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An Assessment of the Potential for Recovery of Humpback Whales off the Pacific Coast of Canada

Évaluation du potentiel de rétablissement des rorquals à bosse au large de la côte canadienne du Pacifique

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ABSTRACT

Humpback whales off Canada's Pacific coast are listed as Threatened under the Species-at-Risk Act. A draft Recovery Strategy for this humpback whale population is being prepared by DFO in 2008, but insufficient information has been available to set quantitative recovery goals in that document. Here, we present an assessment of recovery potential of Pacific humpback whales in Canadian waters to provide a basis for on-going recovery planning for this population. For this assessment, we used an archive of photo-identifications of individual humpback whales collected during 1992-2006 to estimate population abundance and trends using capture-recapture techniques. These analyses indicate that the humpback whale population has grown rapidly since the beginning of this time series at an estimated annual rate of 4.1% (95% confidence limits, 3.9-5.1%) due to recruitment and a high survival rate of 97.6% (96.0-99.2%). This population growth rate is consistent with recent estimates for the North Pacific population as a whole. The best estimate of abundance for humpback whales in British Columbia waters is 2145 whales (1970-2331) in 2006. This is still considerably fewer than the minimum of 4000 animals estimated to have existed off the west coast of Vancouver Island in 1905, before large-scale whaling commenced. Current threats to survival and recovery of this humpback whale population include vessel strikes, entanglement in fishing gear, increasing underwater noise, and prey limitation. None of these threats appears to be affecting the population's growth rate. A Potential Biological Removal (PBR) of 21 animals/year is calculated for this population for allowable harm assessment purposes.

RÉSUMÉ

Les rorquals à bosse au large de la côte canadienne du Pacifique sont désignés comme espèce en voie de disparition en vertu de la *Loi sur les espèces en péril*. Une ébauche de la stratégie de rétablissement de cette population de rorquals à bosse a été préparé par le ministère des Pêches et des Océans (MPO) en 2008, mais l'information était alors insuffisante pour fixer des objectifs de rétablissement quantitatifs. Nous présentons donc ici une évaluation du potentiel de rétablissement des rorquals à bosse du Pacifique dans les eaux canadiennes pouvant servir de base à la planification continue du rétablissement de cette population. Aux fins de l'évaluation, nous avons utilisé des archives de photographies d'identification de différents rorquals à bosse qui ont été recueillies de 1992 à 2006 pour estimer l'abondance de la population et les tendances grâce à un recensement par capture et recapture. Ces analyses montrent que la population de rorquals à bosse a connu une croissance rapide depuis le début de cette série chronologique, avec un taux annuel estimé de 4,1 % (limites de confiance de 95 %, de 3,9 à 5,1 %) en raison du recrutement et d'un taux de survie élevé de 97,6 % (96,0 à 99,2 %). Le taux de croissance de cette population correspond aux estimations récentes pour l'ensemble de la population du Pacifique Nord. La meilleure estimation de l'abondance des rorquals à bosse dans les eaux de la Colombie-Britannique était de 2 145 individus (entre 1 970 et 2 331) en 2006. Ce nombre est encore beaucoup moins élevé que le minimum de 4 000 individus estimés vivant au large de la côte ouest de l'île de Vancouver en 1905, avant le début de la chasse à la baleine à grande échelle. Les menaces actuelles à la survie et au rétablissement de cette population de rorquals à bosse incluent les collisions avec les navires, l'emmêlement dans des engins de pêche, l'augmentation des bruits sous-marins et la limitation du nombre de proies. Aucune de ces menaces ne semble influer sur le taux de croissance de cette population. Un prélèvement biologique potentiel (PBP) de 21 individus par année est calculé pour cette population aux fins d'évaluation des dommages admissibles.

INTRODUCTION

In 1985, the North Pacific humpback whale population was designated Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The status of this population was reassessed and confirmed in May 2003. Reasons for this designation include "humpback whales that use British Columbia waters appear to be well below historical numbers and have not returned to some portions of their former range". This population became legally listed under the Canadian Species-at-Risk Act (SARA) in 2005.

As required by SARA, a Recovery Strategy for humpback whales in Canada is currently being prepared by Fisheries and Oceans Canada with completion scheduled for early 2009. Once accepted by the Minister of Fisheries and Oceans, an Action Plan will be developed to achieve recovery goals and objectives developed in the Recovery Strategy.

DFO Science has recently established a Recovery Potential Assessment (RPA) process to provide information and science advice for meeting SARA requirements for listed species, and for deciding whether to add species to the list (DFO 2007a). An RPA is intended to assess current population status, identify the scope of human induced mortality, and describe the characteristics and availability of critical habitat. Our intention in this report is to provide an assessment of the recovery potential of humpback whales in Pacific Canada that will serve as the scientific basis for establishing population targets and assist in efforts to achieve other recovery objectives and goals described in the draft Recovery Strategy (Fisheries and Oceans 2008a).

SPECIES BIOLOGY

The humpback whale *Megaptera novaeangliae* is a medium-to-large baleen whale that occurs in all the world's oceans, although it is uncommon in Arctic waters. It is a member of the Family Balaenopteridae, along with blue, fin, sei, and minke whales, but due to its substantial morphological differences from these species, it is placed in its own mono-specific genus. Humpback whales typically reach lengths of about 13 m for males and 14 m for females. Adult humpback whales weigh an average of 34,000 kg, and up to 45,000 kg. The species is easily recognizable due to its stocky body shape, long pectoral flippers (to almost 1/3 of the body length), rounded tubercles on the rostrum ("head knobs"), and tendency to raise its flukes when diving. It is well known for its frequent aerial displays, including breaches, tail slaps, and flipper slaps. The species is also noted for its long, complex underwater songs, sung by males primarily while en route to or on low latitude wintering areas.

Like many species of baleen whales, the humpback whale is strongly migratory. The whales spend much of the year, generally spring through fall, in feeding areas that are located in productive cool waters in high latitudes. In late fall, most humpbacks migrate to low-latitude tropical or sub-tropical wintering areas where breeding takes place. These wintering areas are often associated with shallow coastal areas of continents or around offshore island groups. In the North Pacific, wintering areas include the Hawaiian Islands, coastal waters of western Mexico and the Revillagigedo Islands, Central America, the Philippines, and Ryukyu and Ogasawara island groups of Japan. Mating is thought to take place while en route to and in wintering areas. As humpback whales have an 11-12 month gestation period (Chittleborough 1958), most calves are born in these low-latitude locations. Calving in such warm water areas is thought to provide an energetic benefit for growing calves and/or to reduce the risk of calf predation by mammal-eating killer whales, which are typically more common in high latitude feeding areas (Corkeron and Connor 1999; Conner and Corkeron 2001; Clapham 2001). Females give birth to a single calf at intervals of 1-5 years, but mostly commonly every two years. Newborn calves are about 4.5 meters long at birth, and are weaned at about one year of age, though some beginning taking food at about 6 months. Both sexes reach sexual maturity at an average of 5 years and length of about 12 meters. Physical maturity is not reached until 8-12 years following sexual maturity (Clapham and Mead 1999). Longevity is at least 48 years (Chittleborough 1965).

Due to their cosmopolitan distribution and highly migratory behaviour, humpback whales occupy a wide variety of habitats. Wintering areas in both hemispheres are mostly located between 10º and 23º, and little if any feeding takes place in these areas. In summer, the whales feed extensively in productive cold water areas generally between 35º and 65º. Feeding areas include both nearshore and offshore waters. Migratory paths taken by humpbacks between winter and summer concentration areas are poorly known, but they include both coastal and oceanic waters. Humpback whale populations are highly structured genetically both between and within ocean basins (Baker et al. 1994). Within an oceanic area, populations are segregated into discrete subpopulations which are not separated by geographic barriers. Much of this segregation appears to be due to maternally-directed fidelity to particular feeding areas. Considerable mixing of these subpopulations may take place in wintering areas.

The humpback whale is a ‘gulp’ or ‘lunge’ feeder that preys on dense patches of zooplankton or shoals of small fishes. This feeding technique involves engulfing large volumes of mixed water and prey, facilitated by a highly extensible throat, then collecting the prey as water is released using relative short and course baleen plates. Humpback whales use a variety of tactics to corral and concentrate their prey while feeding, such as ‘flick feeding’ and ‘bubble netting’. Humpback whales forage both alone and in cooperation with other individuals, especially when undertaking bubble net feeding. Individual whales may specialize on particular feeding techniques and prey types.

Humpback whales feed primarily on larger zooplankton such as euphausiids and crab zoea, and less so the smaller zooplankton such as copepods, which are targeted by skimming-type feeders (e.g., right whales). In the southern hemisphere, euphausiids (notably *Euphausia superba*) are the primary prey of humpback whales. In other regions, humpbacks feed on euphausiids of several genera, including *Euphausia*, *Thysanoessa*, and *Meganictyphanes*, as well as schooling fish. Species of fish targeted by humpbacks include herring (*Clupea*), mackerel (*Scomber scombrus*), sand lance (*Ammodytes*), sardines (*Sardinops* or *Sardinella*), anchovies (*Engraulis mordax*), and capelin (*Mallotus villosus*).

In high latitude feeding areas such as off the west coast of Canada, the primary activity of humpback whales is feeding. The movements of whales in this region is likely driven by the abundance and distribution of their primary prey, which can vary both intra- and inter-annually (Whitehead and Carscadden 1985; Piatt et al. 1989; Payne et al. 1990).

POPULATION STRUCTURE, STATUS AND TRAJECTORY

Population Structure

Humpback whales in the North Pacific are segregated into a number of regional stocks or populations that differ in frequencies of mitochondrial DNA haplotypes (Baker et al. 1998). Although these populations are genetically distinct, some degree of mixing takes place among them. Under the US Marine Mammal Protection Act, three stocks of humpbacks are currently recognized in the North Pacific. These are 1) the California/Oregon/Washington stock, which feeds off the west coast of the US mainland, 2) the Central North Pacific stock, with feeding areas from Southeast Alaska to the Alaska Peninsula, and 3) the Western Pacific stock, with feeding areas around the Aleutian Islands, Bering Sea and Russia (Carretta et al. 2007). Humpback whales off the Canadian west coast have not been assigned to any of these stocks.

