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Recovery Potential Assessment for the Grey Whale (*Eschrichtius robustus*): Pacific Coast Feeding Group and Western Pacific Population in Canadian Waters

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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TABLE OF CONTENTS

ABSTRACT

Once the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses an aquatic species as Threatened, Endangered or Extirpated, Fisheries and Oceans Canada undertakes actions to support implementation of the Species at Risk Act. In November 2017, COSEWIC split the Eastern North Pacific Grey Whale population into two designatable units (DU): the Northern Pacific Migratory (NPM) population (Not At Risk, ~27,000 individuals) and the Pacific Coast Feeding Group (PCFG, Endangered, 243 individuals). Some individuals from another DU, the Western Pacific (WP) Grey Whale population (Endangered, 282 individuals), migrate across the North Pacific, through Canada and the U.S., to breeding grounds in Mexico. The objective of this RPA is to provide scientific information on the current status of the two Endangered Grey Whale DUs in Canada, threats to survival and recovery, and the feasibility of recovery. All three DUs share breeding grounds in Mexico during the winter and a portion of the migration route along the west coast of North America during spring and fall. The NPM population feeds in the Beaufort, Bering and Chukchi Seas, while the PCFG shows high fidelity to lower-latitude feeding sites, primarily from northern California to northern British Columbia during the summer. The WP population feeds off Sakhalin Island and Kamchatka Peninsula in Russia. PCFG abundance increased from 1998 to 2004, remained relatively stable from 2005 to 2010, and increased from 2011 to 2015. The WP population abundance (including both Sakhalin Island and Kamchatka feeding aggregations), has been steadily increasing at 2 to 5% since the mid-1990s. Primary threats to survival and recovery of the PCFG and WP population are entanglement in fishing gear and vessel collisions. Threats to habitat include coastal industrialization, development projects, or any activity which disrupts or destroys nearshore habitat. Limiting factors for survival and recovery include the impacts of environmental variability and ocean acidification on prey quality, abundance, or availability, exposure to naturally-occurring harmful toxins, and Killer Whale predation. Three recovery abundance objectives are proposed for both the PCFG and the WP population in Canada: 1) Maintain a stable population size, 2) Maintain a growing population size to exceed 250 mature individuals, and 3) Maintain a growing population size to exceed 1,000 mature individuals. Forward projections indicate that reaching objective 1 by 2038 is 86% and 100% probable for the PCFG and WP population respectively, and reaching objective 2 is 11% (PCFG) and 94% (WP) probable, although these probabilities are highly dependent on the current carrying capacity of these populations, which is uncertain for both DUs. Reaching a population abundance of 1000 mature individuals (i.e., no longer an Endangered or Threatened status) has 0% probability for both the PCFG and WP population within a 23-year time frame. A reasonable distribution recovery target for both DUs would be to maintain their current known spatial extent. Using the Potential Biological Removal method, allowable harm was calculated at 1.8 PCFG whales per year and 2.1 WP whales per year (these values are for the entire populations and are assumed to represent anthropogenic mortality over their entire distribution ranges rather than just in Canadian waters.

INTRODUCTION

The Grey Whale population in the Atlantic Ocean was extirpated before the end of the 1800s (COSEWIC 2009). Grey Whales in the Pacific Ocean were traditionally recognized as two geographically and genetically distinct populations, one migrating along the west coast of North America from Mexico to the Bering, Chukchi and Beaufort Seas, and the other migrating along the east coast of Asia from the Korean Peninsula to Russia (Rice and Wolman 1971; LeDuc et al. 2002). The Eastern North Pacific (ENP) Grey Whale population was considered a single population by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and designated Not at Risk in April 1987. Status was re-examined and designated as Special Concern in May 2004. The *Species at Risk Act* (SARA) published a Management Plan for the Eastern Pacific Grey Whale in Canada (Fisheries and Oceans Canada 2010) in 2011, and a Report on the Progress of Management Plan Implementation for the Eastern Pacific Grey Whale in Canada for the Period 2011–2015 in 2019 (Fisheries and Oceans Canada 2019).

Recent findings indicate that some Grey Whales from the Western Pacific (WP) population migrate to the west coast of North America to join the ENP Grey Whales during migration and on breeding grounds in Mexico (Lang 2010; Mate et al. 2011, 2015; Weller et al. 2012; Urbán et al. 2013). Concomitantly, photo-identification and genetic studies have suggested that a group of Grey Whales within the ENP population may be demographically distinct insofar as exhibiting maternally-directed site fidelity to specific feeding sites further south than the larger ENP population, as well as some degree of internal recruitment (Calambokidis et al. 2002, 2017; Frasier et al. 2011; Lang et al. 2014). These two developments led COSEWIC to split the ENP population into two designatable units (DU) in November 2017: the Northern Pacific Migratory (NPM) population, designated as Not at Risk and the Pacific Coast Feeding Group (PCFG), designated as Endangered due to a population size of less than 250 mature individuals (COSEWIC 2017). The WP Grey Whale population, having been previously assessed and designated as Endangered by the International Union for Conservation of Nature (IUCN) (Cooke 2018), was also designated as Endangered by COSEWIC in November 2017, considering that some individuals use Canadian waters for migration and potentially foraging (COSEWIC 2017).

Range-wide population structure of Grey Whales in the North Pacific is an area of ongoing research. The International Whaling Commission (IWC) convened five workshops between 2014 and 2018 to investigate various stock structure hypotheses using all available data sources (International Whaling Commission 2018a). Over-wintering grounds and migratory routes of Grey Whales in the western North Pacific are still uncertain (reviewed in Weller et al. 2002). It is also unknown what proportion of the WP population uses eastern Pacific waters. Current data suggest that not all Grey Whales identified in the western North Pacific share a common wintering ground (Weller et al. 2012).

In support of listing recommendations for both the PCFG and the WP population by the Minister, Fisheries and Oceans Canada (DFO) Science has been asked to undertake a Recovery Potential Assessment (RPA), based on the national RPA Guidance. The advice in the RPA may be used to inform both scientific and socio-economic aspects of the listing decision, development of a recovery strategy and action plan, and to support decision making with regards to the issuance of permits or agreements, and the formulation of exemptions and related conditions, as per sections 73, 74, 75, 77, 78 and 83(4) of SARA. The advice in the RPA may also be used to prepare for the reporting requirements of SARA s.55. The advice generated via this process will update and/or consolidate any existing advice regarding both the PCFG and WP Grey Whale populations.

SPECIES BIOLOGY AND ECOLOGY

The Grey Whale (*Eschrichtius robustus*) is a medium to large-sized mysticete cetacean. It is the only extant species within the family Eschrichtiidae. Adults measure between 11 and 15 m in length, and calves measure 4 to 5 m at birth (Rice et al. 1984). Adults have a mottled skin pigmentation, from light to dark grey in color. Calves are dark charcoal grey, and become paler with age. The skin is often covered with ectoparasites such as whale lice and barnacles, which form white to orange-colored patches (Jones et al. 1984). Grey Whales lack a dorsal fin, and have a series of six to twelve dorsal crenulations along the peduncle to the flukes. The throat has two to five furrows or grooves, which help distend and compress the throat during feeding.

Grey whales feed by filtering small prey through baleen plates which hang from the upper jaw. They are considered generalist and opportunistic predators, consuming a variety of vertebrate and invertebrate prey in both pelagic and benthic environments (Nerini 1984; Darling et al. 1988; Reeves and Mitchell 1988). Most individuals of the species undertake seasonal migrations, spending the winter months in low-latitude breeding grounds and the summer months in temperate and Arctic feeding grounds (Rice et al. 1984). Grey whales generally form small groups of one to three individuals, but migrating whales can be found in groups of up to 20 individuals. Larger aggregations also occur on feeding and breeding grounds (Rice and Wolman 1971).

Both male and female Grey Whales reach sexual maturity around age eight and physical maturity at around age 40. Sexual behaviour has been observed all year, however most calves are conceived in late November and early December during the southbound migration (Rice and Wolman 1971). The gestation period is 13-14 months and females give birth to a single calf between early January and mid-February. The lactation period is approximately six to seven months. The inter-birth interval is two years if females are in good body condition, and longer in years with reduced prey abundance or availability, or other disturbance scenarios resulting in poor body condition (Perryman et al. 2002; Villegas-Amtmann et al. 2015). Generation time, or the average age of parents, is around 23 years. Calf (< 1 y) survival rates are estimated at 0.63 for the PCFG, and 0.67 for the WP population. Non-calf (> 1 y) survival rates are estimated at 0.97 for the PCFG, and 0.98 for the WP population. Life-history parameters and associated references are listed in Table 1.

ASSESSMENT

POPULATION ABUNDANCE AND DISTRIBUTION TRENDS

Grey Whale feeding and breeding areas within the North Pacific (known and historic) are shown in Figures 1 and 2 (International Union for Conservation of Nature 2016). The NPM population (Fig. 3) migrates annually along the west coast of North America from winter breeding and calving lagoons in Mexico to summer and autumn feeding grounds in the Chukchi, Beaufort and northwestern Bering Seas. Given the nearshore migration route taken by Grey Whales, systematic and annual shore-based counts of migrating whales have been used in the past to estimate population abundance. Estimated population size of Grey Whales on their southbound migration along the central California coast increased from 1967 to 1987, was relatively stable during the mid-1990s to 2010 period, and increased from 2014 to 2015. The latest abundance estimate was 26,960 (coefficient of variation [CV] 0.05) in 2015/2016 (Durban et al. 2017), which likely includes members from all three DUs (NPM, PCFG, and WP).

The PCFG qualifies as a designatable unit since it has “attributes that make it ‘discrete’ and evolutionarily ‘significant’ relative to other populations” which may warrant separate management consideration (COSEWIC 2017). Genetic findings, such as a consistent pattern of mtDNA differentiation compared to the NPM population, as well as photo-identification data, suggest the PCFG shows strong maternally directed fidelity to summer feeding grounds. Determining whether the PCFG qualifies as “demographically discrete” would require a better understanding of the degree of internal recruitment versus external immigration (individuals with non-PCFG parents entering the population).

The PCFG shares a migratory corridor and breeding ground with the NPM population, however they feed in lower latitudes, primarily from northern California to northern British Columbia (BC; Fig. 4). They have frequently been observed in Alaska and occasionally in the Beaufort Sea (Darling 1984; Gosho et al. 2011; Calambokidis, Laake, and Klimek 2012). Feeding areas used by PCFG whales lie on the migration path of the larger NPM population. Defining the geographic and temporal range of PCFG whales has been subject to debate. Photo-identification studies show that Grey Whales seen from northern California to northern BC during the summer and fall comprise two groups: 1) individuals that frequently return to the area, show a higher degree of within-season site fidelity, and account for the majority of sightings between 1 June and 30 November, and 2) individuals known as transients, which are often seen in only one year, tend to be observed for shorter periods and within more limited areas (Calambokidis et al. 2017). For management purposes, the IWC has defined the PCFG as individuals observed between 1 June and 30 November from 41°N to 52°N in two or more years (International Whaling Commission 2011, 2012). This definition has been noted within COSEWIC (2017) and used in recent Marine Mammal Stock Assessments in the U.S. (Carretta et al. 2018a). The geographic range is restricted to 52°N since the majority of photo-identification efforts have been within 41°N and 52°N, and thus population estimates are more reliable for this range.

PCFG population size increased from 1998 to 2004, remained relatively stable from 2005 to 2010, and increased from 2011 to 2015. The latest abundance estimate is 243 (SE 18.9) individuals in 2015 (Calambokidis et al. 2017). The annual average number of new non-calf Grey Whales in the PCFG region is 37.2, and the annual average of recruited whales (seen in a subsequent year) is 14.9 (Calambokidis et al. 2017). Given the nature of the definition of a PCFG individual, the dynamic immigration/emigration with the NPM population, and the large interannual variation in capture probability (due to survey area coverage and animal movements between regions), population size is estimated using photographic capture-mark-recapture techniques, with some degree of uncertainty. Recruitment into the PCFG appears to be offset by either mortality or permanent emigration, although those two processes can be hard for models to differentiate and will require further study.

The WP population (Fig. 5) spends the summer and fall feeding in the Okhotsk Sea and the Bering Sea, primarily off northeast Sakhalin Island and southeastern Kamchatka in Russia (Weller et al. 1999; Tyurneva et al. 2010; Burdin, Sychenko, and Sidorenko 2017). Over half of the individuals photographed off southeastern Kamchatka Peninsula have been matched to those near Sakhalin Island (Tyurneva, Yakovlev, and Vertyankin 2013). Some individuals identified on feeding grounds in the western Pacific have been tracked or re-sighted between Alaska and Mexico in the eastern Pacific (Weller et al. 2013; Mate, Iiyashenko, et al. 2015; Urbán et al. 2013); while others likely migrate south to waters off Japan and China (Weller et al. 2016); however, the location of breeding grounds in the western North Pacific remains unclear. Historically, coastal waters off eastern Russia, the Korean Peninsula, and Japan were part of the WP population migratory corridor, and areas within the South China Sea may have been used as breeding/calving grounds (Weller et al. 2002; 2013). Grey Whale numbers in the western Pacific were significantly reduced during commercial whaling, and modern observations of Grey Whales off Japan (Nambu et al. 2010; Nakamura et al. 2017a, 2017b) and China (Zhu 2002; Wang et al. 2015) are infrequent. However, Grey Whale sightings off the Pacific coast of

Japan appear to have increased over the past two decades (Weller et al. 2016; Nakamura et al. 2017b).

Population size and trajectories of the WP population have been assessed using both single- and multi-stock individual-based stage-structured population models (Cooke et al. 2016, 2017). The Sakhalin and Kamchatka feeding aggregations have been increasing at 2-5% per year over the 10 or 20 years prior to 2015. Total non-calf population size for the WP (combined Sakhalin and Kamchatka) was estimated at 282 (CV 0.05) in 2015. Forward projections of Sakhalin-feeding aggregation population model to 2025, assuming no change in the demographic parameters, indicated a high probability (>95%) of continued population growth (Cooke et al. 2016, 2017).

HABITAT AND RESIDENCE REQUIREMENTS

Habitat properties

Grey Whales primarily use coastal habitats throughout the year to carry out important life history functions such as breeding, calving, migrating, and foraging (COSEWIC 2004, 2017). The required habitat properties differ with biological function; for instance, different habitats are sought for foraging compared to reproduction. Use of these habitats also depends on access to connective habitats, such as migration corridors. Two features required for all habitats used by Grey Whales is an adequate acoustic environment (for communication and navigation) as well as adequate physical space to access and exploit habitat.

The spatial extent of suitable habitat for the PCFG and the WP population in Canada is difficult to quantify, and likely fluctuates from year to year. The spatial extent of the areas with suitable habitat properties for foraging whales depends on bathymetry, benthic topographical complexity, environmental factors controlling primary and secondary production, as well as factors contributing to the aggregation and retention of mysids, amphipods, and other crustacean and mollusc prey. Migrating Grey Whales appear to favor a coastal route through Canada, although they are capable of transiting in offshore regions (Ford et al. 2013; Mate et al. 2015).

Breeding and calving habitat

The core winter breeding range of Grey Whales in the eastern North Pacific is situated along the west coast of the Baja California Peninsula, from Morro Santo Domingo (28°05’N) south to Isla Creciente (24°20’N; Urbán et al. 2003). In the eastern Pacific, Grey Whales from all three DUs occupy sheltered, subtropical lagoons and bays principally along the west coast of Baja California in Mexico for courtship, breeding, calving, nursing, and early rearing of young. The four primary breeding lagoons visited annually are Laguna Ojo de Liebre and Guerrero Negro (366 km^2), Bahia Magdalena (1700 km^2) and Laguna San Ignacio (175 km^2). Females occasionally give birth further north, off the coast of California (Sund 1975). Within lagoons, pregnant females and mothers with calves tend to occupy inshore waters furthest away from the open sea, while individuals engaged in sexual behaviour tend to be found more offshore within deeper waters and wider channels (Swartz 1986). These habitats are characterized by shallow water depths with sandy or muddy seafloor substrate, occasionally covered with eelgrass beds and mangrove swamps (Rice et al. 1981). Winter water temperatures within the breeding lagoons vary between 15 and 20°C and are hypersaline (Gardner and Chávez-Rosales 2000). These warm, sheltered habitats may protect newborns from shark and Killer Whale (*Orcinus orca*) predation and favor newborn survivorship (Fleischer and Beddington 1985; Swartz 1986; Jones 1990). Warming ocean temperatures may influence breeding/calving habitat selection in future (Gardner and Chávez-Rosales 2000; Urbán, Gómez-Gallardo, and Ludwig 2003).

