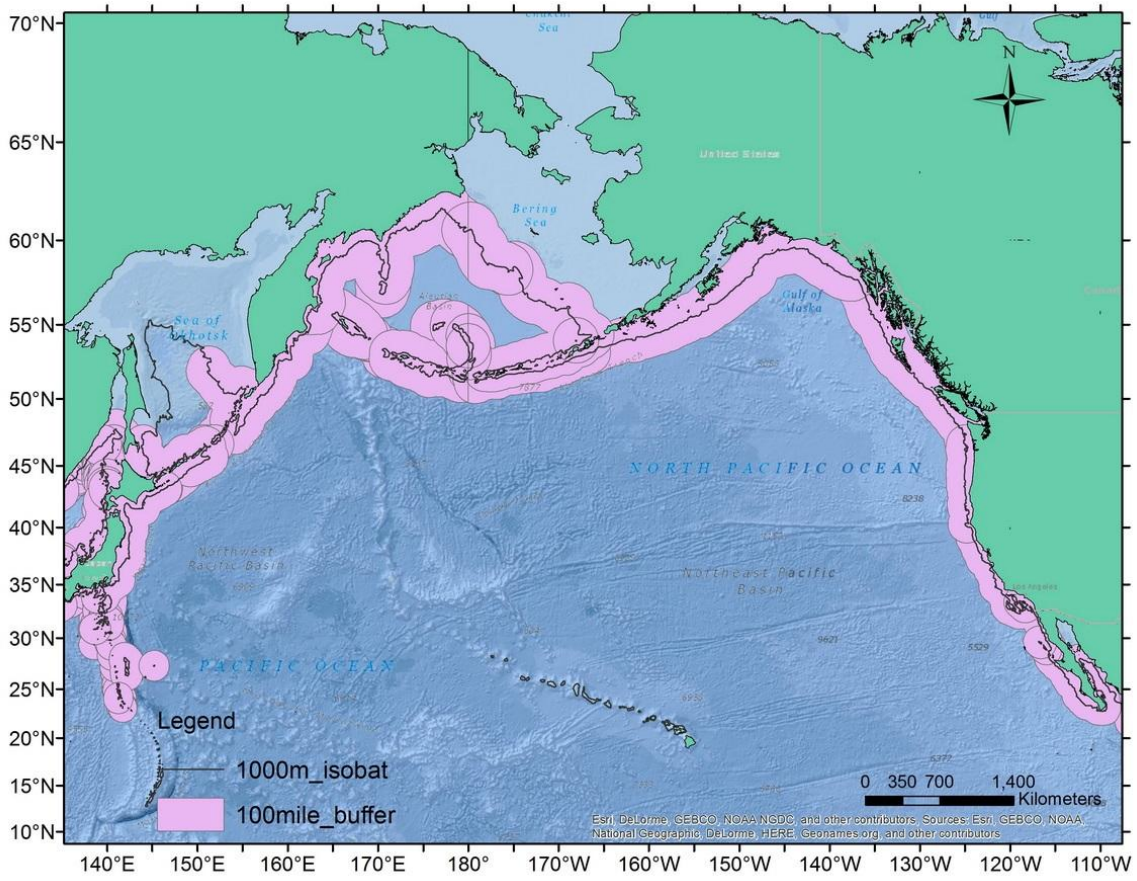

Figure 3. Map of the 100nm zone along both sides of the North Pacific.