Knowledge of population structure in the North Pacific has advanced considerably in recent years as a result of a major international collaborative study known as SPLASH (Structure of Populations, Levels of Abundance, and Status of Humpbacks; Calambokidis et al. 2008). This three-year field effort (2004-06) involved researchers from the US, Canada, Russia, Japan, Mexico, and the Philippines, and involved extensive photo-identification[1] and skin biopsy sampling in both wintering and feeding areas throughout the North Pacific. Photo-identifications in both wintering and feeding areas have revealed a high degree of population structure and complex movements within and between regions. The overall pattern showed that whales in wintering areas on each side of the North Pacific (Asia in the west and mainland Mexico and Central America in the east) move to feeding areas at higher latitudes along the same side of the Pacific (Figure 1). Whales wintering off mainland Mexico and Central America move mostly to coastal areas off California, Oregon, Washington, and southern British Columbia (BC). Whales from the Hawaiian Islands wintering area move to feeding areas that extend from the Aleutian Islands to northern BC. Thus, humpback whales that feed off the Pacific coast of Canada migrate to two geographically discrete wintering areas, which have been shown to be comprised of whales that have different mtDNA haplotype frequencies (Baker et al. 1994). Further DNA analyses using the SPLASH biopsy samples to better elucidate the genetic population structure in the North Pacific are in progress.

Population Abundance and Trajectory

Globally, all humpback populations were drastically reduced by industrial whaling in the 19th and 20th centuries. Evidence suggests that up to 90-95% of the world-wide population was killed (Johnson and Wolman 1984). Whaling for humpbacks ended by international agreement in 1966, though it is now known that illegal Soviet whaling for this species continued after this date (Clapham and Mead 1999).

[1] The photo-identification technique involves standardized photographs of the ventral side of the humpback whale's tail flukes taken as the animal lifts its tail above the surface to dive. Unique features including scars and pigmentation patterns allow reliable individual identification that can be applied in a range of studies (Katona and Whitehead 1981).

North Pacific

In the North Pacific, the pre-exploitation abundance of humpbacks has been estimated at approximately 15,000 (Rice 1977), but this was based on historical whaling data that may have been inaccurate (Calambokidis et al. 2008). It is very likely a substantial underestimate of historical abundance. The post-whaling population size in the North Pacific (>1965) has been estimated at 1,400 (Gambell 1976) and 1,200 (Johnson and Wolman 1984). However, there is considerable uncertainty regarding these estimates due to the methods used (Calambokidis and Barlow 2004). Humpback whale abundance was assessed by Calambokidis et al. (1997) using capture-recapture techniques and photo-identification data collected in the early 1990s from many, but not all, regions of the North Pacific. They estimated a total of 6,000-10,000 individuals. A more recent and improved estimate of abundance for the North Pacific has been provided by the SPLASH project. A total of 17,558 whales was estimated for wintering areas and 19,056 for feeding areas; the average of these two estimates yielded the best overall abundance estimate of 18,302 individuals (excluding calves) for the North Pacific. This estimate is substantially greater than other post-whaling estimates for the North Pacific, and suggests an annual abundance increase of 4.9-6.8%, depending on the method and time period considered (Calambokidis et al. 2008).

British Columbia

The SPLASH project provided regional estimates of humpback whale abundance for both wintering and feeding areas (Calambokidis et al. 2008), but no estimate specifically for waters off the Pacific coast of Canada. Among these regional estimates are 3,000-5,000 whales for Southeast Alaska and northern British Columbia combined and 200-400 for southern British Columbia-northern Washington combined (the division between these two sections of British Columbia is off northern Vancouver Island). Williams et al. (2007) undertook line transect surveys for cetaceans over much of the inner coastal waters of British Columbia in 2004 and 2005. These surveys yielded an abundance estimate of 1,310 humpbacks (95% confidence limits, 755-2,280), which is conservative as the outer waters off the west coasts of Vancouver Island and the Queen Charlotte Islands were not included in the survey.

In order to provide an estimate of the current population abundance of humpback whales using waters off the Pacific coast of Canada, as well as trends in abundance, we undertook analyses of photo-identification data collected by the Cetacean Research Program, Pacific Biological Station (CRP-PBS, Fisheries and Oceans Canada, Nanaimo, BC). In 1984, DFO established a photo-identification program to develop a catalogue of individual humpback whales sighted in BC waters. Photographs were compiled by three general methods: 1) opportunistically collected photographs contributed by individuals and external research groups (1984-2006), 2) photographs collected by DFO during multi-purpose/multi-species cetacean surveys (2002-2006), and 3) humpback-targeted DFO photo-ID surveys (2004-2005). The resulting photographic database consisted of 8,900 records of humpback whale sightings in BC between 1984 and 2006. As effort in the early years was modest and scattered, we removed data collected between 1984 and 1991 (34 records), and only considered records from 1992 onwards. We further restricted data to those for the months of May to October (8,653 records), during which both sampling effort and whale identifications were highest.

Survey design was neither random nor uniform in either its geographical coverage or invested temporal effort, both of which increased exponentially over the 15 years of surveying (Figures 2 and 3). This was partly because survey effort was often focused primarily in regions that had demonstrated high whale density during previous surveys, or had been identified as humpback "hotspots" from commercial whaling records. Budget considerations and availability of ship time also allowed for more intensive sampling in later years. Photographs were collected primarily in an opportunistic manner up until 2001, after which dedicated cetacean surveys were conducted. Although survey track-lines and sighting logs were available for 2002 onward, to make use of the entire dataset, we developed a rough proxy for effort by tallying the number of days photograph were taken per year. Although such an index does not account for hours spent searching per day, nor for effort invested in 'whale-free' regions, a reasonable relative index of overall 'effort days' annually is achieved.

We applied several analytical methods in order to determine the best estimate of abundance and trajectory:

Estimate Method 1: Minimum number alive

The minimum number of individually identified whales alive in 2006 was predicted by calculating the total number of unique whales identified in BC between 1992 and 2006. This method only considers the component of the population which has been 'previously seen', and is therefore considered a minimum estimate. It is first calculated under the assumption of a closed population, however since we can assume that some of these individuals died during the study interval, estimates were also performed using two different values for survival. All three estimates were calculated according to Equation 1, where N_x is the number of newly-identified whales observed in year *x*, and ø is the population survival under one of the following three scenarios:

1a) 100% survival rate - assumes zero mortality or emigration.
1b) Adjusted for a population survival rate of 0.963. This is based on the previously estimated population survival rate for the central North Pacific humpback stock (Mizroch et al. 2004).
1c) Adjusted for a survival rate of 0.98 (intermediate between the previously estimated survival and that of a closed population).

$$N_{2006} = \sum_{x=1992}^{2006} N_x ø^{2006\text{-}x} \qquad (1)$$

During the May to October 1992 to 2006 sampling period, there were 1,779 individual humpback whales photo-identified in the study area. The annual breakdown of 'new sightings' is provided in Figure 2. This represents only the 'sighted' component of the BC humpback population and does not consider the portion of the population yet to be identified. For this reason, 1,779 represents the minimum number of humpback whales that utilized BC waters between 1992 and 2006. If survival during this time was assumed to be 0.963, as seen by Mizroch et al. (2004), the minimum estimate for previously identified BC whales alive in 2006 is 1,500 individuals. If survival is set at an intermediate value of 0.98, halfway between the previous estimate and that for a closed population, the minimum estimate increases to 1,620 individuals. There are no variances for these estimates. Without an understanding of what proportion of the population is made up of sighted versus unsighted individuals, the most conservative deduction is that the population of humpback whales that has used BC waters over the last 15 years is made up of not less than 1,500 individual humpback whales.

Estimate Method 2: Chapman-modified Lincoln-Petersen between adjacent years

The Chapman form of the Lincoln-Petersen estimator was first used to predict population abundance across the entire province between pairs of adjacent survey years (Equation 2). In the first year, *n1* whales are 'marked' (photographically identified), in the second year, *n2* whales are investigated for marks, and of these, *m2* whales examined displayed marks (had been photographically identified previously). If capture probabilities vary between areas or individuals, the result will be to underestimate abundance.

$$N^* = \frac{(n_1+1)(n_2+1)}{m_2+1} - 1 \qquad (2)$$

The coefficient of variation (CV) provides a relative measure of uncertainty for each estimate (Equations 3 and 4).

$$v^* = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \qquad (3)$$

$$CV^* = \frac{\sqrt{\hat{\mathrm{var}}(N^*)}}{N^*} \qquad (4)$$

A parametric bootstrap procedure was used to determine 95% confidence intervals based on a hypergeometric distribution.

Lincoln-Petersen population estimates between adjacent years are presented in Table 1 and Figure 4. N* is the abundance estimate from the Chapman-modified Lincoln-Petersen and NB* is the modified abundance after bias is reduced via the bootstrapping procedure. The very large confidence intervals in 1993, 1996, and 1997 result from these years having very low re-sight values (less than 5 individuals). For CVs less than 25%, at least 16 re-sights are required (Seber 1982). Precision increased substantially in the later years because of larger sample sizes. Abundance values will be underestimates if capture probabilities were heterogeneous across the province, which is assumed likely.

Estimate Method 3: Jolly-Seber

The Jolly-Seber model is considered the best technique for estimating the size of open populations based on capture-recapture data (Krebs 1999). It incorporates birth, death, immigration, and emigration into its estimates, allowing the population to change over time. In order for the Jolly-Seber model to be valid, and its parameter estimates approximately unbiased, the following assumptions must be met:

1. Whether marked or unmarked, every animal alive in the population at a given sample time, has an equal probability of being captured during that sample.
2. Every marked animal alive in the population at a given sampling occasion has the same probability of survival until the next sampling occasion.