Migration habitat

Individuals from all three Grey Whale DUs migrate twice annually within nearshore waters off the west coast of North America (within a few km of the shore; Pike 1962; Rice et al. 1984), and some WP Grey Whales migrate across deep, offshore waters of the North Pacific (Mate et al. 2015). On the northbound migration, mothers with calves often migrate closer to shore, sometimes through areas with shallow kelp beds which may provide shelter from predators (Goley and Straley 1994; Barrett-Lennard et al. 2011). Along the west coast of Vancouver Island, the northbound migratory corridor is approximately 8 km from the shore for breeding and non-breeding adults and juveniles, and within 5 km for mother and calf pairs, with occasional sightings as close as 200 to 400 m from shore (Poole 1984; Perryman et al. 2002). The southbound migratory corridor is geographically similar, with some individuals traveling up to 40 km from shore (Green et al. 1995; Shelden et al. 1999; Meyer 2017).

Foraging habitat

Grey Whale foraging habitats are in coastal temperate and Arctic regions, characterized by shallow water depths and a combination of biotic and abiotic factors that favor aggregation of prey species into suitable densities (Darling et al. 1988; Weitkamp et al. 1992; Dunham and Duffus 2001; Moore et al. 2003; Laskin et al. 2010). Prey species consumed by PCFG whales include amphipods (*Ampelisca spp., Atylus borealis, Corophium spinicorne*), mysids (principally *Holmesimysis sculpta, Neomysis rayii, Acanthomysis spp.),* Ghost Shrimp (*Calianassa californiensis*), small clams *(Cryptomya californica),* planktonic crab larvae (*Pachycheles rudis, Petrolisthes spp., Cancer magister*), and Pacific Herring (*Clupea pallasii*) eggs and larvae (Murrison et al. 1984; Nerini 1984; Darling et al. 1988; Dunham and Duffus 2002; Feyrer and Duffus 2011). Long-term observational data show that all of the central to southern coastline of western Vancouver Island is used by Grey Whales; the timing and residency of different sites during the summer and autumn is likely influenced by distribution and abundance of prey (Darling et al. 1988).

Foraging habitat characteristics vary with prey species being targeted. Early in the feeding season, some PCFG whales forage on herring spawn and larvae in Barkley Sound (COSEWIC 2004), Clayoquot Sound (Darling et al. 1988), and off Haida Gwaii (Nichol and Heise 1992; Ford et al. 1994). During the summer, there is a strong association between Grey Whale relative abundance in Clayoquot Sound and the abundance and density of epibenthic mysids of the family Mysidae (Duffus 1996; Dunham and Duffus 2001, 2002; Feyrer and Duffus 2015). Mysid habitat in Clayoquot Sound is generally found less than 1 km from shore, within the 30 m isobath, over rocky substrate, and at average patch depths of 10 m (Laskin 2007; Feyrer and Duffus 2011; Clare 2015). Similarly, in northwest Washington, Grey Whales are most commonly observed in depths of 5–15 m over rocky substrates and often near kelp forests; depths which coincide with mysid shrimp habitat (Nelson et al. 2009; Scordino et al. 2017b).

When foraging on amphipods, PCFG whales typically occupy habitats with sandy substrate in shallow bays (< 35 m) on the exposed west coast of Vancouver Island and elsewhere, whereas foraging on Ghost Shrimp and small clams has been associated with shallow (< 3 m) sheltered bays and inlets with muddy bottom (Darling et al. 1988; Weitkamp et al. 1992; Dunham and Duffus 2001, 2002). Several studies have addressed fine-scale foraging and prey switching by PCFG whales in Clayoquot Sound over different time scales (Feyrer and Duffus 2011, 2015; Clare 2015; Burnham and Duffus 2016). Certain areas which were prime feeding sites for Grey Whales in previous years have been observed temporarily or permanently abandoned, potentially overgrazed by Grey Whales to the point of no recovery (Nelson et al. 2008; Laskin et al. 2010; Burnham and Duffus 2016). This may be due to the slow reproduction cycle of mysids, and their lower capacity to recolonize (Laskin et al. 2010).

Habitat modelling studies of Grey Whales within Clayoquot Sound have identified two static variables which significantly predict habitat use – depth and benthic topographical complexity, which is a measure of how frequently the slope of the seafloor changes (Laskin et al. 2010). Grey Whales were significantly associated with the 10 m depth contour, most likely due to abundance of prey at this distance from shore where shallow depths, in combination with complex or variable bathymetry, create suitable habitats for mysids. Laskin et al. (2010) suggest that the 10m depths could represent an optimal combination of whale maintaining maneuverability while being able to exploit the highly productive intertidal zone.

Western Pacific Grey Whales feed in nearshore and offshore areas off Sakhalin Island in the Okhotsk Sea, and off the Kamchatka Peninsula. Nearshore habitats off Sakhalin (adjacent to the Piltun and Chayvo Lagoons) are characterized by water depths of less than 20 m and within 5 km of shore. Offshore feeding habitats (southeast of Chayvo Bay, northeast of Niyskiy Bay) have water depths of 40–60 m and are located 30–45 km off the Sakhalin coast (Meier et al. 2007). Amphipods (*Ampelisca eschrichtii*) are one of the most important prey in the diet of WP whales. High abundance and densities of this amphipod species are found in the offshore feeding area of Sakhalin, which is considered a critical foraging habitat for the WP population (Demchenko et al. 2016).

On feeding grounds in the Bering, Chuckchi and Beaufort Seas primarily used by the NPM population and occasionally by the PCFG, the main prey species are epibenthic and infaunal amphipods of the genera *Ampelisca, Atylus*, and *Anonyx* (Nerini 1984; Kim and Oliver 1989). Habitats are characterized by shallow depths and soft bottom substrate, occasionally within coastal lagoons (Gill and Hall 1983; Clarke, Moore, and Ljungblad 1989; Heide-Jørgensen et al. 2012). In the northeastern Chukchi Sea, Grey Whales are associated with high benthic amphipod abundance, primarily within 50 km of the coast in waters less than 50 m deep (Brower et al. 2017).

Opportunistic feeding occurs near and within the breeding grounds (Sánchez-Pacheco et al. 2001; Caraveo-Patiño and Soto 2005), as well as along the California coast during migration. Grey Whales occasionally feed on euphausiids (*Thysanoessa spinifera*) off the coast of California (Benson et al. 2002).

Knowledge gaps or research efforts that would need to be addressed in order to identify critical habitat for PCFG and WP Grey Whales in Canada include:

1. Continue photo-identification programs to identify habitat use patterns specific to each Grey Whale DU in Canada (see Fisheries and Oceans Canada 2019 for a list of research groups involved in PCFG studies in Canada).
2. Identify occurrence and habitat use patterns north of Cape Caution, BC through a dedicated survey program.
3. Quantify relative abundance and residency times of PCFG and WP Grey Whales in known areas of use in Canada.

Residence

DFO interprets residence as “a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating” (SARA s.2(1)). This concept is rarely applied to cetaceans that live in a patchy, dynamic environment and do not rely on a specific dwelling place to carry out life history functions. However, at large geographical scales (100 to 1000 km), Grey Whales occupy certain regions year after year for breeding and feeding. At a smaller, local scale (10 to 100 km), use of specific habitats within these broader areas may fluctuate interannually.

GREY WHALE OCCURRENCE IN CANADA

Several data sources were consulted to produce maps of Grey Whale occurrence in Canada. Note that spatial data specific to each DU were not available at the time of writing this RPA. Moreover, there is strong heterogeneity in the spatial distribution of survey effort for Grey Whales in Canadian waters. Most broad-scale, dedicated cetacean surveys in the region (e.g., DFO's) have been conducted further offshore than where Grey Whales are likely to be encountered. In contrast, most local-scale, long-term research programs on Grey Whales have been conducted nearshore, which is also where most opportunistic sightings are made. Future efforts to assess distribution and habitat use of the PCFG and the WP population in Canada will be necessary to address this disparity in spatial effort.

DFO's Cetacean Research Program (CRP) has carried out surveys off the west coast of Canada using vessel and aerial platforms since 2002 at different times throughout the year (Ford et al. 2010; DFO unpubl. data from PRISMM survey; Nichol et al. 2017). During these surveys, Grey Whale sighting data was recorded both opportunistically and during dedicated survey effort, and most sightings were not assigned to a specific DU (Fig. 6 to 8). DFO has also studied Grey Whale migratory patterns in Canada by remotely tracking both PCFG and NPM individuals (Ford et al. 2013; Fig. 9), conducting surveys from land-based stations (Ford et al. 2013), and using passive acoustic monitoring (Meyer 2017). The Pacific Rim National Park Reserve of Parks Canada has recorded Grey Whale sightings opportunistically since the early 1980s within Barkley Sound and from Barkley Sound to Port Renfrew (Fig. 10). Grey Whale sightings data used in this RPA was also provided by the British Columbia Cetacean Sightings Network (BCCSN; Fig. 11, 12).

Maps of Grey Whale distribution in Canada are presented for two periods, one which captures the temporal range defining the PCFG, "summer-fall" (individuals observed between 1 June and 30 November), and one which captures the temporal range of migrating Grey Whales, "winter-spring", which likely captures a combination of all three DUs. Maps showing DFO's vessel and aerial survey effort are presented as gridded effort index maps overlain with Grey Whale sightings (Fig. 6 to 8).

Combining Grey Whale sightings from DFO's vessel and aerial surveys with the BCCSN and Parks Canada opportunistic sightings, the median distance to shore during the summer-fall period (n=2198) was 457 m, and 75% of observations were less than 1 km from shore. During the winter-spring period (n=740), the median distance to shore of Grey Whale sightings was 597 m, with 75% of observations within 1.9 km from the shore. The furthest sighting offshore was 137 km during summer-fall and 73 km during the winter-spring period. These distances may reflect higher opportunistic effort closer to shore, however few Grey Whale sightings were made during DFO's dedicated vessel and aerial survey effort in more offshore waters across multiple years (Fig. 6 to 8 and the 2018 PRISMM survey, unpubl. data). Ford et al. (2010) mention that most DFO vessel survey effort since 2002 occurred in waters > 5 km from the shore, which may explain why relatively few Grey Whales were observed during these surveys.

Figures 13 and 14 show the depth distribution of Grey Whale sightings during the summer-fall and winter-spring periods. Year-round in Canada, the majority of sightings are in waters less than 20 m deep. Since Grey Whales are a nearshore species, further mapping of important habitat will require high resolution (fine spatial scale) bathymetry data to accurately capture nearshore (<1 km from shore) use of shallow depths. Satellite-tagging data (n=5) showed northbound migrating Grey Whales (Fig. 9) travelling at a median distance to shore of 8.9 km, with 75% of the locations less than 22 km from the coast (max. 62.5 km). Grey Whales migrated in waters with a median depth of 80 m and 75% of locations were in waters less than 150 m deep (max. 1257 m). Shore-based visual surveys based at Bonilla Island (Hecate Strait) and Langara Island (northern Haida Gwaii) were used to monitor northbound migrating Grey Whales. Sightings occurred on average 6.7 km (SE 0.40) from shore at Bonilla Island, with 62% of sightings within 6 km from shore and 22% of sightings were greater than 10 km from shore. Langara station had fewer sightings than Bonilla, all at distances of greater than 10 km from the coast (Ford et al. 2013).

Opportunistic Grey Whale sightings collected through the BCCSN are presented as effort-corrected maps for both the summer-fall and winter-spring period from 1982 to 2018 in Canadian waters (Fig. 11, 12). Methods used to quantify and correct for effort biases within this opportunistic sightings database are detailed in Rechsteiner et al. (2013). Briefly, the spatial distribution and travel patterns typical of different observer groups were reconstructed to estimate effort. Travel patterns included trip distances, proximity to home port, standard travel routes, and maximum sighting distances. The relative effectiveness of each observer group at sighting, identifying and reporting cetaceans was evaluated and used to weight effort maps for each group. The map layers of relative effort for each observer group were then summed to obtain spatially explicit estimates of observer effort and relative abundance indices (Rechsteiner et al. 2013). However, despite these corrections, the resulting maps only show presence of whales where there is effort, and thus absence of sightings does not necessarily imply that whales do not use a particular area.

BCCSN's long-term dataset shows high relative abundance of Grey Whales during the summer-fall and winter-spring periods along the western coast of Vancouver Island from Nootka Island to Port Renfrew. In particular, areas centered around Flores Island, western Barkley Sound, and from Pachena Beach to Port Renfrew. Two additional areas with high relative abundance indices appear during the summer period – around the northern tip of Vancouver Island and along the southeastern coast of Haida Gwaii. Other areas of low to medium relative abundance during the summer period include off the sunshine coast on BC's mainland, off Cape Caution, within Queen Charlotte Sound and Hecate Strait, and around the north and south coasts of Haida Gwaii (Fig. 11). During the winter period, areas with low to medium relative abundance indices include Boundary Bay (south of the Frasier River), around Denman and Hornby Islands off Vancouver Island's east coast, north of Nootka Island, around Brooks Peninsula, and on the north coast of Haida Gwaii (Fig. 12).

Future work on important habitat for the two endangered Grey Whale DUs in Canada will need to incorporate DU-identification of individual sightings (e.g., photo-identification data), or adopt a precautionary approach assuming that any Grey Whale observed in Canadian waters is potentially an individual from one of the two endangered DUs. Further research and recovery planning may benefit from working in partnership with Cascadia Research Collective (CRC, Washington, U.S.), the Pacific WildLife Foundation (BC), and the Whale Research Lab of the University of Victoria (BC) among others, as these groups curate long-term datasets on Grey Whales in Canada.

THREATS AND LIMITING FACTORS

Threats

All three Grey Whale DUs are exposed to threats in Canadian waters (Tables 2 and 3). Threat exposure and severity likely varies for each DU according to time spent in Canada and regions occupied. Data suggest that the PCFG use Canadian waters for a longer duration annually compared to WP and NPM whales (Calambokidis et al. 2002; COSEWIC 2017). Further quantification of threat impact or severity will need to incorporate DU-specific data in Canada.

Current threats identified to Grey Whales in Canada include entanglement in fishing gear, vessel collisions (or ship strikes), disruption or destruction of feeding habitat, physical disturbance, acute and chronic noise, pollutants, and disturbance resulting from some scientific research activities. Potential threats include toxic spills and aboriginal subsistence hunt. The two principal threats to survival and recovery are entanglement and vessel collisions, which were responsible for most Grey Whale mortality and serious injury cases from 1924 to 2015 in the North Pacific (Scordino et al. 2017a). As for all whales, entanglement and vessel collision-related injury and mortality is underestimated in Grey Whales since carcasses may never be discovered or reported, and scarring on live whales is not always visible using standard photo-ID techniques. Within populated areas along the west coast of North America where the probability of carcass detection is likely greatest, only 4 to 13% of Grey Whale carcasses strand or are reported in a given year (Punt and Wade 2012). For recovery planning, dedicated carcass monitoring programs are valuable sources of information, and should be continued in Canada; mapping overlap between nearshore fishing operations, commercial and recreational vessel traffic, and areas of importance for Grey Whales will aid in threat mitigation and management, as well as identifying the origin and type of fishing gear involved in entanglement cases.

Existing monitoring efforts for Grey Whale populations in Canada and other co-occurring species, either associated directly or indirectly with identified threats are compiled in DFO (2019)'s Report on the Progress of Management Plan Implementation for the Eastern Pacific Grey Whale in Canada.

Entanglement – Grey whales are particularly vulnerable to interactions with fishing gear due to their year-round nearshore distribution and their benthic or epi-benthic feeding behaviour. From 1924 to 2015, fisheries involved in Grey Whale entanglement cases in the North Pacific were net (39.7% or 158/397 reports), pot (17.1% or 68/397), and unknown fisheries (21.5% or 85/397; Scordino et al. 2017a). Reports were made primarily from California (62.8%) and between northern California and northern British Columbia (21.5%). In Canadian Pacific waters, commercial fishing operations accounted for 27% of Grey Whale mortality, injury or stranding reports, or approximately two per year (Baird et al. 2002). Fisheries and gear types associated with entanglement cases in Canada include salmon drift gillnet, salmon seine, longline, trap, herring net pen and herring set gillnet (Baird et al. 2002). In the U.S., entanglement-related mortality and serious injury to ENP and PCFG Grey Whales was estimated at 8.65 and 0.95 whales per year, respectively (Carretta et al. 2018c, 2018b); for the PCFG, this is 10 times the number that would be expected if entanglement mortality and serious injury were proportional to the relative size of the two populations. Off Sakhalin Island in the western North Pacific, 18.7% of WP Grey Whales had detectable scarring from entanglements, however the number of entanglement-related mortalities is unknown (Bradford et al. 2009).

Vessel collisions – The Grey Whale migratory corridor in Canada overlaps with areas of significant commercial maritime traffic, such as the entrance to the Juan de Fuca Strait, and from northern Vancouver Island to western Dixon Entrance, which exposes migrating whales to vessel collisions (Ford et al. 2013). Grey Whale coastal habitats overlap with small to medium sized vessel traffic, including recreational vessels, nearshore commercial fishing operations, water taxis, whale-watching vessels, scientific or monitoring vessels, military vessels, and others. Grey Whales are commonly struck by vessels in California (Laist et al. 2001), and some individuals in Canada have noticeable propeller scars (COSEWIC 2004). Scordino et al. (2017a) report that vessel collisions are responsible for a minimum of 19.1% of reported ENP Grey Whale mortalities. In the U.S, between 2012 and 2016, observed serious injury and mortality of

ENP whales due to vessel collision was four whales (four deaths and two non-serious injuries), or 0.8 whales annually. For the PCFG, this value is 2 whales, or 0.4 whales per year (Carretta et al. 2018c, 2018b). Around 2% (3 out of 150) of WP Grey Whales have visible scars from vessel collisions (Bradford et al. 2009).