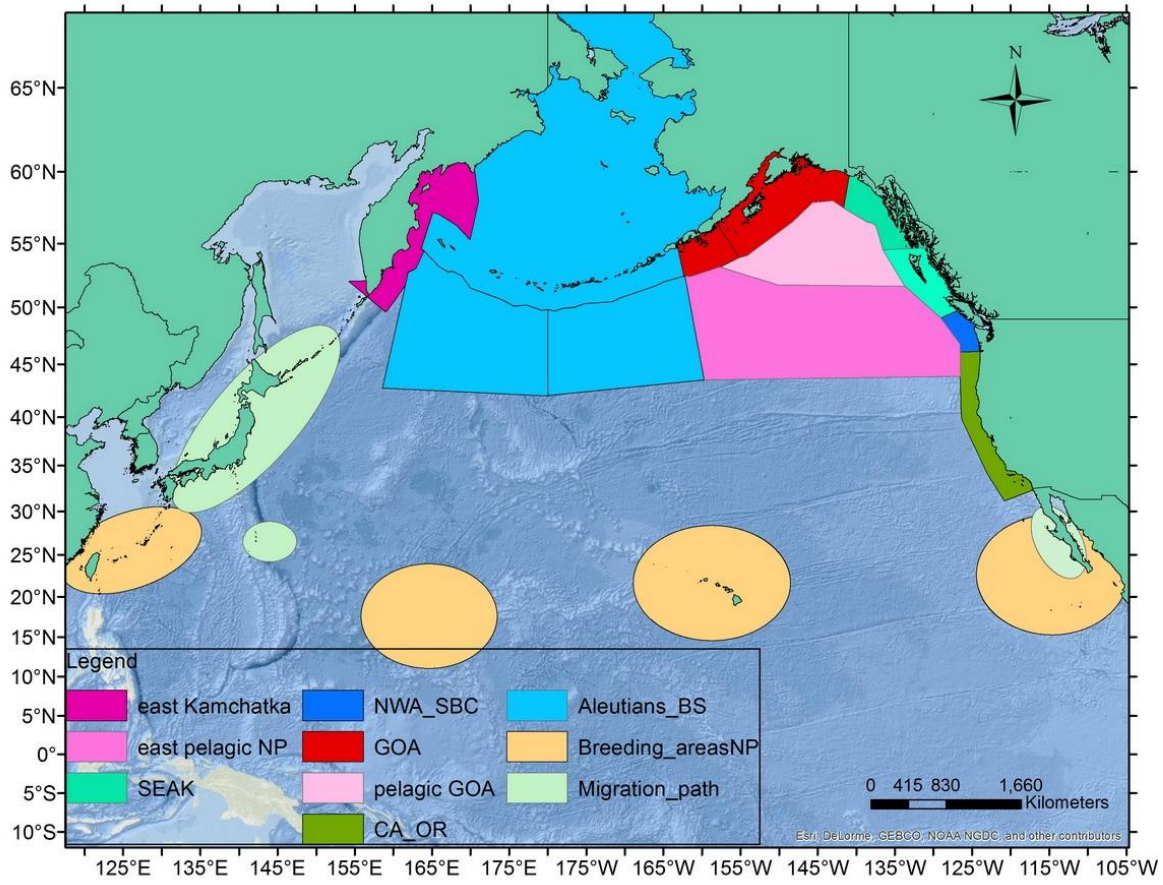

Figure 4. Feeding and breeding regions for the North Pacific humpback whale population.