3. Marks are not lost or overlooked.
4. Sampling time is negligible in relation to intervals between samples.

In addition to population size, the Jolly-Seber model can also be used to estimate survival probabilities and growth rates, and has been shown to produce very accurate estimates (Krebs 1999; Seber 1982; Amstrup et al. 2005). Four data matrices were developed which portrayed the capture-recapture histories by annual cohort, calculated number of whales alive, capture probabilities, and maximum likelihood estimates for marked whales. Total population size, survival, and growth rate were then estimated using Sampling Importance Resampling (SIR) in Program R 2.3.1. As mentioned above, over the study period of 1992-2006, the effort applied to "capturing" whales increased greatly (Figures 2 and 3) both spatially and temporally. No correction could be performed to remove the data's spatial bias; however, we weighted our Jolly-Seber model by effort in order to reduce some of the temporal bias. The forward projection was created by applying the results of the effort-corrected Jolly-Seber model to a population model, and calculated in the R 2.3.1.

The mean estimates (and 95% confidence intervals) predicted by the SIR Jolly-Seber model, after correction for variation in temporal effort, were a 2006 abundance of 2145 whales (1970-2331), an annual survival rate of 97.6% (96.0-99.2%), and a population growth rate of 4.1% per year (3.2-5.0%) (Figures 5 to 7). Using the density distributions for abundance growth, and survival calculated in the effort-weighted Jolly-Seber model, a population growth projection was made for the next 30 years (Figure 8).

There likely exists heterogeneity of capture probabilities among humpback whales in this population as a result of geographical and temporal variability in sampling, as well as the individual biology of the animals. Error resulting from spatial effort violations occurs because sampling effort is largely concentrated in whale 'hotspots', specific areas that humpbacks are known to frequent. Humpback whales show strong site fidelity to summer feeding grounds (Craig and Herman 1997; Rambeau 2008), and as a result, whales found in particular areas have a higher probability of being re-sampled than whales found elsewhere. As a result, the Lincoln-Petersen abundance estimates are likely precise but biased (i.e. they will appear to have low variance and narrow confidence intervals, but the estimates themselves are likely to be underestimates). The spatial bias introduced by focusing sampling on areas of high whale density also contributes to potential inaccuracy in the Jolly-Seber population estimate, but unfortunately, this is a bias associated with the original data collection and could not be corrected for in this study. In order for the calculated growth rate to approximate the population growth rate, and not include a 'discovery rate', weighting our model by temporal effort was necessary. Otherwise, as effort increases over time, the number of 'new captures' per year also increases, making it appear as though the population is growing at a higher rate than it actually is. As a result, the artificially inflated growth rate leads to a larger population estimate than what the model would have predicted otherwise. This error can be somewhat corrected for by using an effort model as was done here.

Our Jolly-Seber model estimate of 2145 (1970-2331) whales in BC appears most reasonable and is consistent with the recent results of the North Pacific-wide SPLASH estimates. The high survival rate of 97.6% (96.0-99.2%) is also agrees with estimates made by previous studies (Mizroch et al. 2004). The population growth rate of 4.1% per year (3.2-5.0%) is also similar to trends observed in various regions of the North Pacific over the past 10-20 years (4.9-6.7%; Calambokidis et al. 2008). The population growth projection (Figure 8) suggests that if this growth rate is maintained, the abundance of humpback whales in BC waters in 30 years could approach 7000. This assumes that no density dependent effects or other limiting factors reduce population growth or use of BC waters.

Population Recovery Targets

From recent deliberations on establishing quantitative recovery targets for Canadian marine mammals, it has been proposed that a population may be considered to have recovered upon reaching a level of 70% of historical or 'pristine' abundance (Lawson et al. 2006; Hammill and Stenson 2007). As no published estimates are available for humpback whales in Pacific Canada, we undertook analyses of historical whaling records to develop such an estimate. Where catch effort information is lacking, Mitchell and Reeves (1983), propose that the total catch at the end of a short period of intensive harvest, assuming no net recruitment during the period, provides a minimum estimate of the population abundance at the start of the period. This approach was used to obtain a preliminary estimate of the historic abundance of humpback whales in B.C. Catches of humpbacks during 1908 to 1918 landed at two whaling stations on the west coast of Vancouver Island, Sechart and Kyuquot, were used for this analysis. Humpback whales comprised the majority of the annual catch during most of this period and there were no restrictions on harvest (e.g., no length limits; Nichol et al. 2002). The annual catch of humpback whales for this period was adjusted upwards with a struck-and-lost rate of 1.02 (Reeves et al. 1985). The adjusted catch of 3,558 humpbacks from these years represents a minimum abundance estimate off west coast Vancouver Island at the start of 1908. Commercial whaling off the west coast of Vancouver Island had started with the Sechart station in 1905 and although catch records are missing it is likely that at least 600 whales were caught in the 3 years prior to 1908, including 97 landed at Page's Lagoon in the Strait of Georgia in the winter of 1907 (Merilees 1985). If this additional estimated catch is included, the minimum abundance of humpback whales off the west coast of Vancouver Island at the start of 1905 could have been 4,158 animals. As population estimates, these should be considered minimums as it is possible that declines in the humpback whale catch after 1913 reflect in part a shift in interest to larger more profitable species of whales. The estimates should also be considered conservative as catch effort from these whaling stations was concentrated off the west coast of Vancouver Island and did not include waters off northern BC, and northern Washington state, where whaling was also occurring. It is clear that at a current population size of about 2100 animals for BC waters, the humpback whale population has yet to recover to historical pre-whaling levels.

HABITAT REQUIREMENTS

Waters off the Pacific coast of Canada serve primarily as a feeding area for humpback whales. Although humpbacks can be found in BC waters in all months of the year, they are particularly common during May-October (Figure 9). They occupy a wide range of habitat types in BC, including narrow channels and straits in inshore areas, waters over the continental shelf, and deep oceanic waters. The locations of humpback whales killed by whaling operations in BC during 1924-65 are shown in Figure 10. Many humpbacks were taken in deep water beyond the continental shelf, likely because the whalers were also targeting whale species such as fin and sei whales, which tend to be found further offshore. Humpback whale sightings during Cetacean Research Program (CRP-PBS) ship surveys in 2002-2008 are shown in Figure 11. A similar map showing the locations of humpback whales photo-identified in the region is depicted in Figure 12. This latter map includes many locations of humpbacks that were photo-identified in areas surveyed in small boats, and were not included in the ship surveys (e.g., off southwestern Vancouver Island). Together, these maps of recent sightings show that despite the widespread occurrence of the species, there are several areas of concentration, or 'hot spots', for humpback whales in BC waters. These include the southeastern and northern coasts of the Queen Charlotte Islands, off the southwestern coast of Vancouver Island, and in certain channels along the mainland coast. The presence of whales in the mainland inlets is greatest from late summer through fall.

Studies in other regions have shown that the distribution of humpback whales in feeding areas is closely tied to their prey (Whitehead and Carscadden 1985; Piatt et al. 1989; Payne et al. 1990) and is maternally-directed, with whales showing strong site fidelity to areas they visited with their mothers (Martin et al. 1984; Baker et al. 1987; Clapham and Mayo 1987). Should prey distribution change, it is assumed that this will be reflected in a parallel shift in humpback distribution, as has been observed in the Atlantic (Whitehead and Carscadden 1985; Piatt et al. 1989; Payne et al. 1990). Analyses of stomach contents taken by whalers during 1949-65 (CRP-PBS, unpubl. data) show euphausiids to be by far the most common prey of humpback whales in BC. Of 287 stomachs that contained food remains, 263 (92%) contained only euphausiids, 12 (4%) contained only copepods, and 2 (0.7%) contained only fish. The remaining stomachs contained mixtures of these prey types and 1 was full of small (2 inch) squid. Only two species of euphausiids were identified from stomach contents, *Euphausia pacifica* and *Thysanoessa spinifera*. It should be noted that the majority of these whales were taken 10 or more nautical miles from shore.

Observations and prey sampling from feeding humpback whales during 2002-07 (CRP-PBS, unpubl. data) also show euphausiids to be the primary prey species. However, these observations also suggest that feeding on schooling fish to be considerably more prevalent than demonstrated in the whaling records, particularly in nearshore waters. Fish species observed to be taken by humpbacks include Pacific herring (*Clupea pallasi*), sand lance (*Ammodytes hexapterus*), and Pacific sardine (*Sardinops sagax*).

Studies on euphausiid foraging by humpback whales in southeastern Alaska indicate that the whales feed in areas with the shallowest and densest prey in the top 120 m of the water column (Dolphin 1987). Although high densities of euphausiids were noted up to 300 m deep, the whales never dove more than 150 m. The whales sought out patches of euphausiids that had a minimum density of 50 euphausiids/m^3, with some patches reaching densities of 3,000-10,000/m^3. When feeding on fish, humpbacks also seem to target dense schools that have formed by tidal currents or as feeding aggregations. They may further concentrate these fish using cooperative techniques involving the use of bubble nets (Sharpe 2001).

There is considerable intra- and inter-annual variation in the distribution of humpback whales in BC waters. For example, density of humpbacks around Langara Island at the northwest corner of the Queen Charlotte Islands was high during the late 1990s, but dropped considerably in the early 2000s. Off the southeastern coast of the Queen Charlotte Islands (within Gwaii Haanas National Park Reserve), whale abundance has been observed to change dramatically within a period of several weeks (CRP-PBS, unpubl. data). Although prey distribution is likely responsible for many of these shifts in distribution, further research is needed to identify thresholds of prey densities that may affect whale persistence within or movements away from particular feeding locations. Studies modeling the biophysical co-variates of humpback whale distribution in BC waters using sightings data from DFO surveys are currently underway (L. Dalla Rosa, Marine Mammal Research Unit, UBC).

Locations that are consistently utilized by humpback whales across years likely represent important feeding habitat that may represent Critical Habitat under SARA. However, further studies are needed to better understand the biophysical characteristics of these locations and their influence on habitat quality and quantity for humpback whales. It is also important to recognize that although prey densities may influence humpback whale movements on feeding grounds, there remains a strong tendency for individual whales to return to and remain in localized feeding areas each year. Rambeau (2008) showed that individual humpbacks in BC waters were re-sighted across years at a median distance of 75 km from previous sightings. Thus, important feeding locations that may represent Critical Habitat would only be so for a fraction of the overall population that uses BC waters.

Although certain areas may meet the requirements for designation as Critical Habitat under SARA, there is no 'residence' for this species as defined in the Act.