Disruption or destruction of feeding habitat – Various human activities such as nearshore or coastal industrialization have the potential to disrupt or destroy nearshore feeding habitat for PCFG and potentially WP Grey Whales in Canada. Any fisheries that operate nearshore (within 1-2 km from shore) and disturb the benthos, or directly or indirectly removes pelagic and benthic prey targeted by Grey Whales such as mysids, amphipods, Ghost Shrimp, small clams (e.g., *Cryptomya californica*), planktonic crab larvae (e.g., *Pachycheles rudis*, *Petrolisthes spp.*, *Cancer magister*), and Pacific Herring eggs and larvae, has the potential to disturb foraging grounds. Habitat degradation of coastal benthic habitats may impact the availability or quality of prey and affect foraging success, resulting in nutritional stress or displacement (Fisheries and Oceans Canada 2010, 2019). Coastal development projects which involve excavation, placement of material or structures in the water, or dredging can alter bottom substrate, sediment, and nutrient availability, which can in turn affect food supply if within Grey Whale foraging habitat.

Physical disturbance – Physical disturbance can arise from the presence of vessels in proximity to Grey Whales. Such disturbance can alter Grey Whale behaviour (Sullivan and Torres 2018), induce vocalization changes (Moore 2016), and may lead to stress if the approaching vessel is perceived as a threat; this can have cumulative negative effects on energy expenditure, physiology, and population-level consequences (Harwood et al. 2016).

Acute and chronic noise – Depending on the sound source characteristics and period of exposure, anthropogenic noise can cause hearing damage, impair communication and navigational abilities by masking similar frequencies used by vocalizing whales, lead to avoidance behaviour, and impact successful completion of life history functions as acoustic habitat is degraded (reviewed in Williams et al. 2015; Erbe et al. 2018; Putland et al. 2018). Areas with a higher density of maritime activity (e.g. ports, shipping lanes, fishing areas, near major cities or towns) will have a greater noise impact on the marine environment.

Acute noise or impulsive sounds produced in the low- to mid-frequency range (e.g. military active sonar training exercises, seismic surveying) can travel long distances and expose Grey Whales and other marine fauna to acute noise effects (Malme et al. 1986; Buck and Tyack 2000). Airgun pulses used during seismic exploration have provoked avoidance behaviour in migrating Grey Whales at distances of up to 5 km (Richardson et al. 1995; Moore and Clarke 2002), and have displaced feeding Grey Whales (Weller et al. 2002). Chronic exposure to low-frequency ship noise has been associated with elevated stress hormone levels in North Atlantic Right Whales (*Eubalaena glacialis*; Rolland et al. 2012), also a coastal species like Grey Whales. The potential impacts of high-frequency sonar (e.g. fish-finding sonar, depth sounders) on Grey Whale physiology, behaviour and communication ability is not well understood. One study found that Grey Whales responded to high-frequency sonar in the 21-25 kHz range (Frankel 2005). Given their proximity to shore, Grey Whales may be more exposed to high-frequency sonar due to a higher density of vessels. Further acoustic studies are required to better understand the influence of high frequency sonar on Grey Whales.

Underwater noise or vibrations emitted during construction and operation of offshore wind farms may disturb Grey Whales (Madsen et al. 2006; Bailey et al. 2014). An offshore wind energy generation project has been proposed between Haida Gwaii and Prince Rupert in northwestern Hecate Strait, which is located in the Grey Whale migratory corridor. The NaiKun Wind Energy Group has procured a 550 km^2 permit area to install wind turbines that will cover an area in

Hecate Strait of less than 100 km^2 when phase one is operational. Wind turbines would be positioned a minimum of eight km from the shoreline southeast of Rose Spit, and would be connected both to the BC mainland near Prince Rupert and to Haida Gwaii via submarine cables (NaiKun Wind Energy Group Inc 2018).

Coastal development or industrialization can increase noise levels in the marine environment, and degrade the quality of Grey Whale feeding and migration habitat (COSEWIC 2004). In the 1950s and 1960s, Grey Whales abandoned a frequently-used breeding lagoon in Mexico (Guerrero Negro Lagoon) during a period of increased dredging and commercial shipping activity, and reoccupied the lagoon years later once dredging and ship traffic had ceased (Bryant et al. 1984). Major coastal development projects planned or proposed in BC are the construction and operation of LNG export terminals, and the associated increase in shipping traffic (BC Oil & Gas Commission 2018). Three facilities are under development: Kitimat, Sarita Bay in the Alberni Inlet on Vancouver Island (about 10 km north of Bamfield), and Prince Rupert. All terminals will involve construction of offshore facilities such as offload jetties for LNG tankers, wharves, and LNG holding tanks. For the LNG Export Terminal in Kitimat, tanker shipping route will be via Dixon Entrance, continuing through Hecate Strait, Browning Entrance, through to Douglas Channel leading up to Kitimat. Around 350 LNG tankers are expected to visit the Kitimat marine terminal annually; approximately one vessel arriving and one vessel departing every day (LNG Canada 2018). It is uncertain how this increase in maritime traffic will contribute to the ensonification of Grey Whale habitat in Canada, as well as the risk of vessel collisions.

Toxic spills – The severity of toxic spills on marine flora and fauna depends on the contaminant in question, volume and spatial extent of the spill, and environmental conditions at the time of spill. Toxic spills from oil and gas activities, transport of oil sand products (e.g. diluted bitumen), crude oil, or other maritime activities have the potential to harm Grey Whales directly or indirectly by contaminating prey and surrounding habitat (Jayko, Reed, and Bowles 1990; Moore and Clarke 2002; Herunter et al. 2017). Pathways of exposure to toxic spills can be either through direct contact, adhesion (skin texture), inhalation, direct ingestion, and ingestion through contaminated prey. Depending on their densities, spilled contaminants will often sink from the surface into the water column, and may become buried in sediments. These contaminants become a persistent source of hydrocarbon toxicity in the marine environment, and Grey Whales may be particularly vulnerable given their benthic feeding behaviour (Lee et al. 2015). An evaluation of the impacts of potential oil exposure on marine mammals in coastal BC ranked baleen whales as highly vulnerable due to their breathing patterns (blowhole and airways exposed to surface contaminants), their filter feeding behaviour (ingestion of residual amounts of oil trapped in baleen plates), and indirect ingestion of oil contaminants via the consumption of invertebrate prey that may accumulate the toxic compounds contained in oil (Rosenberger et al. 2017).

Pollutants – Although toxic spills are pollutants, this section refers to all other non-natural substances or waste products of anthropogenic origin which can have negative effects on Grey Whale health, survival and fitness (Engelhardt 1983; reviewed in Moore and Clarke 2002). Given their year-round nearshore distribution, Grey Whales live in closer proximity to human activity compared to offshore or seasonally coastal species, making them potentially more susceptible to pollutants originating from land. Fisheries and Oceans Canada (2019) notes that "localized areas of nutrient loading from sewage or agricultural runoff may degrade or contaminate coastal feeding areas for Grey Whales. Persistent chemicals (e.g. DDT) and emerging toxins with similar properties (e.g. PBDEs) may accumulate in prey species or areas used by Grey Whales during breeding, feeding, and migration." Incidental ingestion of micro- and macro-plastics can become lodged in the digestion system impairing feeding, or may accumulate in tissues via ingestion of plastic-contaminated prey (Derraik 2002; Andrady 2015). There is a high degree of uncertainty regarding the severity of the effects of pollutants on Grey Whales.

Aboriginal subsistence hunt – Some Indigenous groups in BC have traditionally harvested Grey Whales. Should these groups renew interest in this activity, a hunt for Grey Whales in Canada may constitute a future threat. Grey Whales from the NPM population are currently hunted by aboriginal communities in Alaska and Russia. The Makah tribe in Washington, U.S. has requested authorization to resume hunting Grey Whales in their Usual and Accustomed grounds off Washington State. The Makah Management Plan, which has mitigation measures to avoid taking a PCFG or WP whale, has been approved by the IWC. The National Oceanic and Atmospheric Administration (NOAA) announced a proposal in April 2019 for the Makah tribe to hunt between one and three ENP Grey Whales every year for a 10-year period.

Scientific research – Research on Grey Whales in Canada is conducted to better understand their ecology, population demography, habitat use and movement patterns. Decades of research effort on Grey Whales in the north Pacific revealed the existence of trans-Pacific migrations and demographically-distinct feeding aggregations, among other discoveries. Some scientific research activities have the potential to disturb individual behaviour during close or repeated vessel or aircraft approach, or to physically disturb individuals during biopsy sampling or tagging operations. The Canadian Council on Animal Care ensures research on animals is conducted in an ethically and responsible manner, and the Federal Government of Canada is responsible for issuing marine mammal research licenses to approved programs.

Limiting factors

Environmental variability including persistent changes in ice cover on Arctic feeding grounds, ecosystem regime shifts, and ocean acidification can impact the PCFG and WP population survival and recovery via reduction in prey quality, abundance, and availability, and competition for resources (Fisheries and Oceans Canada 2019). Any significant decline in mysid or amphipod density and biomass could impact foraging success; amphipods have lower fecundity and longer generation times and tend to recover slowly following predation or disturbance (Burnham and Duffus 2016).

An Unusual Mortality Event (UME) left around 634 emaciated gray whales stranded along the coast from Mexico to Alaska in 1999 and 2000 (Le Boeuf et al. 2000; Moore et al. 2001). This increase in Grey Whale mortality and concurrent decrease in calf production were likely caused by a combination of the population reaching its carrying capacity on high-latitude feeding grounds and two consecutive suboptimal feeding seasons, as a result of the Bering Sea remaining ice free for an unusually short duration in 1998 and 1999 (Moore et al. 2001; Perryman et al. 2002; Wade 2002). A new UME was declared in 2019 with 214 strandings across Canada, the U.S. and Mexico, and has continued in the following year with 172 strandings in 2020. These events are believed to have mostly affected the NMP; their impact on the PCFG and WP is poorly understood.

Naturally-occurring toxins, such as those produced by certain species of marine algae can lead to mass mortalities of aquatic organisms, degrade coastal ecosystems, and impact fisheries and public health (Anderson et al. 2002). If environmental conditions favor proliferation of these algal populations, higher trophic level organisms can become intoxicated either directly or indirectly through ingestion of affected food sources (Van Dolah et al. 2003; de la Riva et al. 2009). Algal blooms in BC typically occur from May to September, although warmer climate and anthropogenic nutrient loading have increased the severity and spread of bloom events (Häussermann et al. 2017).

Predation by Killer Whales (*Orcinus orca*) on Grey Whales, predominantly calves, can limit PCFG and WP survival and recovery (Goley and Straley 1994; George and Suydam 1998). Eighteen percent of Grey Whales landed at California whaling stations had scars from Killer Whale attacks (Rice and Wolman 1971). Grey whales appear to follow shorelines in closer proximity in areas where they have encountered Killer Whales in the past (Ford and Reeves 2008; Barrett-Lennard et al. 2011). Any human activity along the migratory path forcing Grey Whales to alter their route may expose them to a greater risk of Killer Whale predation (Corkeron and Connor 1999). White Sharks (*Carcharodon carcharias*) have been known to feed on smaller odontocetes, and perhaps calves of baleen whales, however shark predation on cetaceans in the eastern North Pacific is not well documented (Long and Jones 1996; Swartz 2018).

Threats to co-occurring species

Most threats identified to Grey Whales in Canada also apply to other co-occurring species. Entanglement or entrapment in fishing gear (active or derelict) is a threat to the survival of co-occurring cetaceans, turtles, fish, and seabirds (Laist 1997). Vessel collisions are a risk for all marine species which spend time within the surface layer or at the water surface; certain species may be more susceptible than others due to differences in perception of risk or escape response. The majority of studies have focused on the effects of underwater noise on marine mammals, however other marine species may be negatively impacted by unnatural levels of marine ensonification (e.g. Slabbekoorn et al. 2010). Offshore oil and gas and renewable energy projects may have a localized impact on other co-occurring species at the site of construction or operation, as well as the associated impacts from transport of extracted material or energy. Toxic spills and pollutants have the potential for contamination and degradation of the marine environment.

RECOVERY OBJECTIVES AND TIME FRAME FOR RECOVERY

Historical abundance and carrying capacity

Eastern North Pacific population – The current abundance estimate (2015/2016) for ENP Grey Whales is 26,960 (CV 0.05) (Durban et al. 2017). Based on historical whaling records and habitat availability, the pre-exploitation population size of ENP Grey Whales was around 23,000 to 35,000 (Reilly 1992; Butterworth et al. 2002; Wade 2002). Recent analyses incorporating catch data, life history data, and census data into an age- and sex-structured model suggest the ENP Grey Whale population size in 2009 (21,911) was at 85% of its carrying capacity (25,808) and at 129% of its maximum net productivity level (MNPL), and thus within the range of its optimum sustainable population size (OSP)[1] (Punt and Wade 2012). Carrying capacity is expected to fluctuate with future environmental change and anthropogenic activity (Punt and Wade 2012). Grey Whales may continue to expand their range northwards with the continued reduction of sea ice (Comiso et al. 2008). Nearly two decades ago, Rugh et al. (2001) noted that the summer range of Grey Whales in the eastern North Pacific had expanded considerably since the early 1990s. The Management Plan for the ENP population in Canada has the following management goal (Fisheries and Oceans Canada 2010):

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[1] OSP is defined by the Marine Mammal Protection Act (MMPA) as, "the number of animals which will result in the maximum productivity of the population or the species, keeping in mind the carrying capacity of the habitat and health of the ecosystem of which they form a constituent element."

> To maintain the migration route and foraging habitat in British Columbia for Eastern Pacific Grey Whales, in order to contribute to the maintenance of a self-sustaining population.

In order to achieve this goal, the management plan identified the following distribution objective:

> To maintain the current known distribution and migration route of Grey Whales in Pacific Canadian waters.

Pacific Coast Feeding Group – Determining quantitative abundance recovery objectives for the PCFG is challenging given their historical (pre-exploitation) population size and current environmental carrying capacity in Canadian waters is unknown. Furthermore, a certain degree of mixing (interbreeding), immigration, and emigration with the larger NPM population still occurs (Calambokidis et al. 2017). Population size of the PCFG increased from 1996 to 2004, fluctuated around 210 individuals from 2005 to 2010, and increased from 2011 to 2015. The short period of growth from 1998 to 2000 has been attributed to an irregular pulse immigration event of NPM whales into the PCFG, following a broad-scale unusual mortality event of Grey Whales in the eastern North Pacific in 1999/2000 (Calambokidis et al. 2017). Previous studies have attempted to estimate carrying capacity for the PCFG, however it remains unclear whether the stability of the population at ca. 200 animals from 2005 to 2010 is best explained by a population nearing carrying capacity or being regulated by other mechanisms such as human-induced mortality or emigration (Punt and Moore 2013; Calambokidis et al. 2017). With the existing data, it is not possible to discriminate permanent emigration from mortality for the PCFG (Calambokidis et al. 2017).

Western Pacific population – The pre-exploitation abundance of the WP population is unknown, although some authors suggest between 1,500 and 10,000 individuals (Yablokov and Bogoslovskaya 1984). There is uncertainty in how these values were obtained (Weller et al. 2002). The historical range of WP whales was considerably more widespread than at present, with a potential migratory route along coastal waters of eastern Russia, the Korean Peninsula and Japan. Areas in the South China Sea may have been used as wintering grounds (Weller et al. 2013b). Determining the existence, nature and status of the relict western North Pacific breeding population has been identified as a high priority (Cooke 2018). If such a distinct breeding stock exists, the population size is predicted to be below 50 (Cooke et al. 2017). It is suspected that habitat is currently not a limiting factor to recovery.

Proposed abundance and distribution objectives

Both the PCFG and WP DUs were assessed as Endangered in 2017 according to COSEWIC's criteria D1: "Very Small or Restricted Total Canadian Population – Total number of mature individuals < 250". The following two abundance recovery objectives are proposed over a biologically reasonable time frame (23 years, approximately one Grey Whale generation), assuming 60% of the total population consists of mature individuals (i.e. capable of reproduction; until further data on age structure becomes available). Therefore, we propose three possible objectives (recovery targets):

Objective 1. Maintain a stable population size (ca. 146 mature / 243 total whales for the PCFG; and ca. 169 mature / 282 total for the WP)

Objective 2. Maintain a growing population size to reach Threatened status, i.e., ≥ 250 mature / 417 total whales for both PCFG and WP)

Objective 3. Maintain a growing population size to move beyond the abundance criteria for Threatened status, i.e., > 1000 mature / 1667 total for both PCFG and WP. We note that this is close to the lower range of possible pre-exploitation numbers for WP, and therefore another interpretation of this target is a recovery to the lower range of historical numbers for WP.