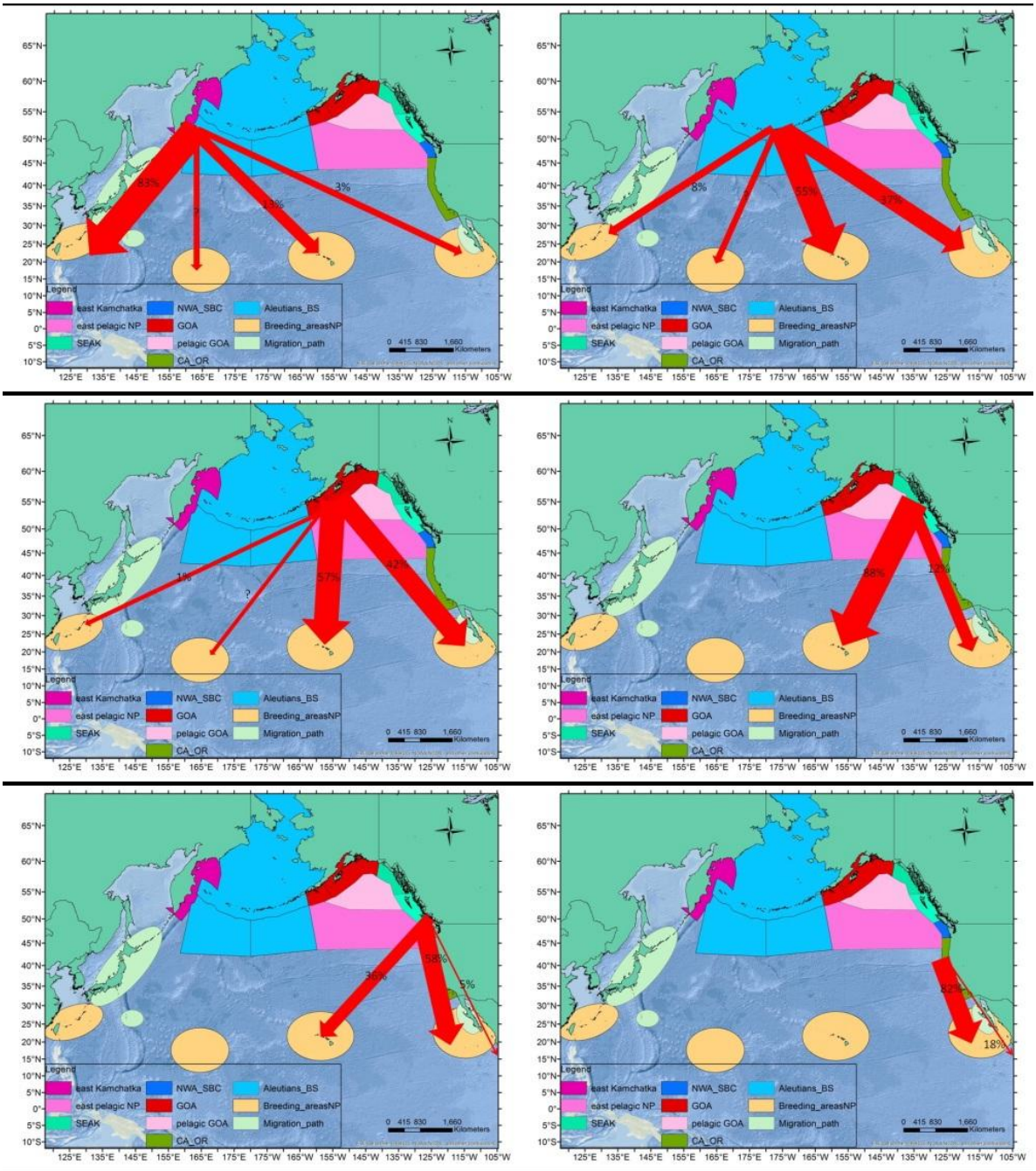

Figure 5. Exchange rates among feeding regions and breeding grounds.

Appendix 1

List of scenarios concerning catches before 1900s

Scenario 1.

- Old Japanese catches - Basic
- California catches, 1854-99: High projected catch

Scenario 2.

- Old Japanese catches - Double catches
- California catches 1854-99: High projected catch

Scenario 3.

- Old Japanese catches - Tripled catches
- California catches, 1854-99: High projected catch

Scenario 4.

- Old Japanese catches - Basic
- California catches, 1854-99: Medium projected catch

Scenario 5.

- Old Japanese catches - Double catches
- California catches, 1854-99: Medium projected catch

Scenario 6.

- Old Japanese catches - Tripled catches
- California catches, 1854-99: Medium projected catch

Scenario7.

- Old Japanese catches - Basic
- California catches, 1854-99: Low projected catch

Scenario 8.

- Old Japanese catches - Double catches
- California catches, 1854-99: Low projected catch

Scenario 9.

- Old Japanese catches - Tripled catches
- California catches, 1854-99: Low projected catch