LIMITING FACTORS

The humpback whale population in the North Pacific may ultimately be limited by factors that affect its intrinsic rate of growth or its maximum potential abundance (carrying capacity). Humpback whales are long-lived animals that suffer low rates of predation as adults and consume a variety of different types of prey. Their reproductive parameters can lead to relatively high rates of growth, allowing for reasonable rates of population recovery.

Population growth rate will decrease towards zero as a population nears carrying capacity and density dependent factors come into play. The current population estimate for humpback whales in the North Pacific (18,302) is higher than the historic, albeit potentially unreliable, estimate of 15,000. This might suggest that the North Pacific humpback population is approaching carrying capacity. However three factors currently prevent drawing this conclusion: 1) historic carrying capacity is uncertain, 2) the true (current) carrying capacity may differ substantially from the historic one as a result of ecosystem changes (large-scale depletion of other whale and fish populations), and 3) there is currently no evidence that the rate of increase of this population is slowing. Thus, at this time, there is not enough weight of evidence to support the suggestion that the humpback whale population is nearing carrying capacity.

Since humpback whales experience relatively low rates of predation (Ford and Reeves 2008), they are ultimately limited by "bottom up" ecological processes involving prey limitation. Humpback whale populations require substantial prey resources and could have a significant impact on prey populations. For example, it has been estimated that in waters of the North Atlantic near Iceland, a population of about 1,800 humpbacks consumed approximately 230,000-280,000 tonnes of prey annually (Sigurjónsson and Víkingsson 1997).

THREATS TO SURVIVAL OR RECOVERY

Current and potential anthropogenic threats to humpback whales in British Columbia include vessel strikes, entanglement, a reduction in prey quantity and/or quality, and chronic and acute noise. Other potential threats considered to be of less immediacy or severity include persistent bioaccumulating toxins, biotoxins, physical disturbance, and resumption of whaling, however based on current knowledge these threats are not yet considered significant or imminent in nature. The following summarizes more extensive discussion of threats found in the draft Humpback Whale Recovery Strategy.

Vessel Strikes

The tendency of humpback whales to occupy continental shelf and coastal waters means their habitat may frequently coincide with both large and small vessel traffic. Globally, humpback whales are the second most commonly struck species, after fin whales, resulting in mortality or an unknown fate (Jensen and Silber 2003). Humpback whales are the most commonly reported species of cetacean struck by vessels in BC waters. Between 2001 and 2008, the DFO Marine Mammal Response Program has received 21 confirmed vessel strike reports involving humpback whales. Of these, 15 were witnessed collision events while the remaining 6 were of individuals documented with fresh injuries consistent with recent blunt force trauma or propeller lacerations from a vessel strike.

On the U.S. Atlantic coast, 30% of dead stranded humpbacks showed injuries consistent with evidence of a ship-strike (Wiley et al. 1995), whereas in Washington State, only one humpback whale mortality was considered the likely result of a ship strike (Douglas et al. 2008). Similarly in BC, there is only one record of a dead humpback whale whose mortality could be attributed to a vessel strike.

According to Laist et al. (2001), vessels travelling at speeds of more than 14 knots (26km/hr) provide the greatest threat of collision with cetaceans. Reported humpback-vessel strike incidents in B.C. waters have mainly involved small vessels (<10m long), typically capable of speeds of 25-30 knots (46-55 km/hr).

There are no confirmed reports of humpback whale collisions in BC waters that are attributable to shipping, cruise or ferry traffic. However, as large vessels are less likely to detect the impact of a cetacean collision than smaller vessels, fewer strikes may be reported than are occurring.

Where high densities of humpback whales (Figures 3 and 11) overlap with intense seasonal vessel traffic, such as in shipping lanes, the incidence of vessel strikes can be expected to be highest. Over the past 20 years, container and cruise ship traffic through BC ports has increased by over 200% (Transport Canada 2005) and is expected to continue to rise. As an increase in marine traffic coincides with humpback whales population recovery, and as technology allows for increased vessel speeds, the frequency of strikes is likely to increase in BC waters.

Entanglement in Fishing Gear

Entanglement in fishing gear has proven to be a threat to numerous baleen whale species around the world, including humpback whales (Volgenau et al. 1995; Clapham et al. 1999). Entanglements have been documented among North Pacific humpback whales in both their wintering areas (Mazzuca et al. 1998) and feeding areas (Neilson 2006; CRP-PBS, unpubl. data). Within BC there have been 40 reports of entangled humpback whales since 1987, including 4 confirmed mortalities (CRP-PBS, unpubl. data). It has been estimated in some regions that reported entanglement rates only capture 10% of actual events and thus is of limiting value in understanding how common entanglements occur (Robbins and Mattila 2004). A different approach, based on the analysis of scarring patterns, has been developed and used to estimate non-lethal entanglement rates for several humpback stocks. In Southeast Alaska between 2003-04, 52% of photographed animals showed clear evidence of previous entanglement (Neilson et al. 2007). Similar analyses currently underway using data from the SPLASH effort, suggest that non-lethal entanglements of humpback whales using northern British Columbia waters are consistent with those rates found in Southeast Alaska (J. Robbins, Provincetown Center for Coastal studies; D. Mattila, NOAA, pers. comms.). Although the sample size of suitable photographs from southern BC was too small for meaningful results, they do indicate that animals in the south are not free of entanglement wounds.

Entanglement reports, even if only capturing a small portion of actual events, are important to understanding fishing gear types involved. Of the 40 entanglement reports within BC, various gear types were documented including gillnets (27.5%), traps (22.5%), herring pond structures (7.5%), aquaculture gear (5.0%), longline gear (2.5%), seine nets (2.5%), and anchor lines (2.5%), with the remaining 30% of unknown type (CRP-PBS, unpubl. data). Gillnets and various types of trap gear have also been shown to pose entanglement risks to humpback whales in the western Atlantic and southeast Alaska (Johnson et al. 2005; Neilson et al. 2007).

As the preliminary data suggest, gillnet fisheries (salmon, herring roe), trap fisheries (crab, prawn, sablefish), groundfish long-line fisheries, spawn on kelp, herring bait ponds, aquaculture facilities, and seine fisheries all pose entanglement risks to humpbacks within B.C. These fisheries are present year round on the BC coast with the gillnet fisheries concentrated March through October (DFO 2008a, b, c, d, e, f, g). The salmon gillnet fishery likely presents the greatest entanglement risk to humpbacks in BC waters, and this risk will likely increase as the humpback population grows and increases its use of inland coastal waters were considerable gillnet fishing activity takes place.

Reduced Prey Availability

Localized depletion of commercially important fish stocks are expected to have a negative effect on marine mammals over the next century, in particular for coastal species (DeMaster et al. 2001). How this might affect humpback whales, however, is not known. Although humpback whales have numerous feeding strategies and a wide prey base, they require large volumes of prey and may show localized and seasonal prey preferences. Changes in prey quality (nutritional value, energy density, etc.) and changes in abundance of prey species, may force populations to switch to prey of ‘lesser quality’. Nutritional stress caused by prey limitation could have a range of effects on humpback whales, including reduced reproductive success, survival, and displacement from traditional feeding habitats. Grey whales in the northeast Pacific showed a significant and sudden population decline in 1999-2000 that appears to have resulted from unusually extensive ice cover in the Bering Sea that prevented access to important feeding habitat (Perryman et al. 2002). Calf production dropped by 30%, strandings increased to 8 times average rates, and there were numerous observations of emaciated animals (Moore et al. 2001; IWC 2002, 2003).

The primary prey of humpback whales in BC waters are euphausiids, and the prey biomass requirements of this growing population are substantial. Estimates of consumption rates of humpback whales derived from studies in Iceland are 125-160 tonnes/year/animal (Sigurjónsson and Víkingsson 1997). Based on stomach content information from BC whale catches described earlier, up to 90% of the food consumption of humpbacks in this region could be euphausiids. If so, the current population of about 2000 whales in BC waters could consume as much as 250,000-320,000 tonnes/year. There is currently no coast-wide estimate available for euphausiid abundance. However, the current harvest of euphausiids in BC waters is around 500 tonnes/year in the Strait of Georgia area, which is not significant relative to the biomass potentially consumed by humpbacks. However, should harvest levels increase substantially or be focused in particular humpback feeding areas, the potential for negative effects exist.

Pacific herring and Pacific sardine are consumed by humpback whales in BC waters and these species are also the focus of on-going fisheries in the province. Since the 1985 implementation of fishery control rules, annual estimates of adult herring population abundance range from approximately 70,000 to 270,000 tonnes, with an average of 190,000 tonnes. The lowest abundance is for the 2008 spawning season. Declines in abundance estimates for regionally assessed BC stocks from 2003 to 2008 are prevalent and commercial fishing has been reduced or closed accordingly in each region. Throughout BC, there are strong signals of increased natural mortality, poor recruitment and reduced size at age for herring during this recent period when humpback whale abundance and distribution has been increasing.

Sardine abundance has fluctuated widely over the past 75 years as a result of overfishing and shifts in distribution patterns due to changing ocean conditions. From the 1920s to 1940s, harvest rates for sardine in BC waters were maintained at high levels for several years (i.e., 50% or greater). The stock declined drastically in the 1940s leading to a fishing moratorium and COSEWIC listing of Special Concern in 1987. Sardines reappeared in BC waters in 1992 and abundance has generally increased since then. Sardine biomass estimates off the west and north coasts of Vancouver Island from 1997-2008 range from 136,208 to 258,489 tonnes. Commercial fishing on sardine in BC began in 1995 and has increased with increasing sardine abundance. The 2008 fishing season is anticipated to reach its quota of 12,500 tonnes.

There is considerable uncertainty about the proportion of humpback whale diet that is comprised of herring and sardine. There are likely considerable regional differences in the importance of these prey species, and certain individuals may feed preferentially on schooling fish (e.g., whales that are commonly observed in cooperative bubble-net feeding groups; Sharpe 2001). Further research is needed to better understand the seasonal and regional importance of the various components of humpback whale diet, and the ability of humpbacks to prey shift when availability of a particular prey species declines. There is no indication of a slowing in the population growth rate of humpback whales in BC, so prey limitation does not appear to be a factor in their population dynamics at present.