The extent to which habitats were exploited historically in Canada by the PCFG and WP DUs are not well understood. A feasible distribution objective would be to maintain current distribution for both DUs.

POPULATION PROJECTIONS

Considerable population modeling efforts have been undertaken in recent years to evaluate stock structure of Grey Whales in the North Pacific (IWC 2018), to assess annual abundance of ENP Grey Whales from shore-based counts (Durban et al. 2017), to estimate annual abundance from capture-recapture data for PCFG and WP whales (Cooke et al. 2016, 2017; Calambokidis et al. 2017), and to project population trajectories for the WP population under various scenarios (Cooke et al. 2016, 2017). Times series of abundance estimates from capture-mark-recapture analyses are available from 1998 to 2015 for the PCFG and from 1995 to 2016 for the Sakhalin Island feeding aggregation of the WP population. Abundance estimates for the combined Sakhalin-Kamchatka feeding aggregations are available for the years 1995 and 2015 (International Whaling Commission 2018a).

Model description

Several complex population models have been developed to estimate abundance and population dynamics parameters of the three DUs, including age-structured and individual-based models (Punt and Wade 2012; Punt and Moore 2013; Cooke et al. 2016, 2017; International Whaling Commission 2018a). To project population trajectories in the near future, it was deemed preferable to use a simpler projection approach that uses values estimated by previous studies (and their range of uncertainty) rather than trying to re-estimate parameters based on the same data. This custom projection tool can then be used to explore various future scenarios. For this exercise, the most recent abundance estimates for the PCFG and WP population were projected forward over the next 23 years (until 2038) using a resampling approach and species- or population-specific population dynamics parameters and associated uncertainties from the literature. Future population growth was projected using a surplus production model without sex- or age-class structure, with density-dependence implemented using a theta-logistic equation (Gilpin and Ayala 1973):

$$N_{t+1} = N_t + R_{max} N_t \left(1 - \left(\frac{N_t}{K}\right)^{\theta}\right) - C_t - M_t$$

where N_{t+1} is the population abundance of either the PCFG or the WP population in year t, R_{max} is the exponential growth rate, K is the theoretical carrying capacity, and θ allows for the potential asymmetric growth of the population, depending on its density. C_t and M_t denote catches (aboriginal harvest) and non-harvest human-caused mortality in year t. The exponent θ is related to the MNPL, which is equivalent to the maximum sustainable yield level often used as a limit reference point in fisheries management. The MNPL is defined as the greatest net annual increment in population size, after taking into account additions from reproduction/recruitment and losses due to natural mortality (reviewed in Wade 2018). The theta-logistic model assumes a density-dependent decline in annual population growth as the population nears carrying capacity K. Both R_{max} and K are held constant over the forward population trajectories (i.e. do not vary year to year). This projection tool can used to model the impact of different management scenarios (for instance increased or decreased anthropogenic mortality, changes in growth rate and carrying capacity).

Parameter distributions

For each of 10,000 projection runs, values of the parameters (starting population size, R_{max}, K, θ, mean annual C_t+M_t) were drawn from a random distribution. These distributions for input model parameters were informed from the literature (see Fig. S1 in Appendix). Initial population sizes (i.e. the most recent abundance estimates) were assumed to follow a log-normal distribution with mean 243 and CV 0.08 for the PCFG and mean 282 and CV 0.05 for the WP population (both Sakhalin Island and Kamchatka feeding aggregations).

The most recent estimate for R_{max} for the ENP population is 6.2% (90% CI 3.2–8.8%; Punt and Wade 2012). This value was used for both the PCFG and WP population as it is currently the best available estimate, and is likely representative of life history characteristics at the species-level rather than population-level. We assume the input parameter R_{max} follows a scaled beta distribution, for which parameters have been chosen so that it has a mean of 6.2% and a 5% to 95% quantile range of 3.2–8.8%.

Median posterior values for carrying capacity K for the PCFG population were previously estimated between 265 to 293 (mean of medians across several scenarios was 280), with upper 95% estimates close to 500. For this exercise, we assumed K follows a beta distribution in which the lower range cannot be less than the maximum observed abundance in recent years (N = 243). The range of values for MNPL for the PCFG population are estimated at 0.6–0.8 (Punt and Moore 2013), equivalent to θ values of 2.4 to >10. Considering a uniform distribution on θ does not yield a uniform distribution on MNPL, a scaled beta distribution on θ was used to obtain a reasonably uniform distribution on MNPL. To our knowledge, values of K and θ have not been estimated for the WP population. Pre-exploitation abundance of the WP population was estimated between 1,500 and 10,000 individuals, although there is uncertainty in how these values were determined (Weller et al. 2002). We set the initial parameter distribution for K of the WP population as a uniform distribution over this 1,500 – 10,000 range. The same distribution for θ was applied to the WP population.

Levels of human-caused mortality (due to entanglement and vessel collision) were estimated at 1.35 PCFG whales per year from 2012 to 2016 in U.S. waters (Carretta et al. 2018b, 2018c); the same mean value is assumed for the WP population as no quantitative human-caused mortality estimates are available at this time and the two populations are approximately the same size (i.e., it is assumed that the risk of entanglement and ship-strike is proportional to the size of the DU). The Russian aboriginal subsistence harvest takes on average 128 whales per year from the NPM population, and no whales from either PCFG or WP populations. The proposed Makah hunt would be timed in a way to avoid taking a PCFG or WP whale, although the Management Plan could result in a maximum of one PCFG whale per year, under certain conditions (see IWC website for further details). Catches C_t (aboriginal harvest) were assumed to have an annual mean of 1.0 for the PCFG and 0 for the WP population. Since total human-caused mortality (C_t+M_t) is the sum of separate processes (entanglement, vessel collisions, harvest), it was included in the model as a random Poisson distribution that expresses the probability of a given number of independent events occurring in a fixed interval of time with a known rate and independently of the time since the last event. The Poisson distribution was given a rate parameter λ equal to the sum of mean annual mortalities (2.35 for PCFG and 1.35 for WP).

Projections

Population projections from 2015 to 2038 for both the PCFG and the WP population are shown in Figure 15. These projections are by definition highly sensitive to the choice of parameter values, and in particular to the population growth rate and carrying capacity. The assumption of a constant carrying capacity through time is simplistic, considering inter-annual fluctuations in the environmental productivity and long-term environmental change can alter available resources and influence carrying capacity. Moreover, the projections do not include rare dramatic events such as the Unusual Mortality Events that have affected the NMP, which potential impacts on the PCFG and WP are poorly understood.

Under current population dynamics and known sources of human-caused mortality, the PCFG has an 86% and 11% probability of reaching abundance objectives 1 and 2 by 2038 (Fig. 15). The WP population has a 100% and 94% probability of reaching abundance objectives 1 and 2, respectively (Fig. 15). Reaching a population abundance of 1000 mature individuals (i.e. no longer Endangered or Threatened) is 0% probable for both the PCFG and WP population within a 23-year time frame. It should be noted that the current WP population growth rate is lower than what would be expected of a population far below carrying capacity, and that the probability of achieving recovery targets is highly dependent on the values used as a prior for carrying capacity.

Population projections were also run with lower values of anthropogenic mortality C_t to simulate the effect of mitigation measures to reduce this source of mortality. These scenarios do not change the probabilities of reaching recovery objectives significantly, as current population dynamics are driven mostly by the values of K and R_{max}, rather than by anthropogenic mortality. Under a scenario of no anthropogenic mortality (C_t = 0), the probabilities of reaching abundance objectives 1 and 2 after 23 years were 94% and 13% for the PCFG, and 100% and 99% for WP.

The parameters and associated values used to project the PCFG and WP population abundance were informed from complex models and long time series of data representing a considerable body of peer-reviewed work. Specialized features of population models (e.g., age structure, or a 3-DU spatially explicit model) would only be required if some threats were shown to have a disproportionate impact on some population segments, or if more information was available on population structure and exchange between the DUs (e.g., immigration, emigration). It would be important to refine our understanding of anthropogenic mortalities to PCFG and WP DUs to allow meaningful exploration of additional scenarios. For the time being, we recommend using the parameters described above.

Given available data, it is uncertain whether the supply of foraging habitat in Canada will meet the demands of a larger PCFG population size in future. If the PCFG is currently at or near carrying capacity, then suitable habitat space may be saturated and unlikely able to support more individuals. Knowledge regarding Grey Whale prey species biomass and density dynamics across broad spatial and temporal scales within Canada could be used to inform this. The WP population is believed to use Canadian waters primarily for migration. The supply of suitable migratory habitat is not expected to be a limiting factor for the recovery of either DU.

SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

Consultation of Fisheries and Oceans Canada’s (2010) Management Plan for the Eastern Pacific Grey Whale in Canada, as well as Fisheries and Oceans Canada’s (2019) Report on the Progress of Management Plan Implementation for the Eastern Pacific Grey Whale in Canada is recommended, as substantial effort has been made to identify management actions (and associated progress) for Grey Whales in Canada. The following two documents are also relevant: Parks Canada Agency’s (2016) Multi-species Action Plan for Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site, as well as Parks Canada Agency’s (2017) Multi-species Action Plan for Pacific Rim National Park Reserve of Canada.

See Table 4 for a brief overview of the feasible mitigation measures and alternatives to activities considered as threats to the PCFG and WP populations in Canada. Any mitigation measure proposed in Table 4 or within the above-referenced documents would likely increase the survivorship of Grey Whales in Canada. It is difficult to directly increase productivity of the PCFG and WP populations, as this will primarily depend on environmental conditions influencing prey availability and carrying capacity. Productivity can likely be indirectly influenced by reducing anthropogenic threats to reproductively mature females and calves.

The primary threats to Grey Whales are entanglement and vessel collisions. A better understanding of spatio-temporal patterns of overlap between the PCFG/WP DUs in Canada and fishing effort and vessel traffic is required to estimate the reduction in mortality expected by proposed mitigation measures or alternatives. Incorporating knowledge of which fishery gear types are more likely to entangle or entrap Grey Whales would also be informative. For instance, entanglement in net (39.7%) and pot fisheries (17.1%) was responsible for the majority of human-caused injuries and mortalities to Grey Whales in the North Pacific from 1924 to 2015 (Scordino et al. 2017). Fishery gear types identified in Grey Whale entanglement cases in U.S. waters from 2012 to 2016 included set and drift gillnets, pot, and trap gear (Carretta et al. 2018c, 2018b). In the Russian Far East, coastal salmon set net fisheries pose a high entanglement risk for WP whales feeding off northeastern Sakhalin and Kamchatka (Lowry et al. 2018). In addition, bottom-set gillnets, demersal longlines, Danish seines, and trap and pot fisheries overlap considerably with WP Grey Whale foraging habitats, increasing the risk of bycatch (Lowry et al. 2018). Identifying the type of vessels and circumstances involved in Grey Whale-vessel collisions is challenging, however most negative interactions are suspected to occur in nearshore waters and likely with fast-moving vessels with which Grey Whales do not react quickly enough to avoid.

ALLOWABLE HARM ASSESSMENT

Both the PCFG and the WP populations have been assessed as Endangered by COSEWIC due to small population size, thus any human-induced mortality should be minimized. The Government of Canada currently does not have a standardized, quantitative definition of "allowable harm" to a species. Under the Marine Mammal Protection Act of the U.S. Government, the potential biological removal (PBR) level has been adopted as a means of quantifying the maximum number of animals, excluding natural mortality, that may be removed per year while still allowing the target population to reach or maintain its OSP within 100 years (Wade 1998). Therefore, PBR has a built-in management objective that differs from the recovery targets proposed above. PBR is calculated as:

$$PBR = N_{min} \times \frac{1}{2} R_{max} \times F_R$$

where N_{min} is the most recent minimum population abundance estimate, R_{max} is the maximum theoretical population growth rate, and F_R is the recovery factor. N_{min} is often defined as the 20th percentile of the assumed log-normal distribution around the abundance estimate, and is calculated with the following equation (Wade et al. 1998),

$$N_{min} = \frac{N_{est}}{\exp(z\sqrt{\ln(1 + CV(N_{est})^2)})}$$

where N_{est} is the point estimate of the most recent population size, z is the standard normal variate (0.842 for the 20th percentile), and CV(N) is the coefficient of variation for the estimated population size N_{est}.

The population estimate for the PCFG in 2015 was 243 (CV 0.08), resulting in an N_{min} of 227. The population estimate for the WP population (Sakhalin Island and Kamchatka feeding aggregations combined) in 2015 was 282 (CV 0.05) or N_{min} = 270, and 191 (CV 0.042), N_{min} = 184 for the predominantly Sakhalin Island-feeding individuals (International Whaling Commission 2018b, Table 2, p. 380). A value of 6.2% was used for R_{max} for both populations.

The recovery factor F_R is a constant ranging from 0.1 to 1.0, where values less than 1.0 allocate a proportion of the expected net production to population growth, while compensating for uncertainties which may hinder population recovery (National Marine Fisheries Service 2016). Population simulation studies have recommended using default F_R values of 0.1 for Endangered stocks (or designatable units) and 0.5 for Threatened stocks and stocks of unknown status (Barlow et al. 1995; Wade 1998). Given the uncertainties regarding levels of external versus internal recruitment and stock structure, the National Marine Fisheries Service (U.S.) has assigned an F_R value of 0.5 for the PCFG and a value of 0.1 for the WP population (Carretta et al. 2018a). Here, we propose alternate recovery factors based on Canadian criteria (Hammill et al. 2017), which suggest using a value of 0.25 for small populations that have been assessed by COSEWIC as Threatened or Endangered but are increasing or stable (as opposed to small, declining populations – or with unknown trends – with the same designations, for which a factor of 0.1 is deemed appropriate).

Using this recovery factor of 0.25, the PBR for the PCFG is 1.76 whales per year, and 2.09 whales annually for the WP population. These PBR values are for the entire populations and are assumed to represent anthropogenic mortality over their entire distribution ranges (i.e., not just mortality in Canadian waters).

Since the WP population only uses U.S. waters seasonally, Carretta et al. (2018) multiplied the above PBR by estimates of the proportion of the WP population which occupies U.S. waters (0.575) and the proportion of the year that those individuals are within the U.S. (3 months or 0.25 years), resulting in a PBR of 0.07 whales per year. The WP population is believed to use Canadian waters for migration only, however there is a possibility that some individuals stop to forage or socialize during the migration. If we assume that the same proportion of the WP population uses Canadian waters as they migrate to breeding grounds in Mexico, and the proportion of time WP individuals spend in Canadian waters is also equivalent to 3 months, Canada’s portion of the PBR would be 0.30 WP whales per year (using F_R = 0.25).

TABLES

Table 1. Life-history parameters for Grey Whales. PCFG: Pacific Coast Feeding Group Designatable Unit (DU); WP: Western Pacific DU, ENP: Eastern North Pacific population; GW: Grey Whale species (not DU-specific).

Life-history parameter	DU	Value	Reference
Age at sexual maturity	GW	8 y	Rice and Wolman (1971)
Age at first parturition	GW	10 y	Taylor et al. (2007)
	WP	10.7 y (SE 0.6)	Cooke et al. (2016)
Age at physical maturity	GW	40 y	Rice and Wolman (1971)
Gestation time	GW	13-14 mo	Rice and Wolman (1971) Rice (1983)
No. of offspring per birth	GW	1	Rice and Wolman (1971) Rice (1983)
Lactation duration	GW	6-7 mo	Sumich (1986)
Inter-birth interval	GW	2 y	Jones (1990)
Sex ratio at birth (female proportion)	WP	0.41 (SE 0.05)	Cooke et al. (2016)
Maximum age of reproductive females	GW	55 y	Taylor et al. (2007)
Generation time	GW	22.9 y	Taylor et al. (2007)
Calf (< 1y) survival rate	ENP	0.706–0.730	Punt and Wade (2010)
	PCFG	0.63 (SE 0.09)	Calambokidis et al. (2017)
	WP	0.67 (SE 0.07)	Cooke et al. (2016)
Non-calf (> 1y) survival rate	ENP	0.972–0.983	Punt and Wade (2010)
	PCFG	0.967 (SE 0.007)	Calambokidis et al. (2017)
	WP	0.980 (SE 0.004)	Cooke et al. (2016)

Table 2. Population-Level threat assessment for the Pacific Coast Feeding Group (PCFG) and the Western Pacific (WP) Grey Whale Designatable Units (DU) in Canada; H: Historical, C: Current, A: Anticipatory (see DFO 2014 for category definitions).

Threat	DU	Likelihood of Occurrence	Level of Impact	Causal Certainty (Rank)	Population-Level Threat Risk	Population-Level Threat Occurrence	Population-Level Threat Frequency	Population-Level Threat Extent
Entanglement	PCFG	Known	Medium	High (2)	Medium (2)	H, C, A	Continuous	Extensive
	WP	Known	Medium	High (2)	Medium (2)	H, C, A	Continuous	Narrow-Broad
Vessel collisions	PCFG	Known	Medium	High (2)	Medium (2)	H, C, A	Continuous	Extensive
	WP	Known	Medium	High (2)	Medium (2)	H, C, A	Continuous	Narrow-Broad
Disruption or destruction of feeding habitat	PCFG	Likely to occur	Low	Medium (3)	Low (3)	H, C, A	Recurrent	Narrow-Broad
	WP	Likely to occur	Low	Medium (3)	Low (3)	H, C, A	Recurrent	Restricted-Narrow
Physical disturbance	PCFG	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Narrow-Broad
	WP	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Narrow
Acute noise	PCFG	Likely to occur	Unknown	Medium (3)	Unknown (3)	H, C, A	Recurrent	Narrow
	WP	Likely to occur	Unknown	Medium (3)	Unknown (3)	H, C, A	Recurrent	Narrow
Chronic noise	PCFG	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Narrow-Broad
	WP	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Narrow-Broad
Toxic spills	PCFG	Unlikely	Medium-High	Low (4)	Medium (4)	H, C, A	Recurrent	Narrow-Broad
	WP	Unlikely	Medium-High	Low (4)	Medium (4)	H, C, A	Recurrent	Narrow-Broad
Pollutants	PCFG	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Narrow-Broad
	WP	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Narrow-Broad
Aboriginal subsistence hunt	PCFG	Unlikely	Low	Very high (5)	Low (5)	H	Recurrent	Restricted
	WP	Unlikely	Low	Very high (5)	Low (5)	H	Recurrent	Restricted
Scientific research	PCFG	Known	Low	Low (4)	Low (4)	H, C, A	Recurrent	Restricted
	WP	Known	Low	Low (4)	Low (4)	H, C, A	Recurrent	Restricted

Table 3. Species-Level threat assessment for the Grey Whale in Canada; H: Historical, C: Current, A: Anticipatory DFO 2014 for category definitions).

Threat	Likelihood of Occurrence	Level of Impact	Causal Certainty (Rank)	Population-Level Threat Risk	Population-Level Threat Occurrence	Population-Level Threat Frequency	Population-Level Threat Extent
Entanglement	Known	Medium	High (2)	Medium (2)	H, C, A	Continuous	Extensive
Vessel collisions	Known	Medium	High (2)	Medium (2)	H, C, A	Continuous	Extensive
Disruption or destruction of feeding habitat	Likely to occur	Low	Medium (3)	Low (3)	H, C, A	Recurrent	Narrow-Broad
Physical disturbance	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Narrow-Broad
Acute noise	Likely to occur	Unknown	Low (4)	Unknown (4)	H, C, A	Recurrent	Narrow
Chronic noise	Known	Unknown	Low (4)	Unknown (4)	H, C, A	Continuous	Narrow-Broad
Toxic spills	Unlikely	Medium-High	Low (4)	Medium (4)	H, C, A	Recurrent	Narrow-Broad
Pollutants	Known	Unknown	Very low (5)	Unknown (5)	H, C, A	Continuous	Narrow-Broad
Aboriginal subsistence hunt	Known	Low	Very high (1)	Low (4)	H	Recurrent	Restricted
Scientific research	Known	Low	Low (4)	Low (4)	H, C, A	Recurrent	Restricted

Table 4. Overview of feasible mitigation measures and alternatives to the activities considered as threats to the PCFG and WP population in Canada. See Fisheries and Oceans Canada (2010, 2019) for a list of mitigation actions completed or underway and activities supporting conservation of Grey Whales in Canada.

Threat	Mitigation measure(s) and/or alternatives to activities
Entanglement	1. Undertake a spatial-temporal mapping exercise to document which areas Grey Whales have a higher risk of being entangled in fishing gear in Canada. 2. Document the type(s) and source(s) of fishing gear found on entangled Grey Whales in Canada. 3. Reduce or shift (geographically and/or temporally) fishing operations to avoid negative interactions with Grey Whales. 4. Consider modifying fishing and aquaculture gear to reduce the incidence and/or severity of entanglement. 5. Public outreach and communication on the risk of entanglement to Grey Whales and other marine mammals; how to report and document entanglement cases. 6. Ensure adequate enforcement of the Canadian Marine Mammal Regulations (MMR) regional guidelines. 7. Continue development of fisheries observer programs, reporting standards, marine mammal species identification, and guidelines to aid bycatch management. 8. Continue to support the Marine Mammal Response Program (MMRP) and associated data collection.
Vessel collisions	1. Undertake a spatial-temporal mapping exercise to document which areas Grey Whales have a higher risk of being struck by vessels in Canada. 2. Document the type of vessels and specific circumstances involved in collisions with Grey Whales in Canada. 3. Reduce vessel speeds or shift (geographically and/or temporally) vessel traffic to avoid negative interactions with Grey Whales. 4. Public outreach and communication on the risk of vessel collision to Grey Whales and how to report and document vessel collision cases (e.g. Promotion of *Be Whale Wise* guidelines). 5. Ensure adequate enforcement of the Canadian Marine Mammal Regulations (MMR) regional guidelines. 6. Continue to support the Marine Mammal Response Program (MMRP) and associated data collection.
Disruption or destruction of feeding habitat	1. Undertake a foraging habitat mapping exercise to identify 1) known PCFG (and potentially WP) feeding areas in Canada, and 2) areas

Threat	Mitigation measure(s) and/or alternatives to activities
	for which baseline studies are required to investigate foraging habitat use patterns. 2. Avoid coastal development, industrialization, or any other activity with the potential to disrupt or destruct coastal foraging habitat used by Grey Whales. 3. Review project proposals with potential to impact to areas used by Grey Whales (e.g. benthic habitat degradation, use of seismic or sonar surveying) and provide project-specific advice for mitigation or avoidance with respect to Grey Whale habitat requirements.
Physical disturbance	1. Ensure adequate enforcement of the Canadian Marine Mammal Regulations (MMR) and regional guidelines. 2. Public outreach and communication on the risk of physical disturbance to Grey Whales and how to report and document physical disturbance cases (e.g. Promotion of *Be Whale Wise* guidelines). 3. Ensure adequate enforcement of the Canadian Marine Mammal Regulations (MMR) regional guidelines.
Acute and chronic noise	1. Apply Fisheries and Oceans Canada standards for mitigation of seismic noise, regional implementation protocols (i.e. *The Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment*). 2. Ensure adequate enforcement of the Canadian Marine Mammal Regulations (MMR) regional guidelines. 3. Public outreach and communication on the risk of acoustic disturbance to Grey Whales. 4. Reduce vessel speed in important habitat for Grey Whales. 5. Avoid, reduce or shift (geographically and/or temporally) underwater anthropogenic noise sources which overlap or are in close proximity to important habitat for Grey Whales. 6. Promote development of quieting technologies for vessels.
Toxic spills	1. Ensure preventative measures are in place to avoid toxic spills of any nature. 2. Develop comprehensive toxic spill response to mitigate or avoid impacts to Grey Whales or their feeding habitat in Canada. 3. Identify the source of toxic spills in the marine environment and determine appropriate strategies to reduce or avoid repeated spills. 4. Ensure those responsible for toxic spills have appropriate teams, training and materials to respond and remediate spill events.

Threat	Mitigation measure(s) and/or alternatives to activities
Pollutants	1. Public outreach and communication regarding the risk of marine pollution on the environment and marine organisms. 2. Document and identify sources of marine pollution. Investigate how to reduce marine pollution at the source. 3. Support programs dedicated to removing anthropogenic debris from the marine environment and coastline.
Aboriginal subsistence hunt	Develop co-management strategies for traditional whaling, in support of treaty negotiated rights.
Scientific research	1. Ensure proposed scientific programs are relevant and provide knowledge value for the survival, recovery and management of endangered Grey Whales in Canada. 2. Proposed programs should adhere to the standards for ethically responsible research on animals (see the Canadian Council for Animal Care).

FIGURES

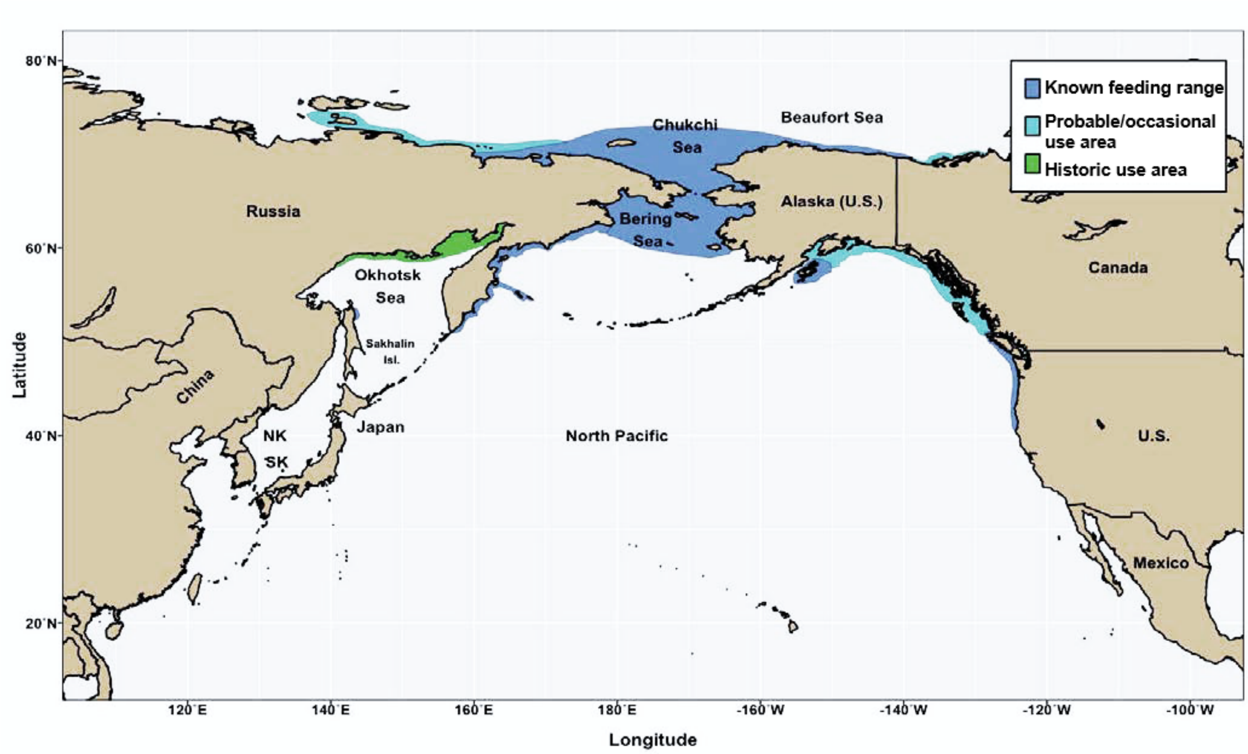


Figure 1. Approximate feeding distribution of Grey Whales in the North Pacific Ocean showing known feeding range (dark blue), areas likely used for feeding (light blue), and feeding areas used in the past (green). Figure adapted from the International Union for Conservation of Nature and International Whaling Commission (2016).

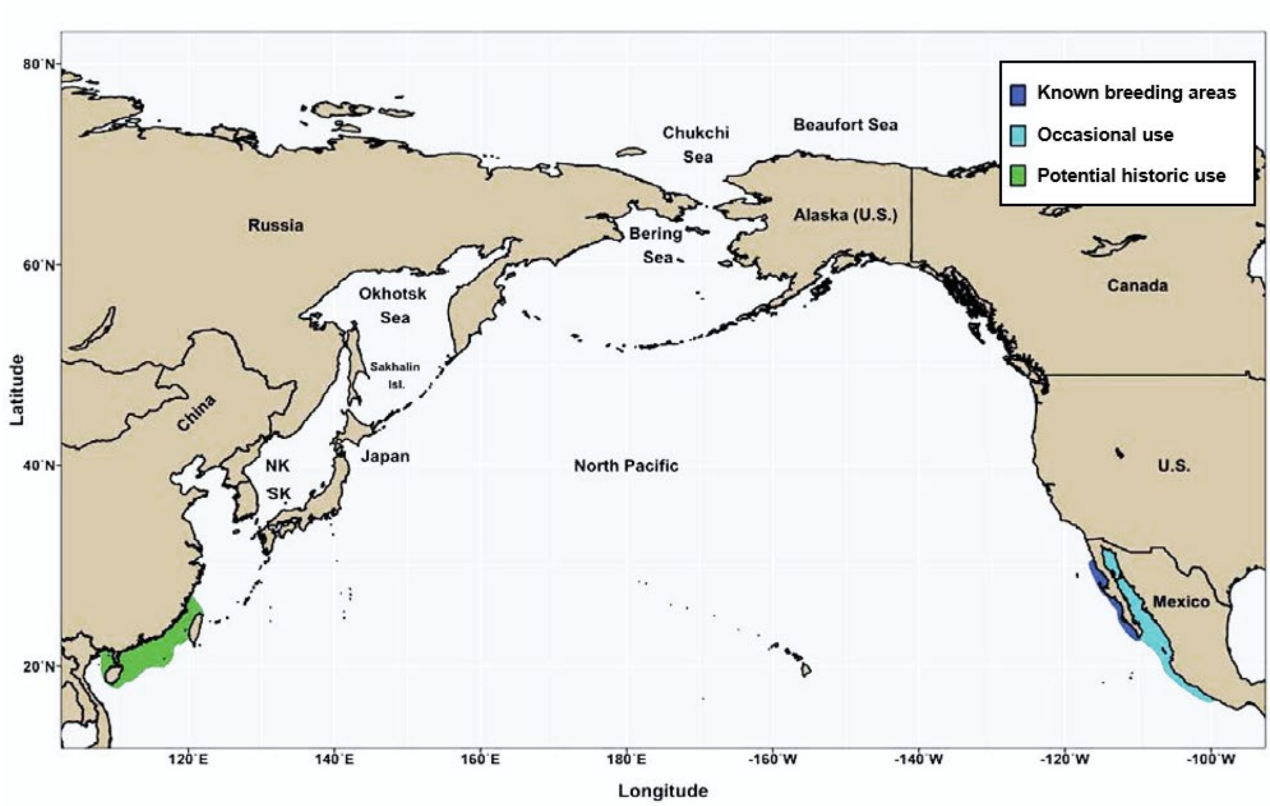


Figure 2. Approximate wintering distribution of Grey Whales in the North Pacific Ocean showing known breeding areas (dark blue), breeding areas of occasional use (light blue), and breeding areas potentially used in the past (green). Figure adapted from the International Union for Conservation of Nature and International Whaling Commission (2016).

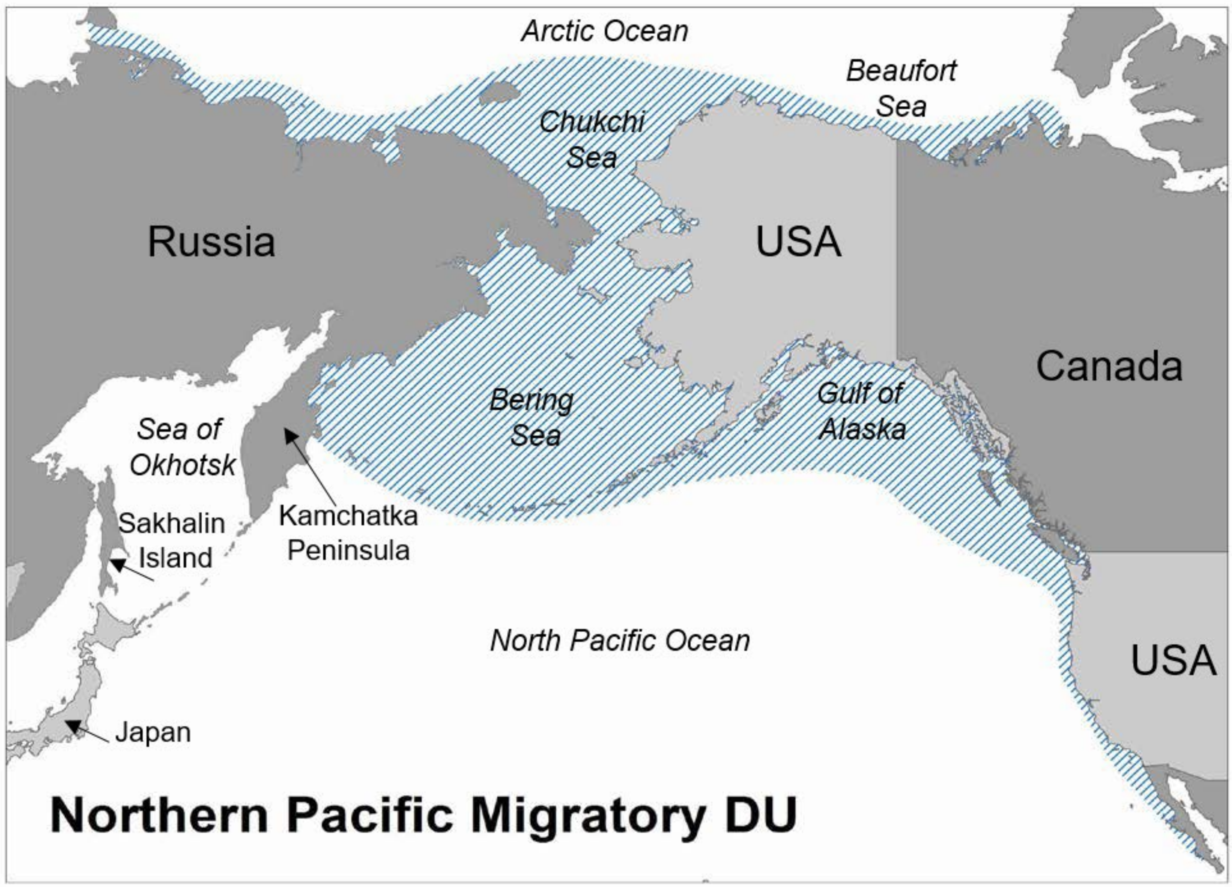


Figure 3. Approximate distribution of the Northern Pacific Migratory (NPM) Grey Whale Designatable Unit (DU) including summer and autumn feeding areas, wintering areas and migration route (figure adapted from COSEWIC 2017).