Acoustic Disturbance

There has been increasing concern in recent years about the potential effects of underwater noise on cetaceans. Acoustic disturbance can be of two types: chronic and acute. Chronic noise is primarily associated with motorized vessel traffic of all types, from commercial shipping to whale watching. Chronic noise can result in masking of communication signals used for social contact or behavioural coordination, or potentially interfere with auditory cues used for navigation or prey detection.

Sources of acute noise include military and commercial sonars, airguns used in seismic surveys for oil exploration or geophysical research, and pile driving and underwater explosions associated with construction. These sounds can be extremely intense and may travel large distances underwater. Loud acute noises have the potential to cause a variety of effects in cetaceans, including hearing threshold shifts, production of stress hormones, and tissue damage, as well as a variety of behavioural responses.

Strong avoidance reactions to underwater noise by grey, humpback and bowhead whales have been observed at received levels of 160-170 dB (Richardson et al. 1995). Reactions include avoidance, interruption of feeding, moving away from the sound source, and changes in respiration and dive patterns (Frankel and Clark 2000; McCauley et al. 2000; Stone and Tasker 2006). Although these responses were detectable, it is unclear whether the presence or absence of a behavioural reaction is a meaningful measure of effect. Humpback whales exposed to underwater explosions in Trinity Bay Newfoundland, did not react visibly by altering surface behaviour or distribution in the area. A coincident increase in the occurrence of humpback whale entanglement in fishing nets was observed and it was suggested that exposure to the explosions may have affected the ability of some humpbacks to orient and navigate (Todd et al. 1996). Two humpback whales that died following the underwater blasting were found to have inner ear damage consistent with blast exposure (Ketten et al. 1993).

Behavioural reactions of humpback whales to seismic operations include avoidance of the seismic operation at distances of 3 km with some avoidance behaviour evident at 5 to 8 km. Other behaviours observed are swimming and remaining near the surface, perhaps to take at advantage of the sound shadow (sound less intense near the surface) (McCauley et al. 2000; Weir 2008). In 2002 an unusual increase in the number of stranded adult humpback whales in an area along the coast of Brazil used by breeding humpback whales occurred coincidently with seismic surveys in the area (Engel et al. 2004). However, it has not been established that the seismic activity was responsible for these strandings.

Seismic surveys have been undertaken recently in BC waters, although not extensively. Since 2003, there have been 4 proposed seismic operations that have been reviewed by DFO. In 2001 the BC provincial government lifted a moratorium on oil and gas exploration and is requesting that the federal government follow suit. A full lifting of the moratorium would be expected to result in an increase in seismic survey activity in BC waters.

The production of intense underwater sound associated with naval operations has the potential to disturb or harm cetaceans, including humpback whales. Low frequency active sonar (LFA) is used by the military for long range surveillance and produces pulses at frequencies of < 1 kHz. Mid-frequency sonar, used for tactical purposes, produces pulses between 1 and 20 kHz (IWC 2004). Mid-frequency active sonar used by the US Navy has been associated with strandings of beaked whales and recently in Haro Strait, Washington in May, 2003, with strong avoidance or fright responses from several species of marine mammals including killer whales, Pacific white-sided dolphins and a minke whale (Evans and England 2001; Jepson et al. 2003; Anon 2005). There has also been concern about the US Navy's use of SURTASS low frequency active sonar. Recent studies of the behavioural response of singing humpback whales in Hawaiian waters indicate that individuals exposed to LFA pulses at received levels of 150 dB responded by increasing the length of their songs, perhaps in response to masking effects of the SURTASS signals (Miller et al. 2000; Fristrup et al. 2003).

The Canadian Navy uses active sonar during training exercises and equipment testing in designated training areas off the BC coast. There are 5 primary types of sonar that are used by the Canadian Navy. Of these, the most powerful is the mid-frequency active SQS-510 sonar, which emits ten times less energy than the SQS53C sonar used by the US Navy. The Canadian Navy also use helicopter dipping sonars and active sonobouys although these emit far less energy than the SQS 510 (Fisheries and Oceans 2008b). Canadian test ranges, such as the one off the west coast of Vancouver Island are also used by other navies to test equipment and train personnel, thus a wide variety of active sonar systems may be used in Canada's Pacific waters.

The vulnerability of humpback whales in BC to underwater noise requires further study. There is no evidence to date that existing anthropogenic noise types or amplitudes have caused any detrimental effects at the population level. However, should activities associated with production of acute underwater sounds, such as oil exploration and pile driving, increase spatially or temporally, monitoring of potential effects should be undertaken and mitigation should be implemented as required.

ALLOWABLE HARM ASSESSMENT

In order to estimate the level of human-caused mortality that may be allowable without causing serious population-level consequences or prevent recovery, the U.S. National Marine Fisheries Service has devised a means of calculating the Potential Biological Removal (*PBR*) for marine mammal populations. *PBR* estimates the maximum number of animals, excluding natural mortality, that may be removed per year while still allowing the population to reach or sustain to its 'optimum sustainable population' (Wade 1998). *PBR* is calculated as:

$$PBR = N_{MIN} \text{ X } ½ R_{MAX} * F_R$$

where:

N_{MIN} = the minimum population estimate

½ R_{MAX} = one-half the maximum theoretical or estimated net productivity of the stock at a small population size,

F_R = a recovery factor between 0.1 and 1.

To calculate *PBR* for humpback whales in BC, we use the following values:

N_{MIN} = 2066, the 20th percentile of the estimated population size in 2006
R_{MAX} = 0.04, the default value recommended for cetaceans (Wade 1998), and

F_R = 0.5, the recommended recovery factor for non-endangered cetaceans (Wade 1998; Angliss and Outlaw 2007).

PBR for the BC humpback whale population was calculated to be 21 animals.

MITIGATION AND ALTERNATIVES TO THREAT-CAUSING ACTIVITIES

The following provides a summary of the key approaches that are or could be employed to minimize or mitigate the impacts of human activities on humpback whales and their habitat. These are addressed in greater detail in the draft Recovery Strategy for Humpback Whales in BC (Fisheries and Oceans 2008). Note that these generally include only mitigation measures available in Canadian waters.

Vessel Strikes

Efforts taken to date to minimize vessel-whale interactions include raising awareness of whale distribution, encouraging reporting of collision events to help inform vessel traffic management policies and mitigation efforts, as well as the development and support of multi-jurisdictional, transboundary (Pacific Canada and Washington State, USA) guidelines for vessel operations around marine mammals. It is currently unknown to what degree these measures have reduced the number of humpback whale-vessel interactions.

The newly-formed BC Marine Mammal Response Network (see below) will increase the probability that vessel collisions involving cetaceans, including humpbacks, will be reported.

Entanglements

Actions taken so far in BC to mitigate the occurrence or effects of entanglement of whales, including humpbacks, in fishing gear have focused mostly on developing regional capacity to disentangle animals. Since 2000, several sets of specialized disentanglement equipment have been acquired from the Center for Coastal Studies (Provincetown, MA, USA), which disentangles whales off the northeast US under contract to NOAA Fisheries. In 2005, a disentanglement workshop was held at the Vancouver Aquarium, which included both theory and on-the-water simulated disentanglement exercises. In BC waters since 1987, five humpback whales have been disentangled from trailing gear, while 9 attempts were made to disentangle whales from active fishing gear.

The DFO Marine Mammal Response Program (see above) will also increase the likelihood that entangled humpback whales will be reported and a response initiated in time to effect a successful disentanglement effort.

Other potential actions to reduce the frequency of humpback entanglements in fishing gear in BC include monitoring of spatial and temporal overlap between fishing operations and humpback whale occurrence, with the implementation of temporary area closures as needed. The inclusion of weak links in fixed long-line or trap gear so that buoy lines will part if entangled is another potential mitigative action.

Reduced Prey Availability

The abundance of humpback whales in BC waters has been growing at an annual rate of approximately 4%/year since the early 1990s. This growth has yet to show signs of slowing, which might be indicative of prey limitation causing density dependent effects. However, should future population growth slow significantly, especially before population recovery targets are met, the possibility of prey limitation should be investigated and mitigative actions should be taken as required. In order to assess the potential for prey limitation in this population, further research is necessary in order to better understand the seasonal and regional importance of different prey resources to these whales. Also important are quantitative estimates of the biomass of key prey species needed to sustain a growing or recovered humpback whale population. If reduced availability of commercially important species such as herring or sardine is found to be constraining recovery of humpback whales in BC, this populations' requirements should be incorporated into fishery management plans to ensure a sufficient biomass is available.

Underwater Noise

Military sonar

The Department of National Defence (DND) has established protocols to protect marine mammals from disturbance and/or harm from the use of military active sonar. Maritime Command Order 46-13, for marine mammal mitigation, is to avoid transmission of sonar any time a marine mammal is observed within the defined mitigation avoidance zone, which is established specific to each type of sonar. Ship's personnel receive training in marine mammal identification and detection. All foreign vessels are subject to Canadian regulations while in Canadian waters (D. Freeman, DND, pers. comm.). There remains some concern regarding compliance by foreign vessels with Canadian regulations and the effectiveness of these mitigation protocols.

Seismic air guns

There are currently few industrial or scientific seismic surveys conducted in western Canadian waters. Some projects involving seismic surveying trigger screening under the Canadian Environmental Assessment Act (CEAA), while others are reviewed regionally by DFO. In 2005, DFO developed a draft Statement of Canadian Practice on the Mitigation of Seismic Noise in the Marine Environment, to address concerns regarding the potential impact of seismic use on marine mammals and other marine life. This Statement of Practice, which was revised in 2007, is considered to be minimum standards to be applied at the national level (DFO 2007b). In the Pacific Region, each proposed seismic survey is reviewed by DFO marine mammal experts and mitigation measures are developed based on the species of concern in the area of the survey for each project. Seismic mitigation protocols recommended by DFO Pacific Region are designed to prevent exposure of cetaceans to received sound pressure levels in excess of 160 dB re 1 μPa, which is generally the level at which behavioural disturbance can be anticipated. A slow ramp-up of air gun pressure, or a 'soft start', is utilized to allow cetaceans to leave the area ensonified with intense sound. A safety zone corresponding to the estimated 160 dB re 1 μPa isopleth is established around the sound source, and a marine mammal observer monitors this zone while air guns are operating. If a cetacean enters the safety zone, air gun use is suspended until it has left the zone.

A DFO Science workshop to assess the effectiveness of existing methods used to mitigate the effects of seismic surveys on marine mammals is planned for 2009.

Construction noise

Mitigation protocols to prevent exposure of cetaceans to noise associated with construction activities such as dredging and pile driving in the Pacific Region are similar to those for seismic air guns.

Chronic noise

There is currently no mitigation of chronic noise in the marine environment that originates from shipping and other marine vessel traffic in the habitat of humpback whales in BC.

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TABLES

Table 1. Chapman-modified Lincoln-Petersen estimates of humpback whale abundance between year pairs, 1992-2005.

Start year	End year	N*	CV*(%)	NB*	Lower CI	Upper CI
1992	1993	580	54	744	487	1002
1993	1994	630	34	633	143	1122
1994	1995	590	22	587	299	874
1995	1996	516	19	517	309	725
1996	1997	910	38	930	184	1677
1997	1998	1149	42	1226	347	2106
1998	1999	945	15	939	639	1238
1999	2000	1052	12	1054	794	1315
2000	2001	702	11	702	544	859
2001	2002	1133	11	1136	900	1372
2002	2003	1434	9	1434	1189	1680
2003	2004	1460	6	1462	1286	1638
2004	2005	1888	7	1886	1634	2138
2005	2006	1659	7	1660	1428	1892

FIGURES

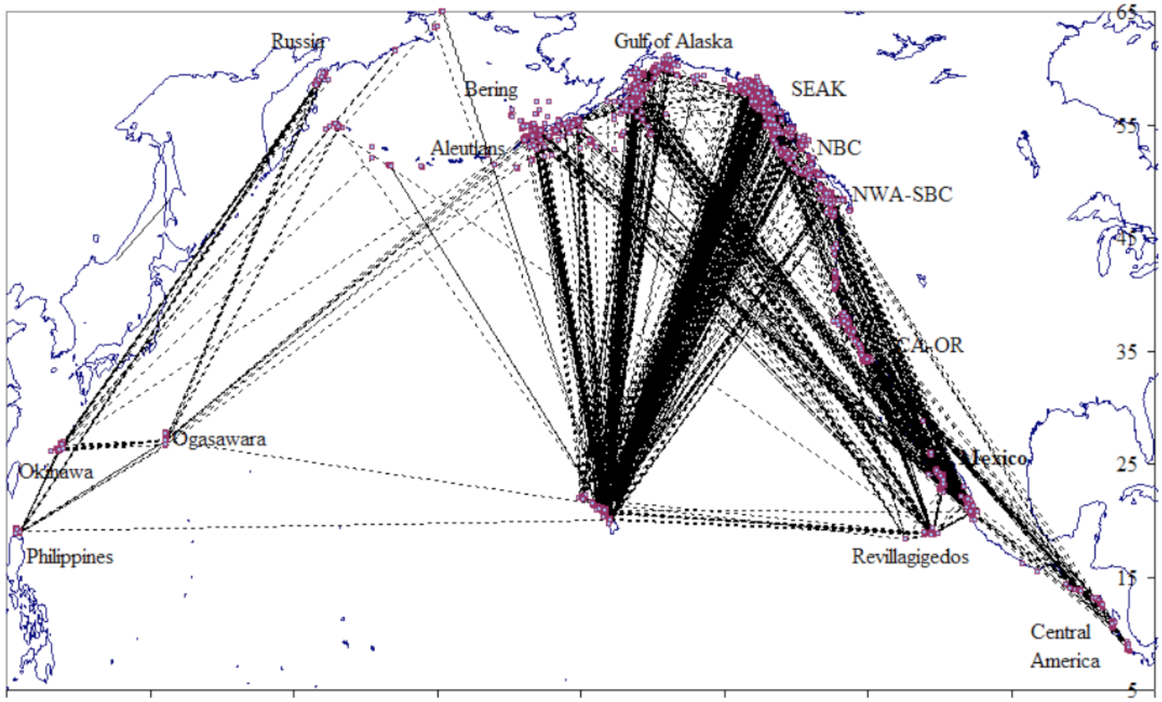

Figure 1. Locations of 873 photo-identified humpback whales in the North Pacific documented in the SPLASH project, 2004-2006. Lines connect sequential sightings of the same individual. Figure reproduced from Calambokidis et al. (2008).

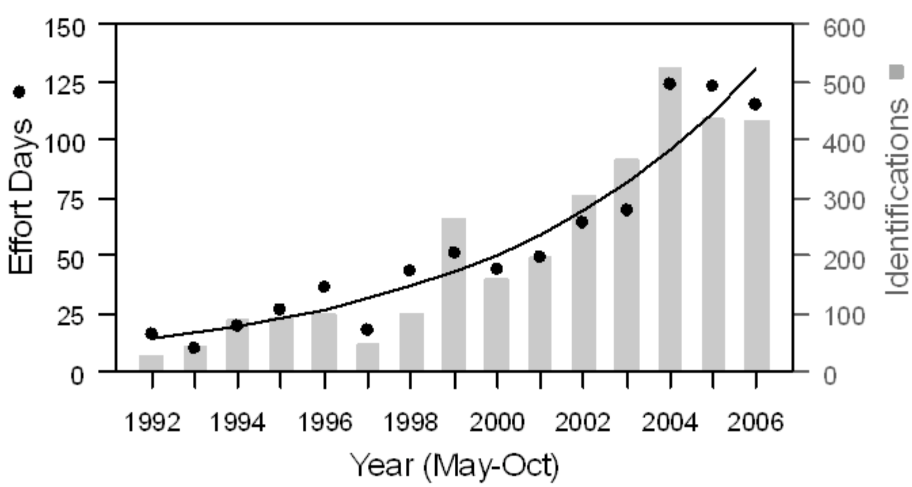

Figure 2. Exponential increase in number of days identification photographs were taken and number of humpback whales identified in BC from 1992 to 2006. Effort days (points) are the number of days an ID photograph was taken between May and October that year. Identifications (grey bars) represent the total number of unique individual humpback whales photographed in BC between May and October that year. An exponential

regression was fit to the effort days' data to show how it increased over 15 years (*Effort*=12.5e0.08*years*)

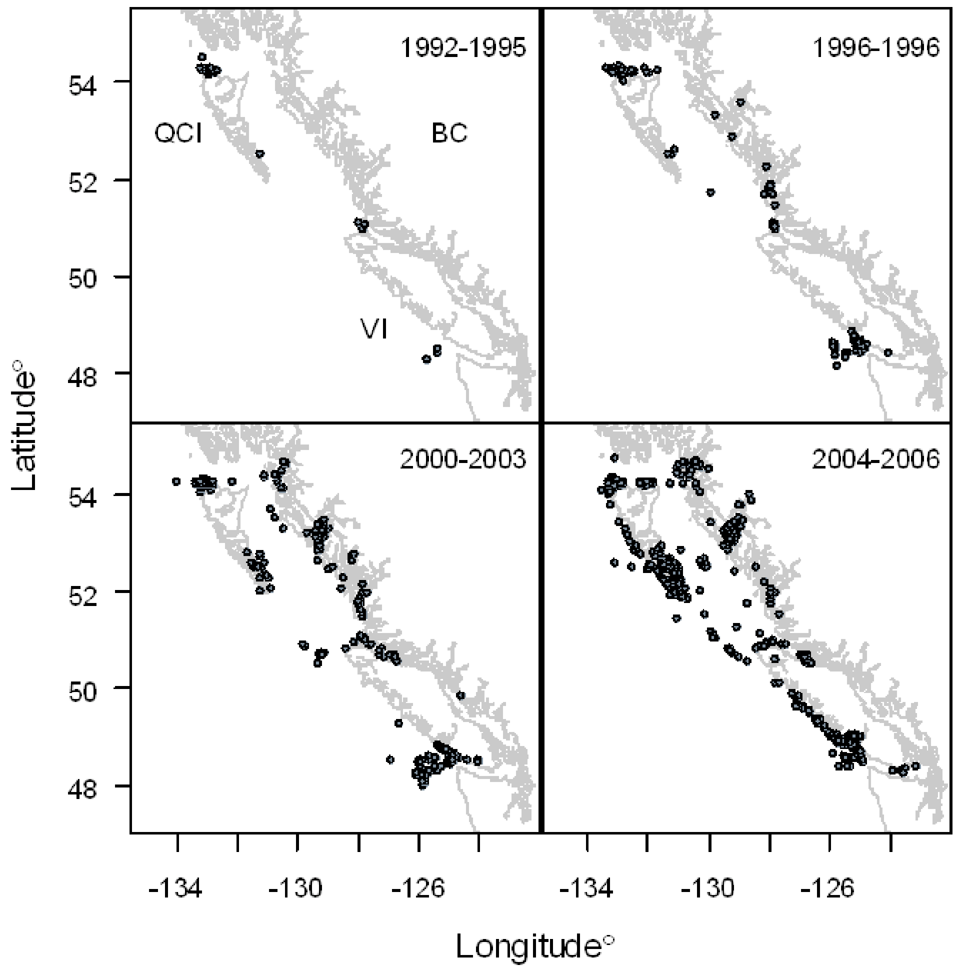

Figure 3. Locations of photo-identified humpback whales, showing variation in spatial effort from 1992 to 2006 in British Columbia (BC), Canada. Years are pooled for ease of viewing only. QCI = Queen Charlotte Islands, VI = Vancouver Island

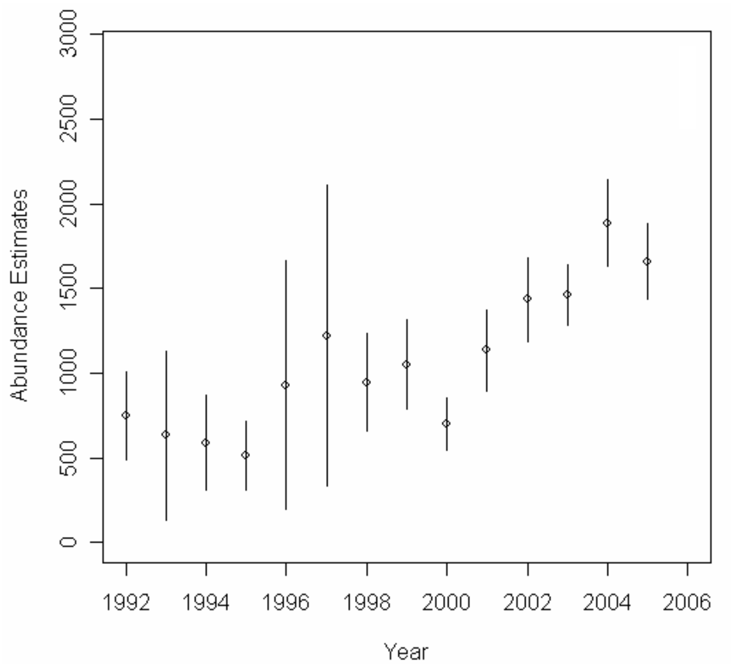

Figure 4. Bootstrap-corrected Chapman-modified Lincoln-Petersen abundance estimates (with 95% confidence intervals) for humpback whales in BC waters, 1992-2005.