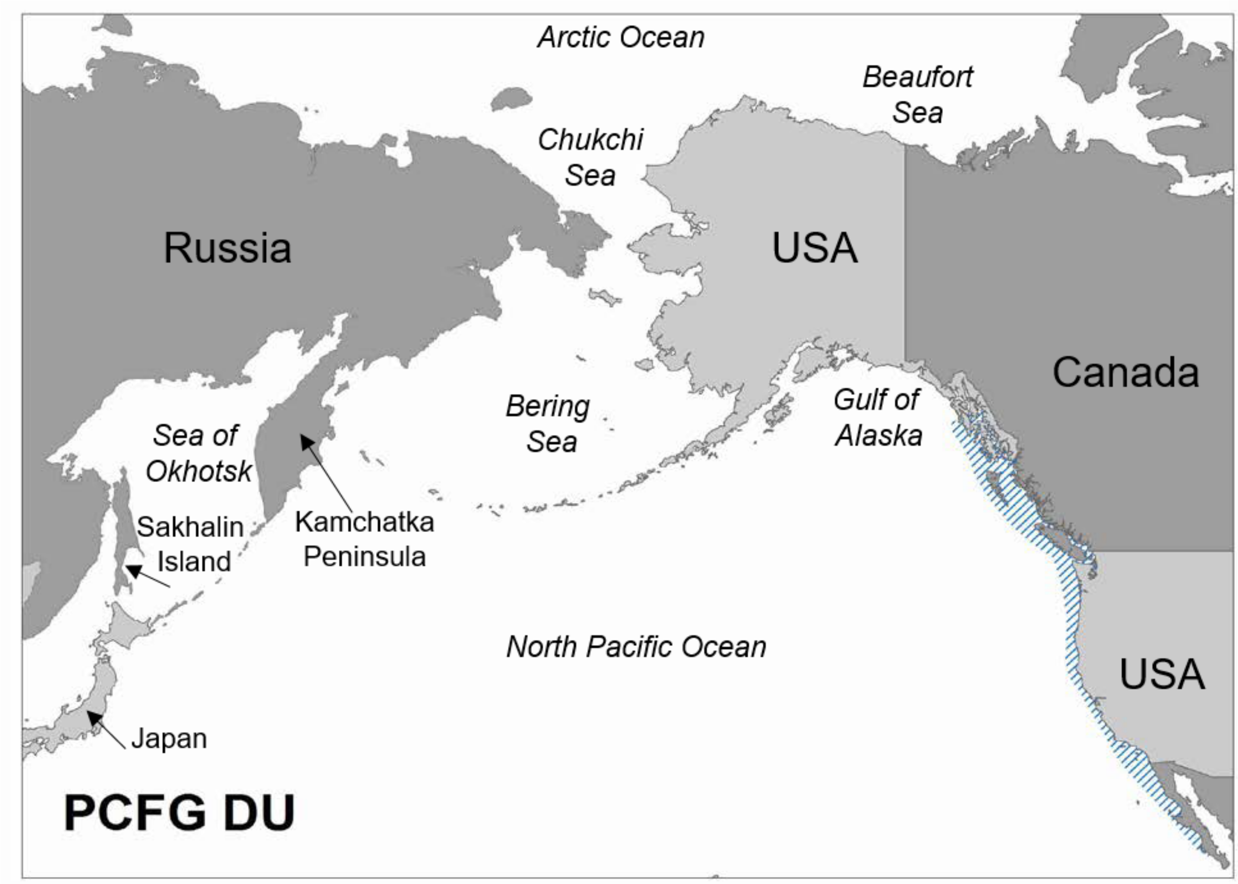


Figure 4. Approximate distribution of the Pacific Coast Feeding Group (PCFG) Grey Whale Designatable Unit (DU) including summer and autumn feeding areas, wintering areas and migration route (figure adapted from COSEWIC 2017).

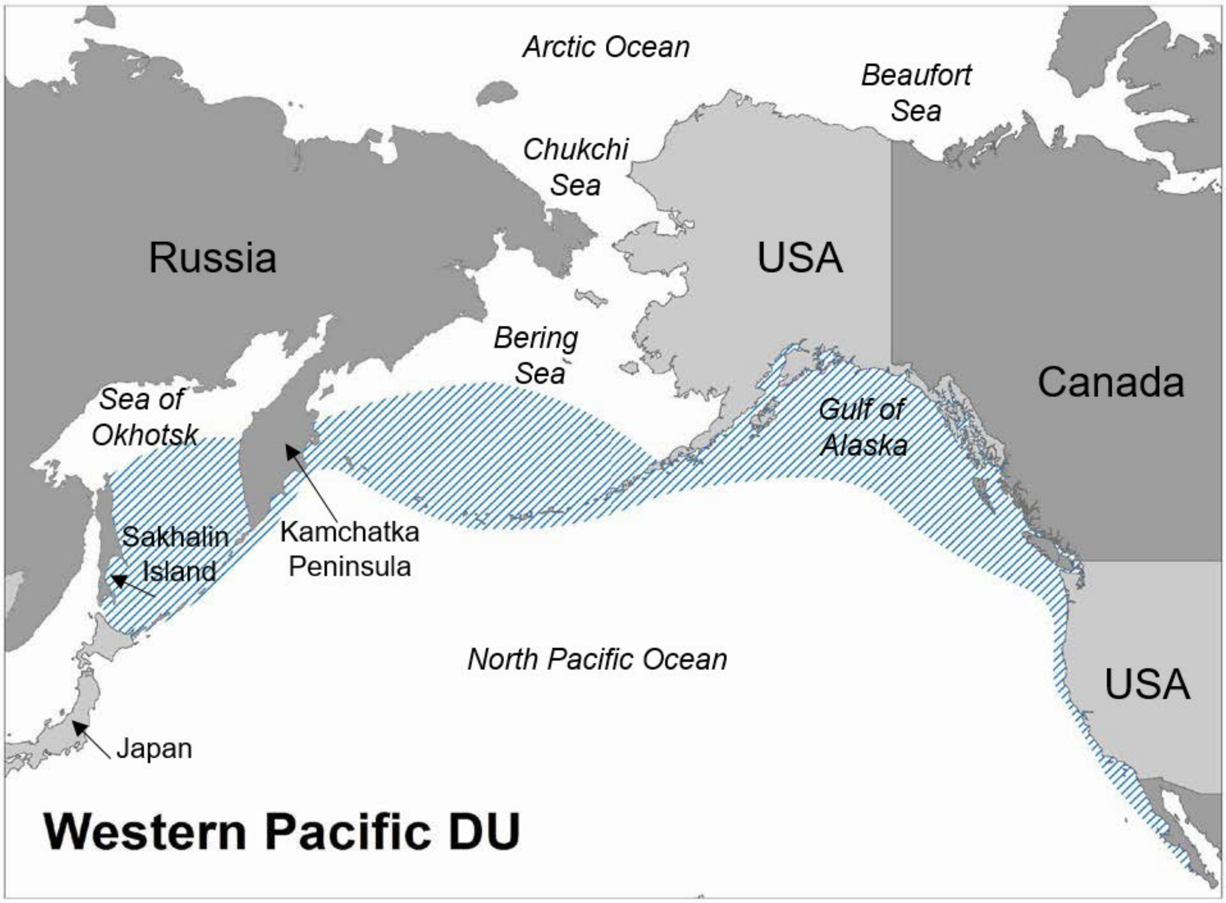


Figure 5. Approximate distribution of Western Pacific (WP) Grey Whale Designatable Unit (DU) including summer and autumn feeding areas, wintering areas and migration route (figure adapted from COSEWIC 2017).

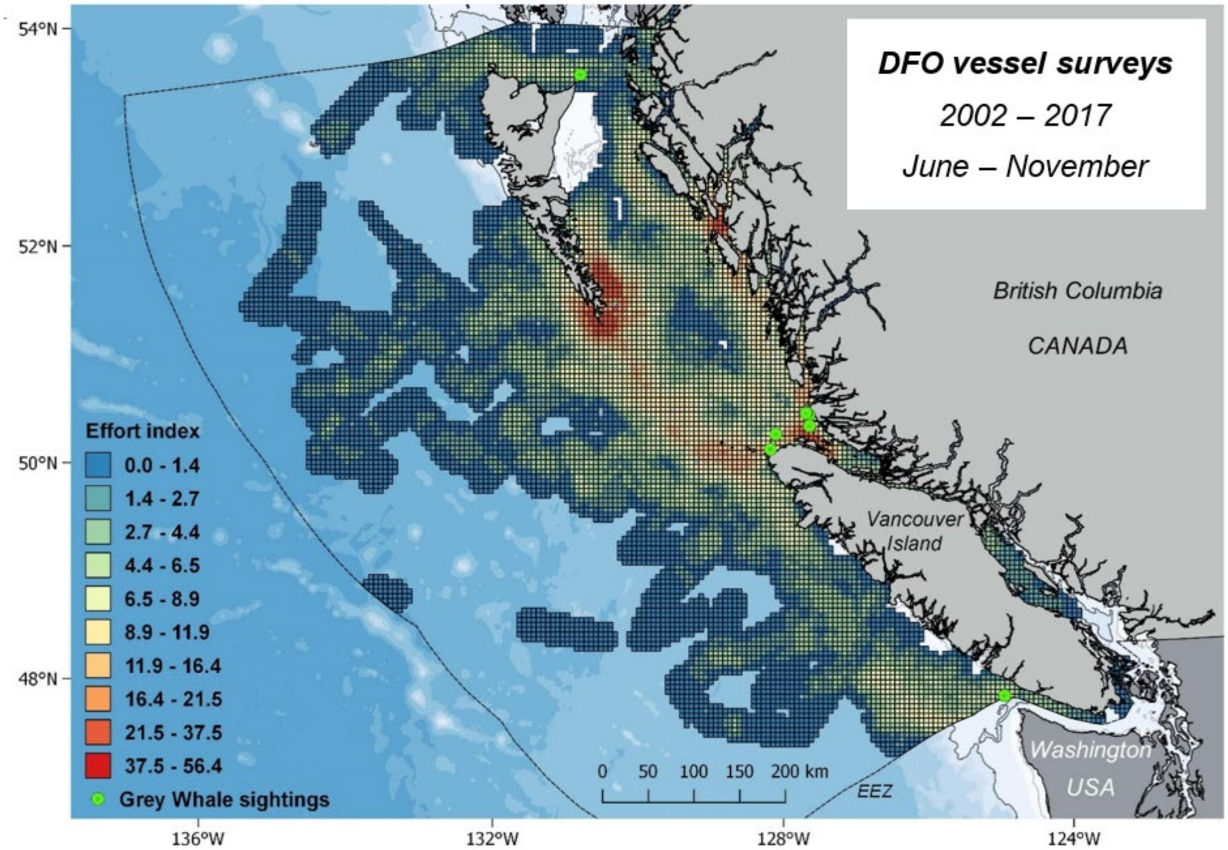


Figure 6. Vessel surveys conducted by Fisheries and Oceans Canada (DFO) off the west coast of British Columbia, Canada from 2002 to 2017 during the summer and fall (June 1 to Nov 30). Effort index shows the number of times a 5x5 km (25 km$^{2)}$ grid cell was cumulatively surveyed over the years. Lime green points are Grey Whale sightings (non-designatable unit specific), comprising eight observation events and 17 individuals. EEZ: economic exclusive zone of Canada. Map projection: NAD83 BC Albers.

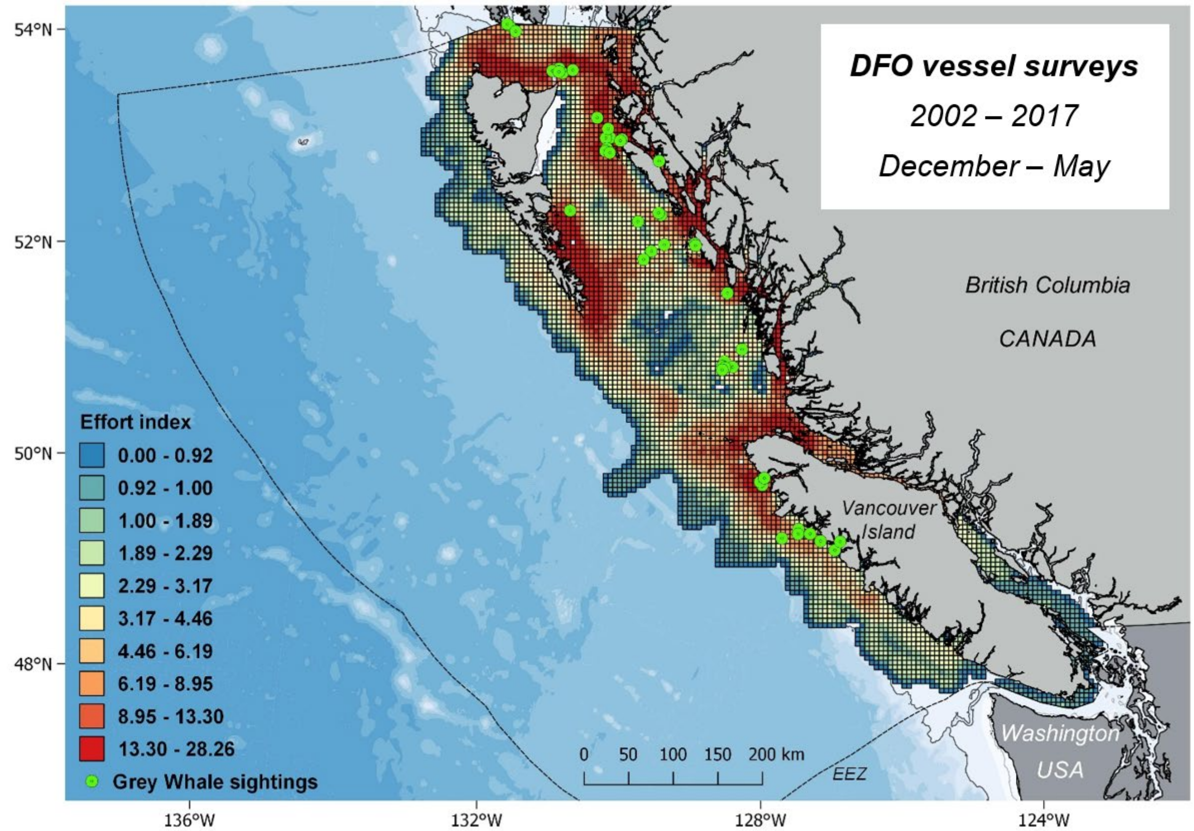


Figure 7. Vessel surveys conducted by Fisheries and Oceans Canada (DFO) off the west coast of British Columbia, Canada from 2002 to 2017 during the winter and spring (Dec 1 to May 31). Effort index shows the number of times a 5x5 km (25 km$^{2)}$ grid cell was cumulatively surveyed over the years. Lime green points are Grey Whale sightings (non-designatable unit specific), comprising 44 observation events and a minimum of 92 individuals. EEZ: economic exclusive zone of Canada. Map projection: NAD83 BC Albers.

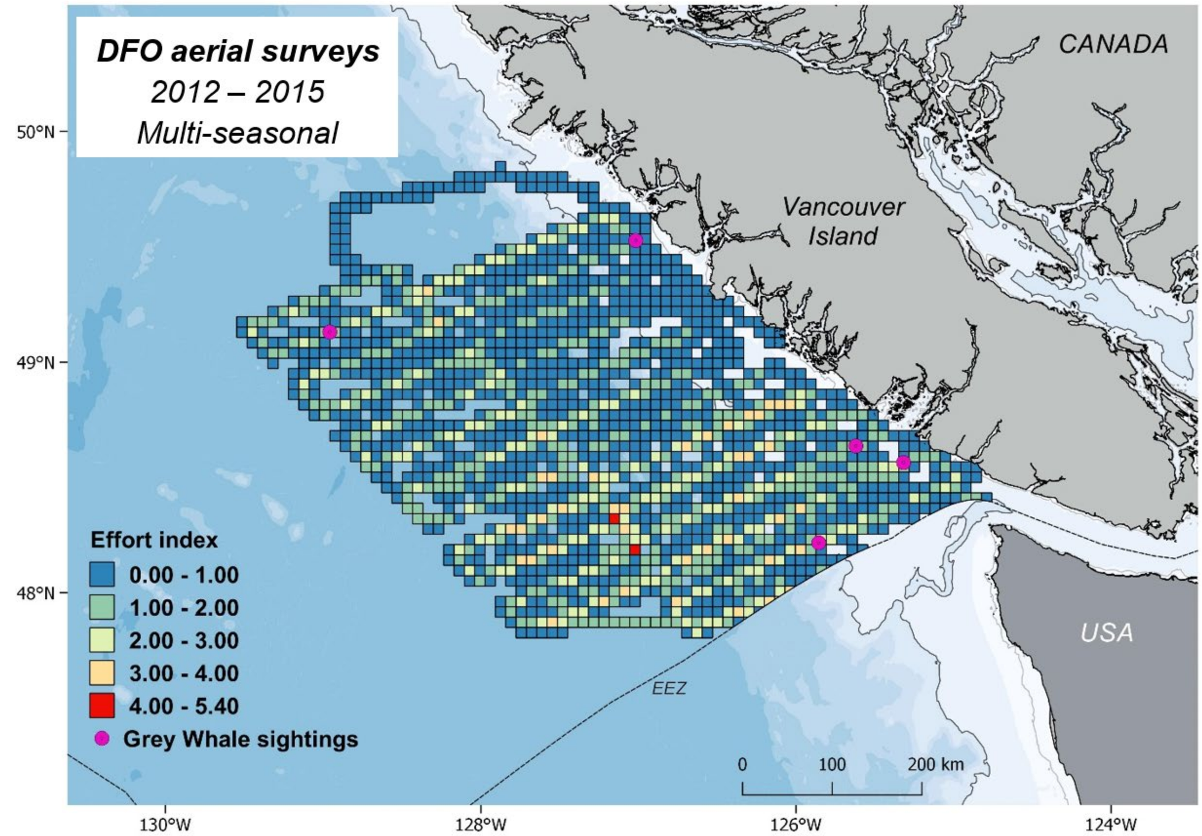


Figure 8. Multi-seasonal aerial surveys conducted by Fisheries and Oceans Canada (DFO) from 2012 to 2015. Effort index shows the number of times a 5x5 km (25 km^2) grid cell was cumulatively surveyed over the years. Pink points are Grey Whale sightings (non-designatable unit specific), comprising five observation events and nine individuals (three in January, one in March and one in December). EEZ: economic exclusive zone of Canada. Map projection: NAD83 BC Albers.

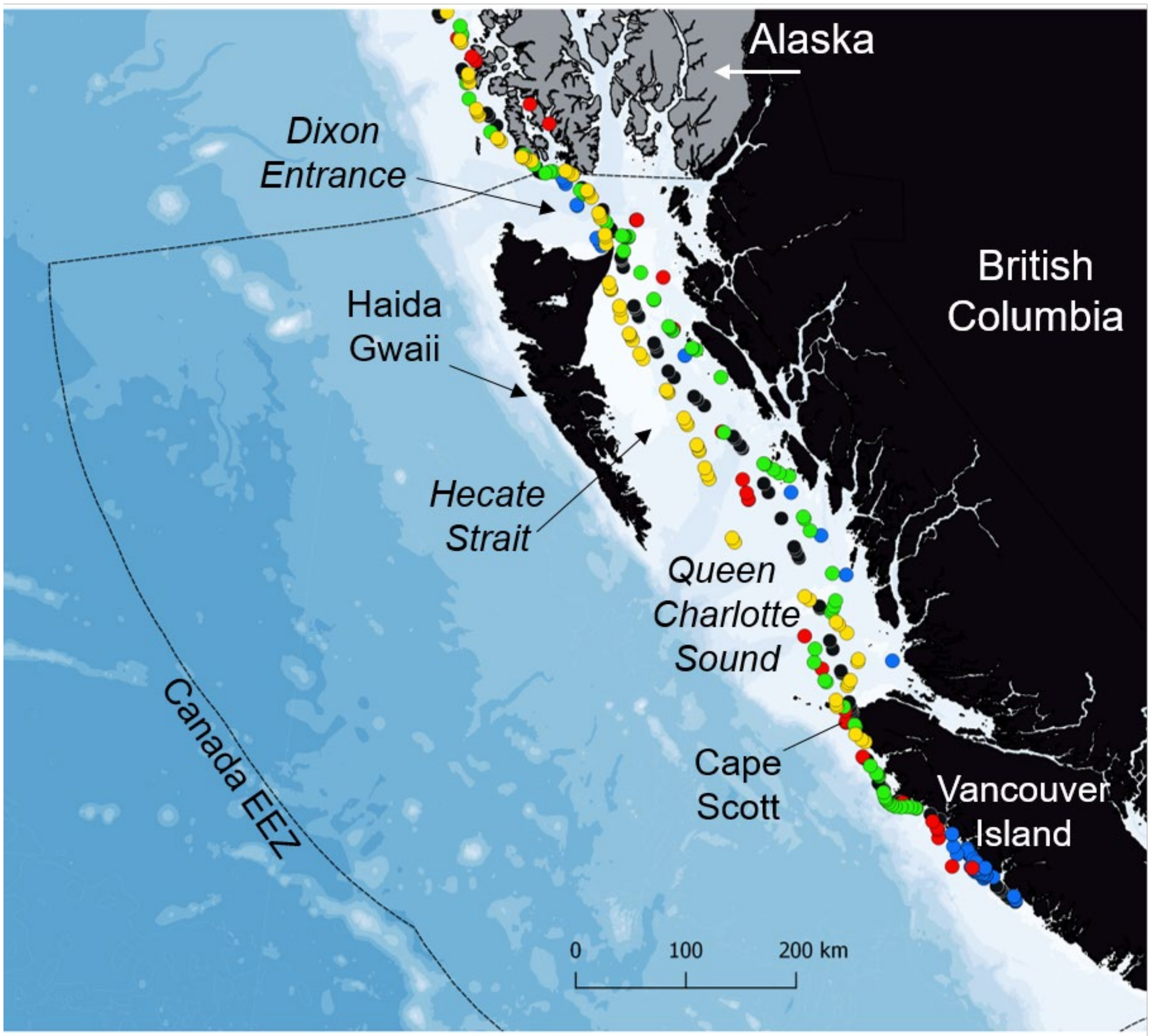
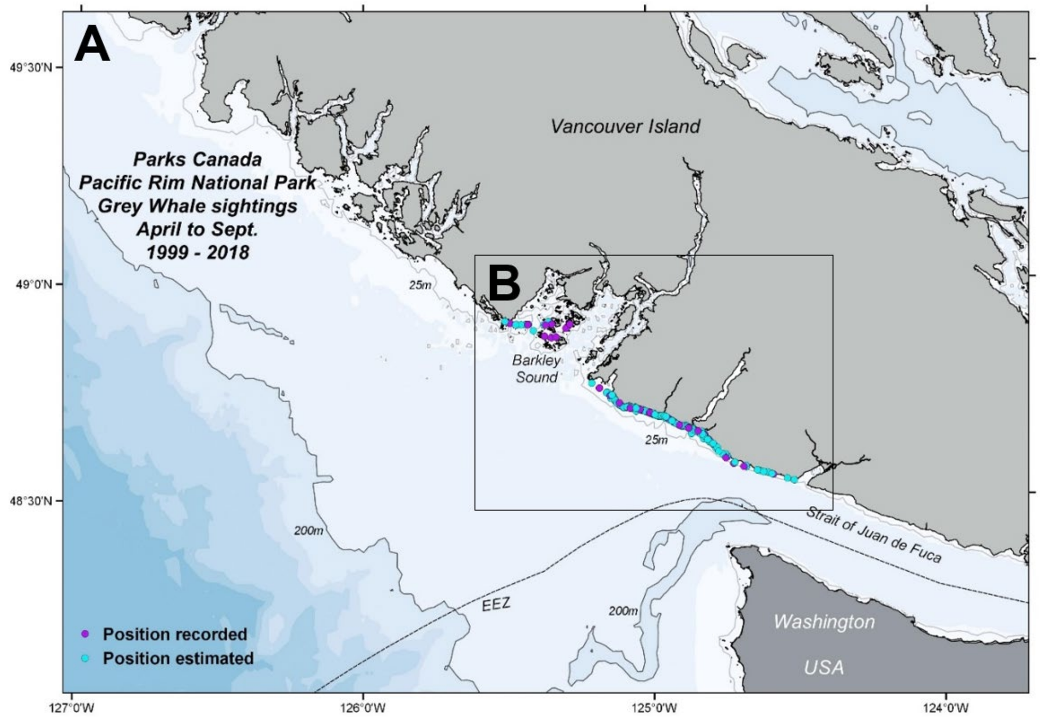


Figure 9. Satellite tracks from five northbound migrating Grey Whales (each represented with a different color). Tags were deployed in March from 2009 to 2011 off the central west coast of Vancouver Island. EEZ: economic exclusive zone of Canada. Map projection: NAD83 BC Albers (map reproduced from Ford et al. 2013).



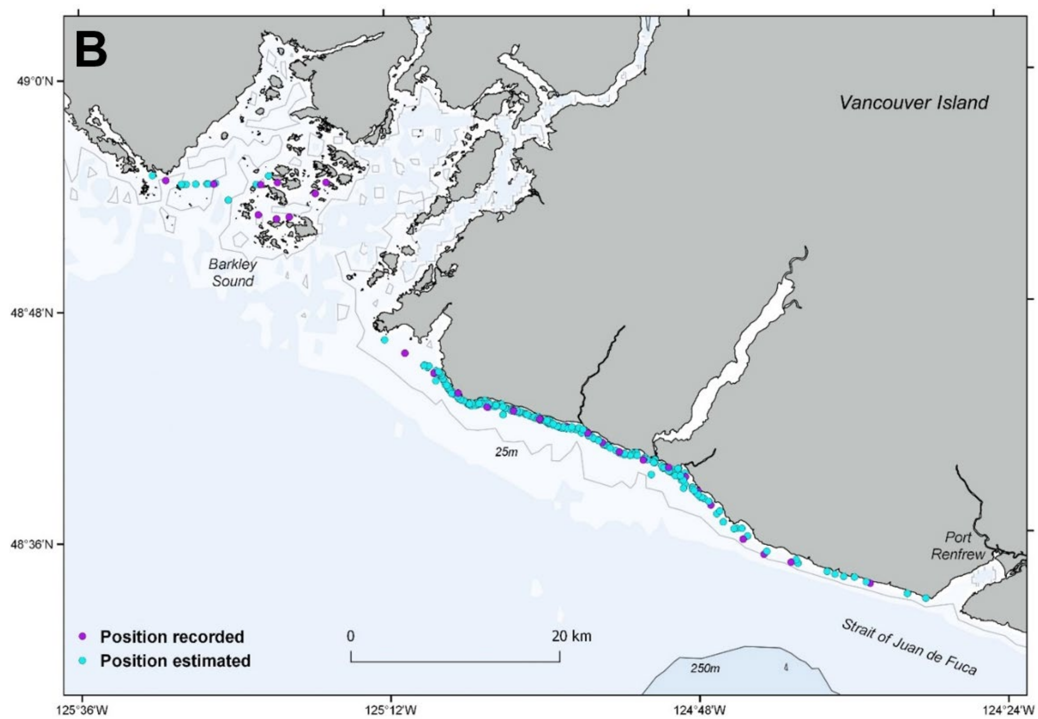


Figure 10. Grey Whale opportunistic sightings in southwestern Vancouver Island from April to September, 1999 to 2018. Data provided by Parks Canada - Pacific Rim National Park Reserve. Purple dots denote true positions of whales, while blue dots denote approximate positions. Map projection: NAD83 BC Albers.

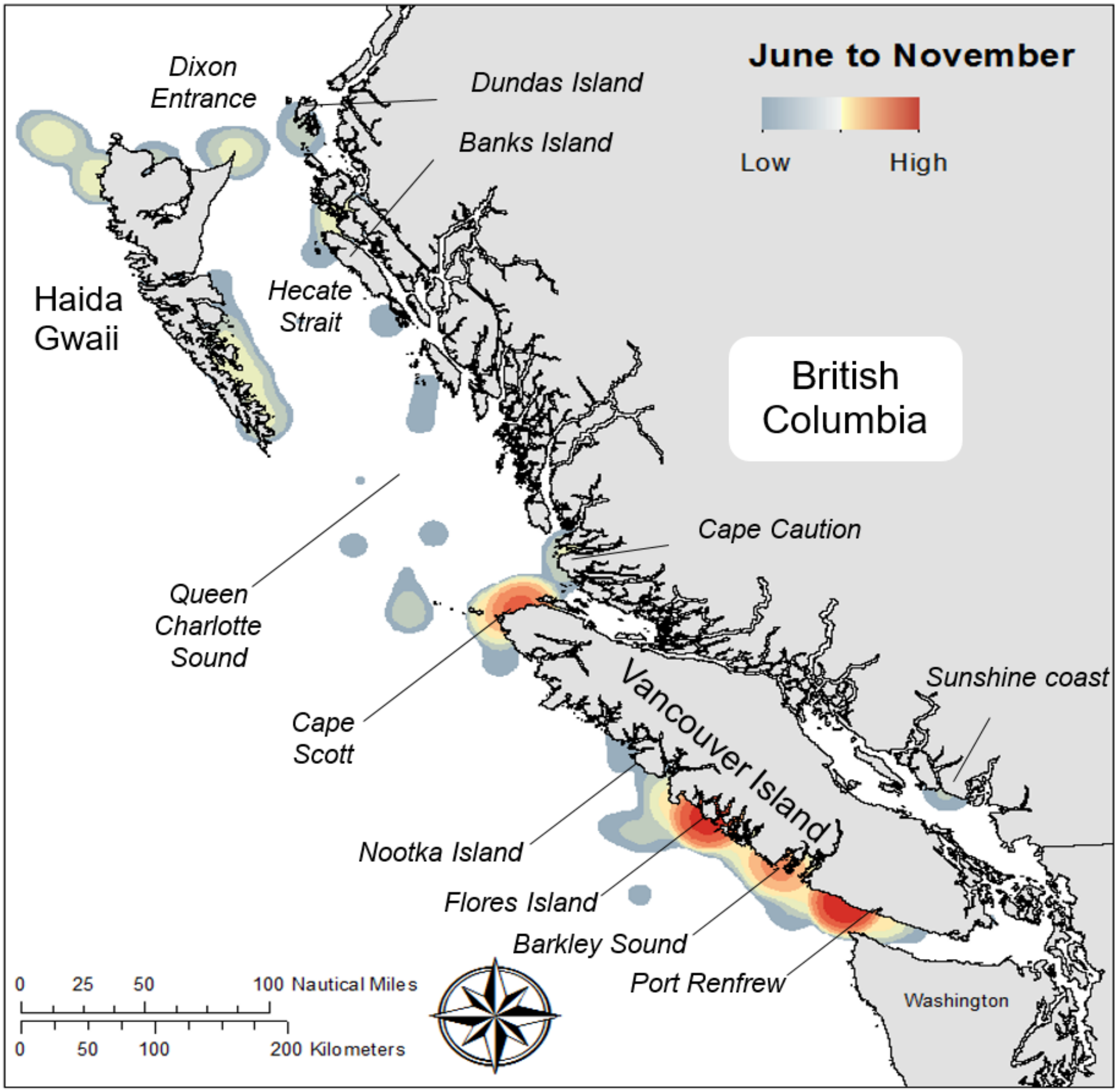


Figure 11. Relative abundance (low to high) of Grey Whales in British Columbia from June to November. Data and map are provided by the British Columbia Cetacean Sightings Network (BCCSN) and have been effort-corrected (Rechsteiner et al. 2013).