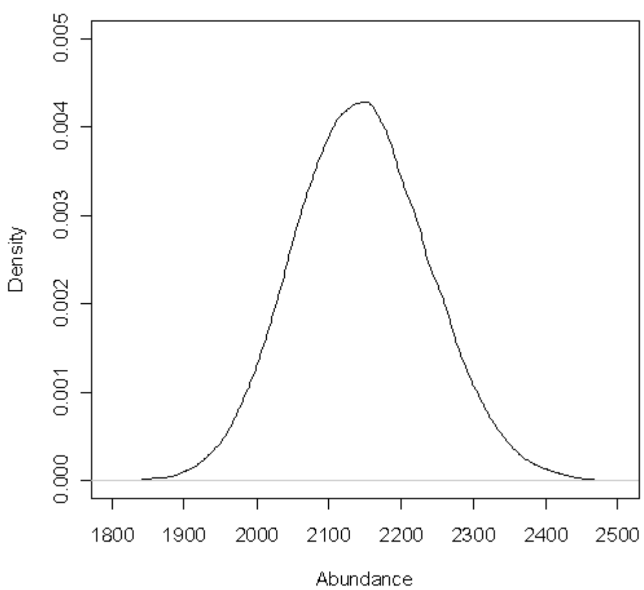

Figure 5. SIR Jolly-Seber estimate of 2006 abundance of humpback whales in BC waters.

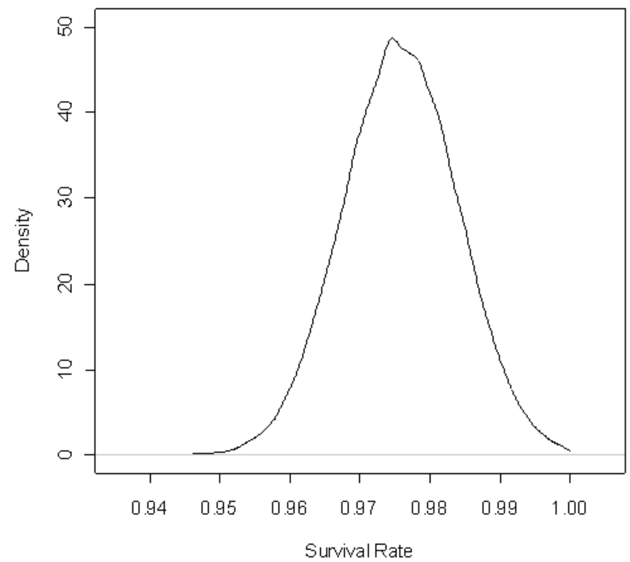

Figure 6. SIR Jolly-Seber estimate of annual survival rate of humpback whales in BC waters.

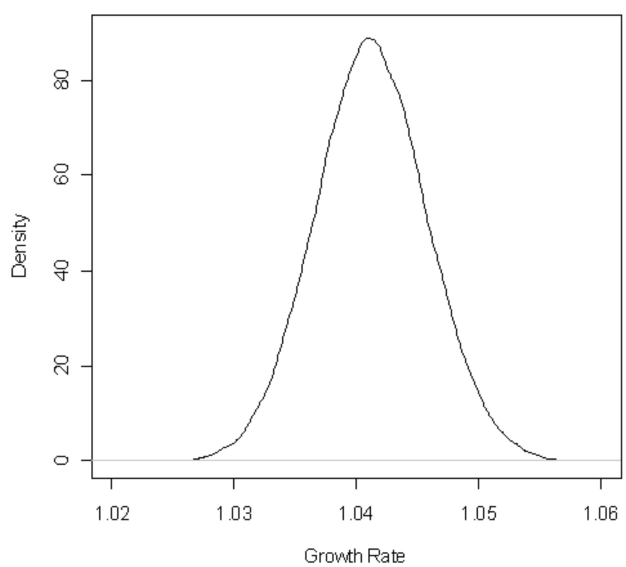

Figure 7. SIR Jolly-Seber estimate of annual population growth rate of humpback whales in BC waters.

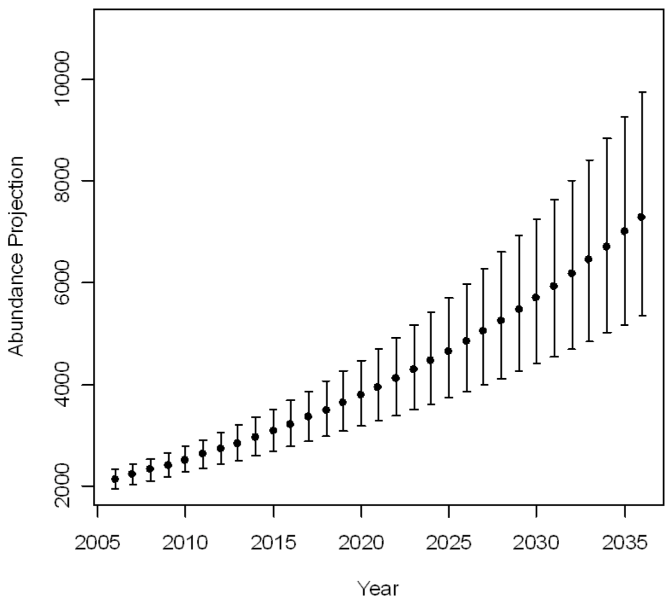

Figure 8. Estimated forward population trend of humpback whales in BC waters over the next 30 years (with 95% confidence intervals).

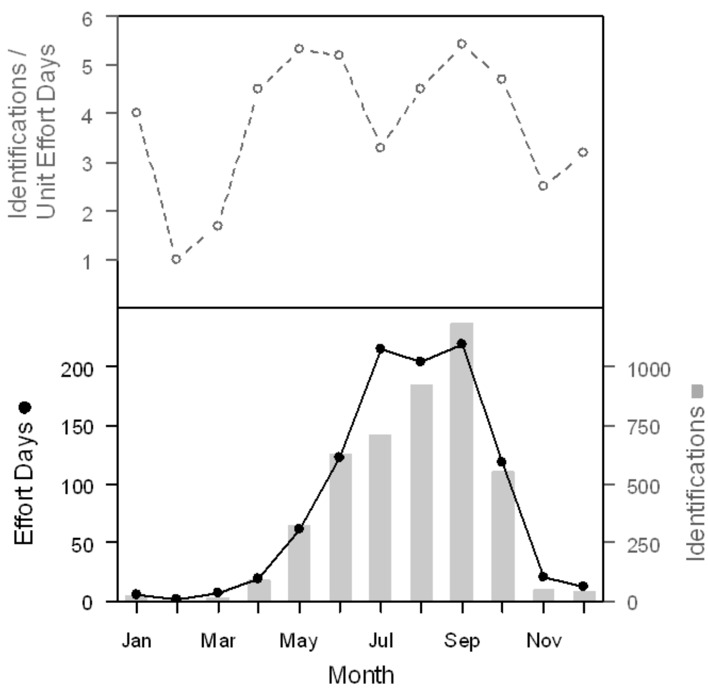

Figure 9. Seasonal representation of the number of days that an identification photograph was taken (effort days) and the cumulative number of individual humpback whale identifications obtained in BC in each month during 1992-2007 (bottom panel), and identifications per unit effort (top panel).