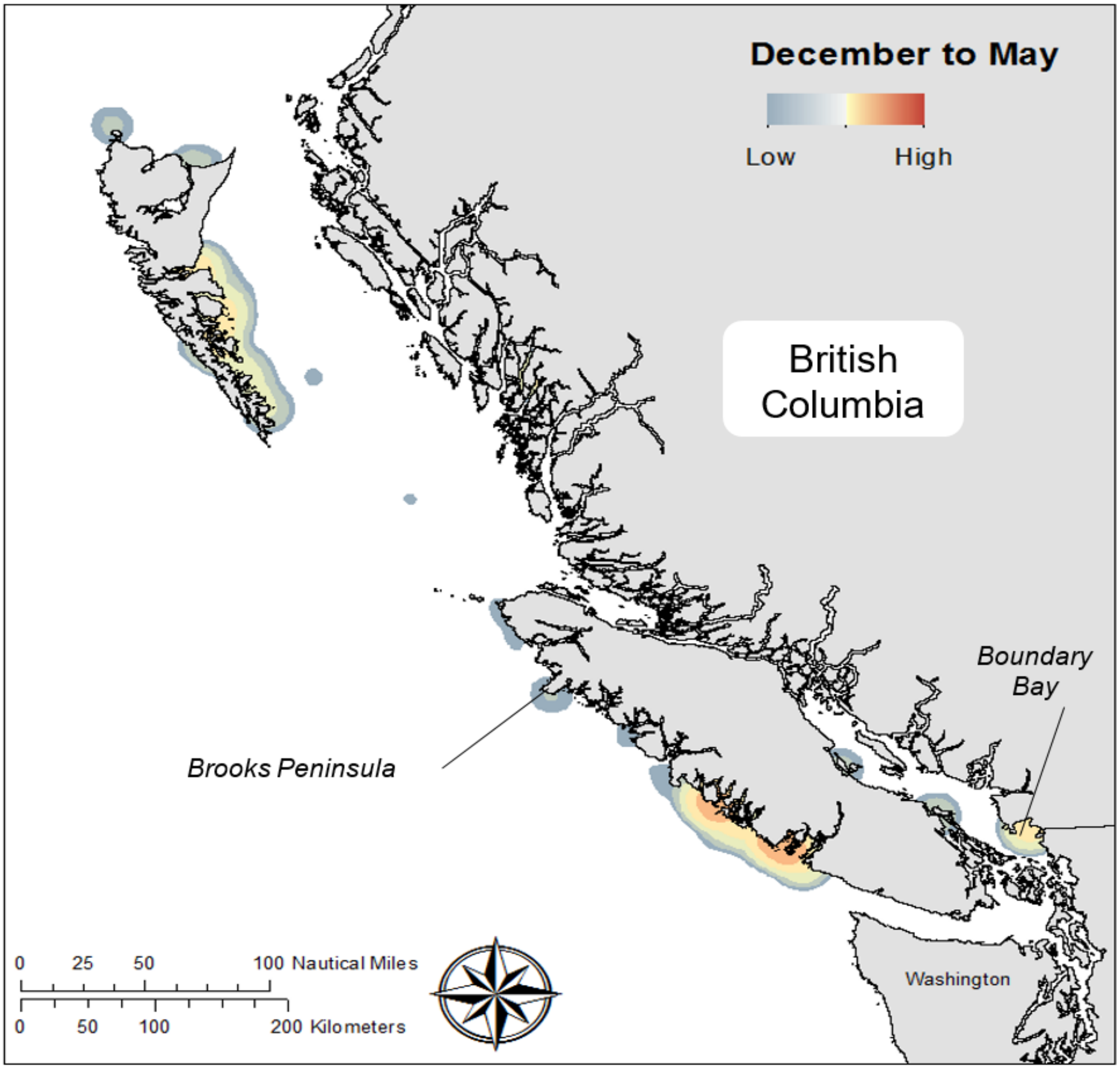


Figure 12. Relative abundance (low to high) of Grey Whales in British Columbia from December to May. Data and map provided by the British Columbia Cetacean Sightings Network (BCCSN) and have been effort-corrected (Rechsteiner et al. 2013).

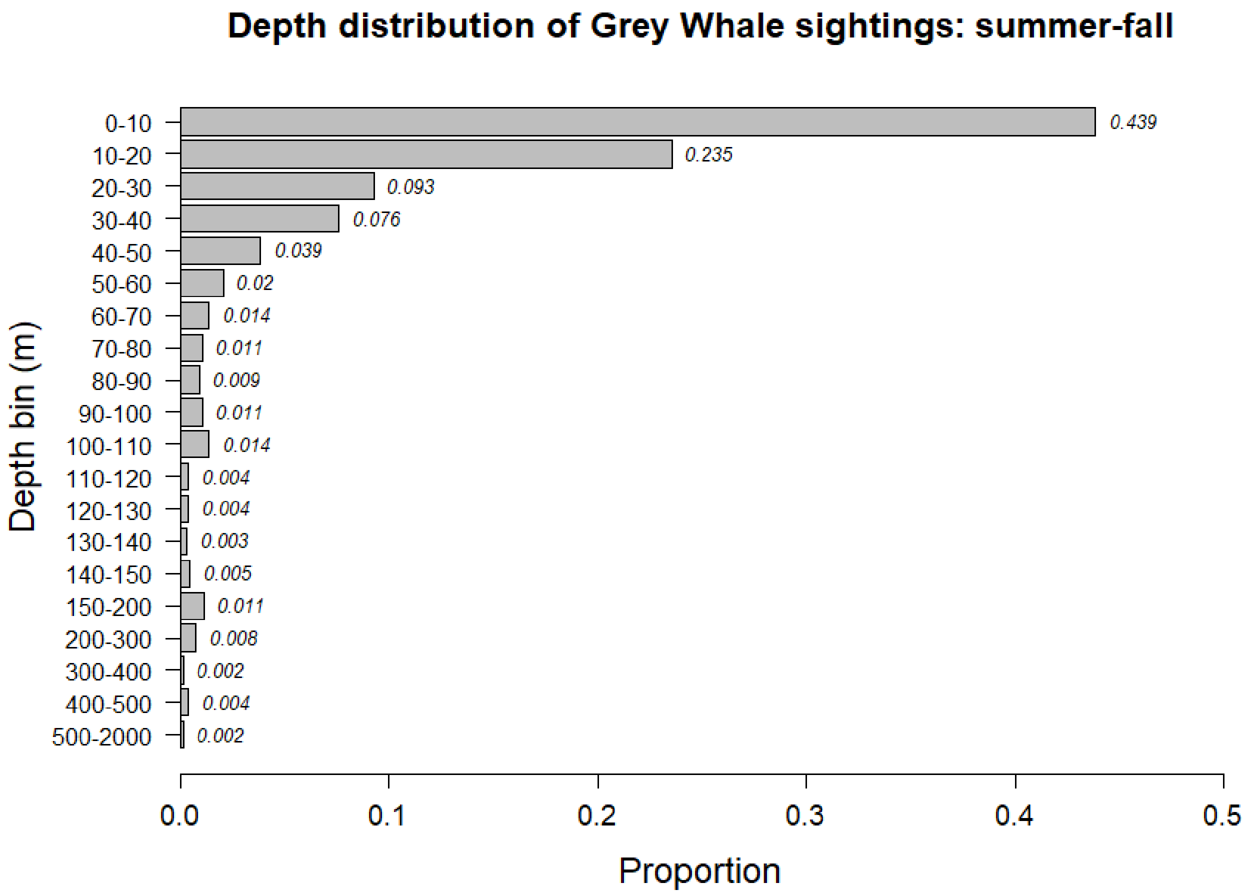


Figure 13. Depth distribution of Grey Whale sightings in Canada during the summer and fall between 1988 and 2018. Data sources include Fisheries and Oceans Canada (DFO) vessel and aerial surveys, British Columbia Cetacean Sightings Network (BCCSN) opportunistic sightings, and Parks Canada – Pacific Rim National Park Reserve opportunistic sightings (n=1320). Note depth bin interval change from 150 m onwards. The proportion of sightings within each depth bin is shown to the right of each bar.

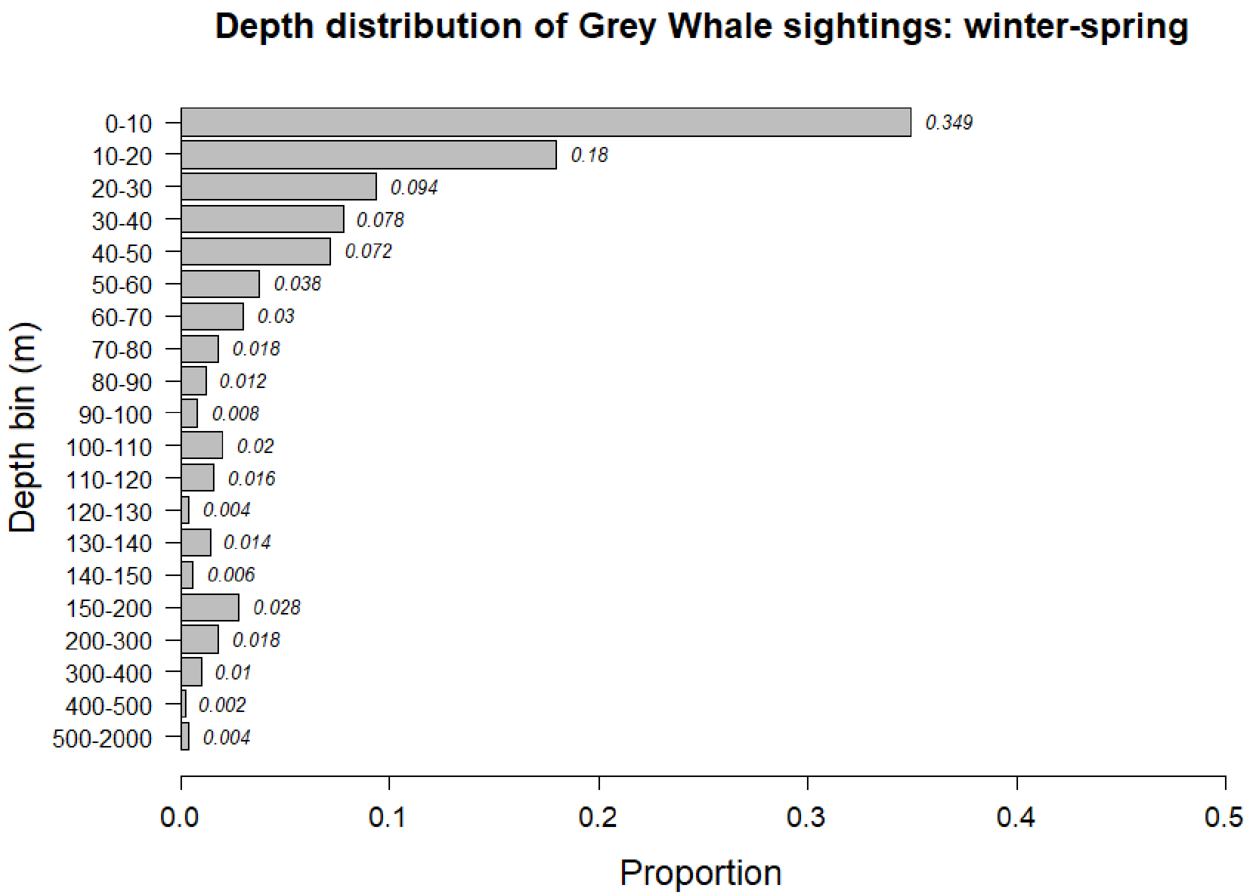


Figure 14. Depth distribution of Grey Whale sightings in Canada during the winter and spring between 1982 and 2018. Data sources include Fisheries and Oceans Canada (DFO) vessel and aerial surveys, British Columbia Cetacean Sightings Network (BCCSN) opportunistic sightings, and Parks Canada – Pacific Rim National Park Reserve opportunistic sightings (n=502). Note depth bin interval change from 150 m onwards. The proportion of sightings within each depth bin is shown to the right of each bar.

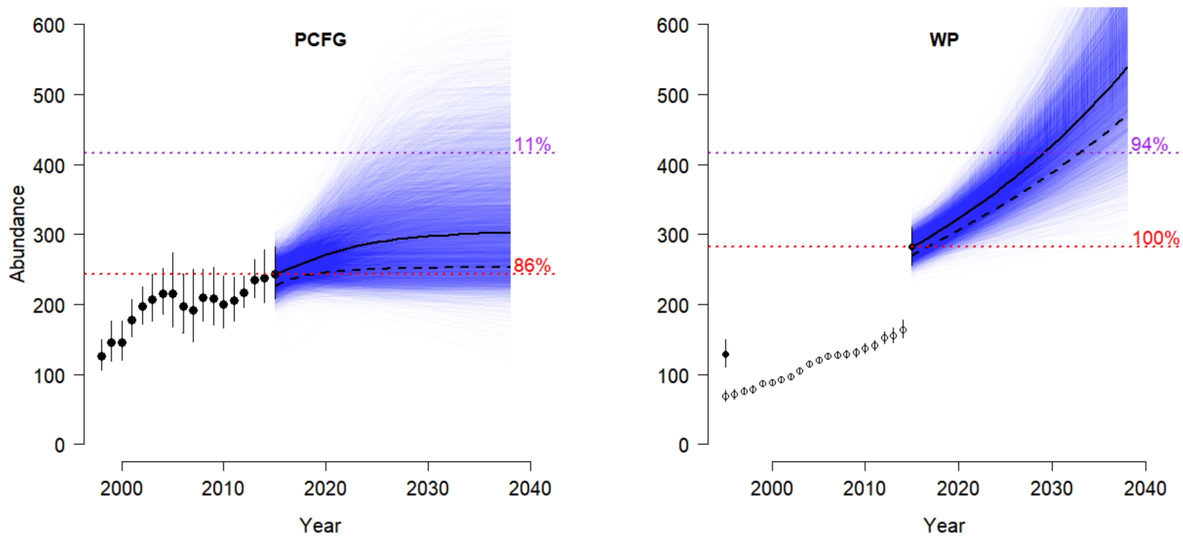


Figure 15. Abundance estimates (with 95% CI) for the Pacific Coast Feeding Group, PCFG (left; 1998–2015) and the Western Pacific population, WP (right), showing separate estimates for the Sakhalin Island feeding aggregation (open circles; 1995–2014) and the combined Sakhalin-Kamchatka feeding aggregations (closed circles; 1995 and 2015). Population abundance is projected from the last abundance estimates (2015) to 23 years in future (2038). Projection iterations are presented (blue lines) with median (black solid line) and 20% quantile (dashed black line). Red and purple dotted lines depict abundance recovery objectives 1 and 2, respectively, and the associated probability of reaching these objectives after 23 years. For both populations, there was 0% probability of reaching objective 3 of 1,667 total whales.

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APPENDIX

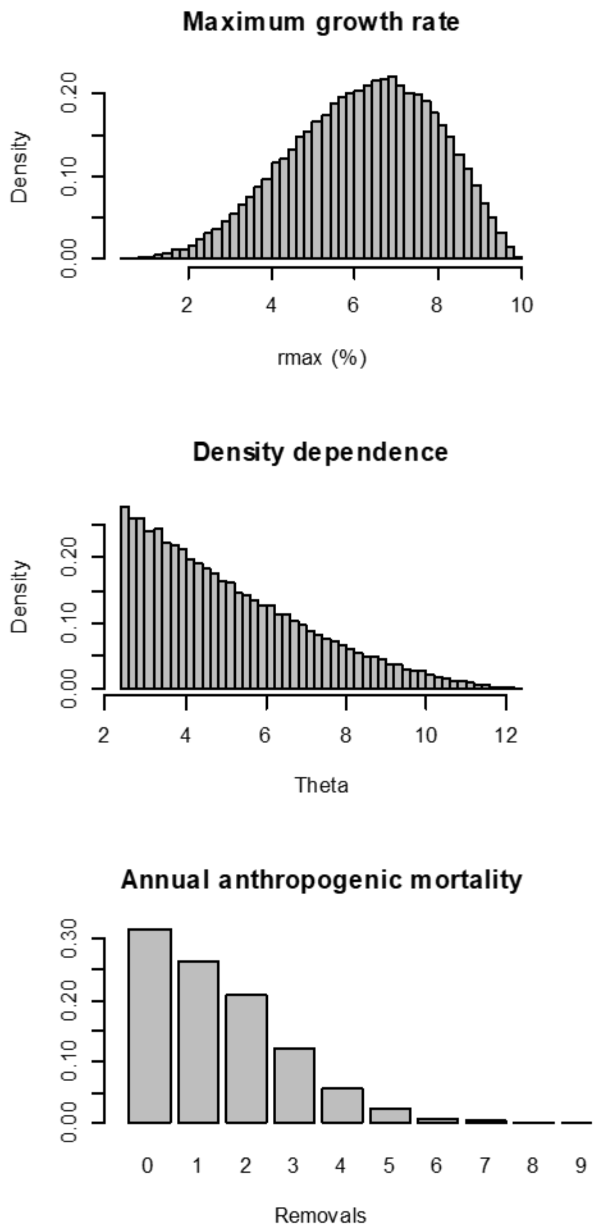

Figure S1. Example of model input parameter distributions informed from published studies, used for future projections of the Pacific Coast Feeding Group (PCFG). Top left to right: maximum population growth rate (R_{max}, %), carrying capacity K; middle left to right: density dependence parameters theta θ and MNPL (maximum net productivity level); and bottom: total annual anthropogenic removals, including both aboriginal catches and human-induced mortality from entanglement and vessel collisions ($C_t + M_t$).