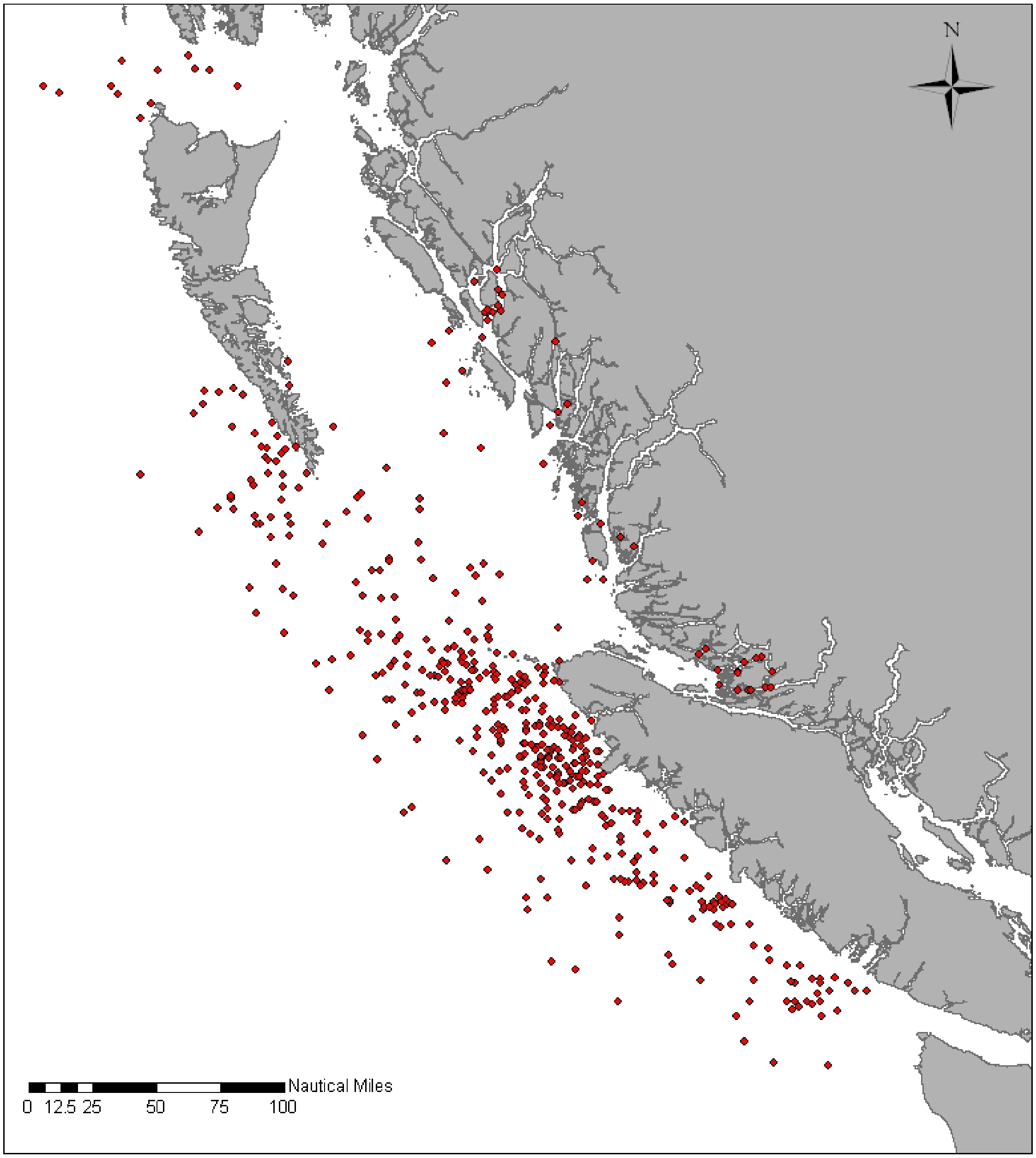

Figure 10. Locations of 629 humpback whales killed off the BC coast during the whaling periods of 1924-28 and 1949-65.

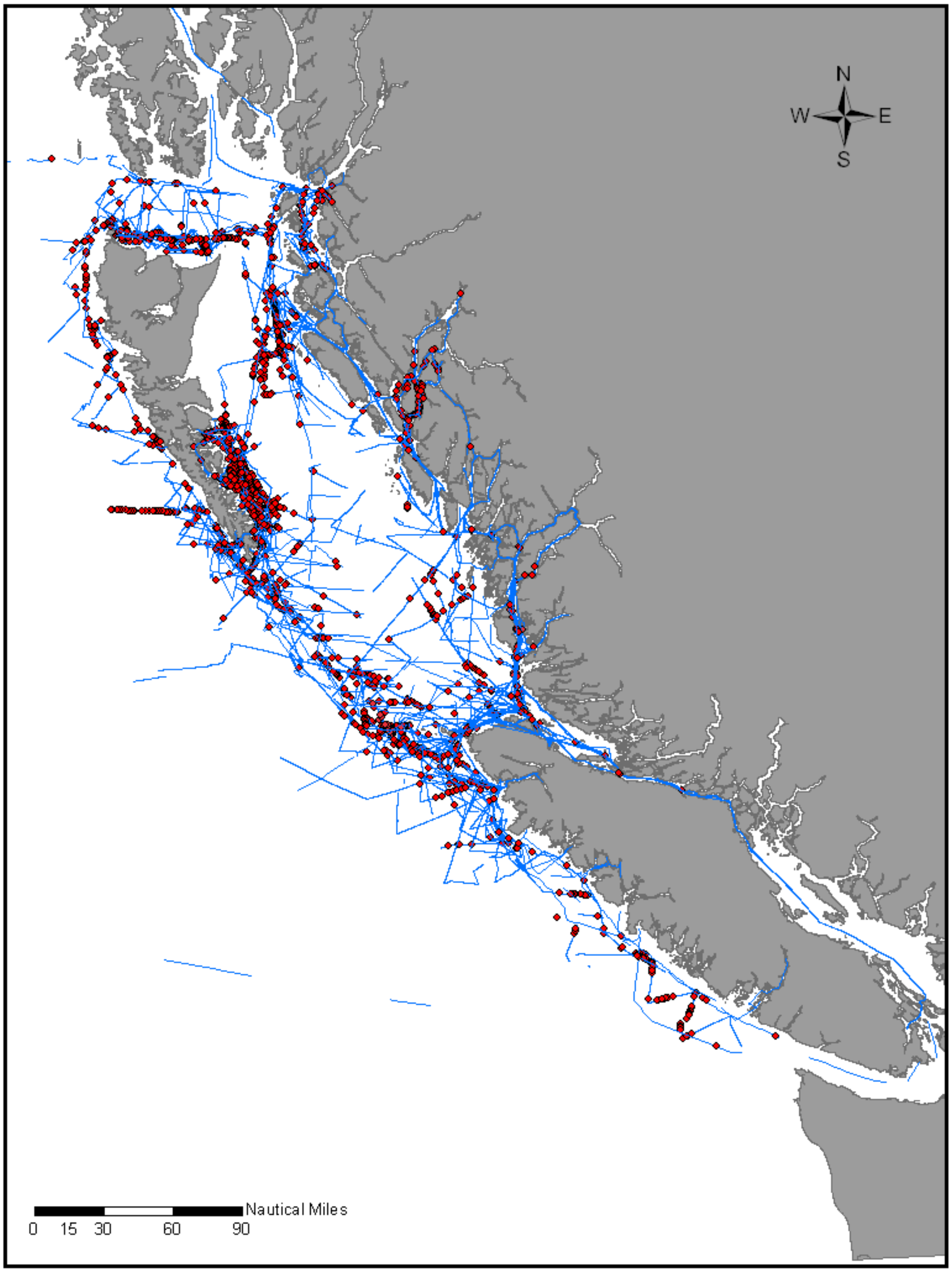

Figure 11. Locations of 1906 humpback whale sightings made during 26 DFO shipboard cetacean surveys, 2002-2008. Red dot indicates location of one or more humpback whales, blue lines indicate on-effort survey track.

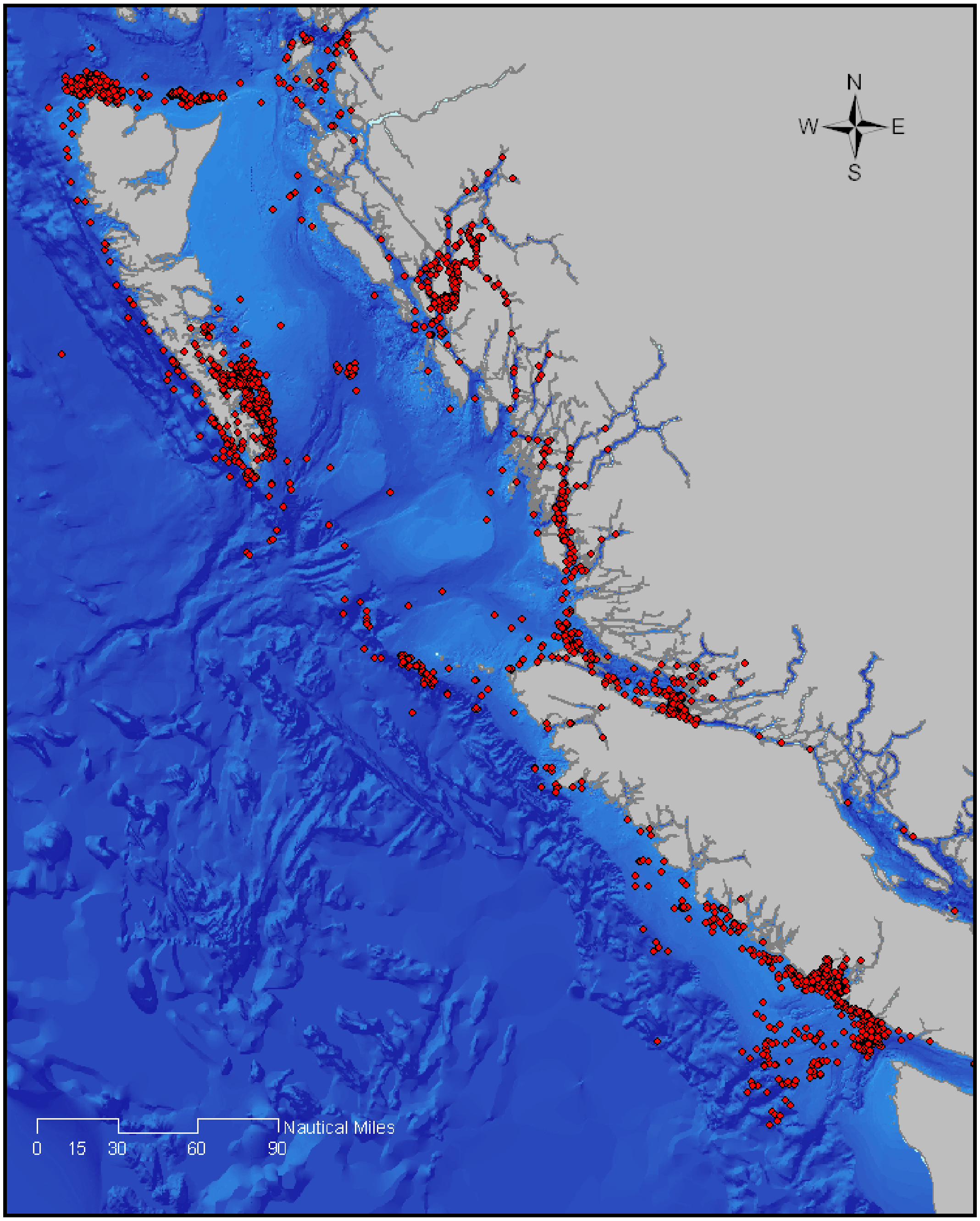

Figure 12. Locations of 6401 humpback whale photo-identifications in BC waters, collected during 1984-2007.