# Update on the status of gray whales since the 2020 Implementation Review

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## ABSTRACT

The International Whaling Commission's Scientific Committee conducts regular Implementation Reviews (IRs) of the biology, threats and status of whale species subject to aboriginal subsistence whaling. The last IR of plans for hunting eastern North Pacific (ENP) gray whales by the Chukotka Natives of the Russian Federation and the Makah Tribe of the United States of America occurred in 2020. This paper presents a review of new scientific findings on gray whales to assess whether the current status of the stock(s) is within the parameter space tested in the 2020 IR. Updated information on gray whale stock structure hypotheses, abundance and calf productivity, health and strandings, human removals by hunting and non-hunting sources, population growth rates, immigration into the Pacific Coast Feeding Group, parameterisation of the Makah hunt, and future episodic mortality events (EMEs) were reviewed for this assessment. For almost all factors, it appears that the current dynamics of the ENP gray whale population are within the parameter space evaluated in 2020 IR. The exception is that EMEs affecting whales in the ENP are occurring more frequently and at a greater magnitude than previously evaluated. However, preliminary evaluations suggest that the performances of the Gray Whale Strike Limit Algorithm (SLA) and Makah Management Plan are robust to recent and future EMEs of Northern Feeding Group gray whales and reductions of productivity of the Pacific Coast Feeding Group, at least under the initial parameterisations. We therefore conclude that there is no compelling need for a Special IR prior to the next scheduled IR in 2026, while noting that additional abundance data for 2022/23 and 2023/24 analysed after drafting this paper could strengthen or weaken the evidence for this conclusion.

**KEYWORDS:** GRAY WHALE; MANAGEMENT PROCEDURE; NORTH PACIFIC OCEAN; ABORIGINAL WHALING

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## INTRODUCTION

The Scientific Committee (SC) of the International Whaling Commission (IWC) conducts regular reviews of the biology, removals and status of species subject to aboriginal subsistence whaling, with reviews occurring about every six years (IWC, 2019a). These are known as Implementation Reviews (IRs). The SC can call for a Special IR if new information gives the SC cause for concern about the sustainability of aboriginal subsistence whaling (IWC, 2019a). In 2010, for instance, the SC called for an IR to start in 2011 for the eastern North Pacific (ENP) gray whales after having completed the scheduled IR in 2010 because a new study reported on genetic differences between Pacific Coast Feeding Group (PCFG) whales and other gray whales of the eastern North Pacific breeding stock (EBS) (Frasier *et al*., 2010, 2011; IWC, 2011). This information raised concerns that the Makah Tribe's proposed hunt could have disproportionate impacts on the PCFG.

The most recent gray whale IR (2020) used a modeling structure developed during the range-wide review of gray whale stock structure and status (IWC, 2019b, 2021). Like all whale stocks subject to aboriginal subsistence whaling, the exact values of many parameters needed to model and forecast the abundance of gray whales are not known with precision, particularly for models that forecast future conditions. The gray whale IR tested a range of conditions by using evaluation and robustness trials to assess how well the Gray Whale Strike Limit Algorithm (SLA) and the Makah Management Plan met management objectives (IWC, 1995). These tests ensured the following: (a) risks to extinction are not seriously increased;[13] (b) stocks are maintained or recovered to levels at or above the Maximum Sustainable Yield Level; and (c) aboriginal subsistence harvest needs are satisfied to the greatest extent possible while meeting conservation targets. Evaluation trials are simulations based on parameter values considered to have higher levels of plausibility and form the basis of management recommendations. Robustness trials are considered to be less plausible and do not typically contribute to management recommendations, but they may be used as a technical tool to explore and better understand the limits of performance for management strategies. The 2020 IR found that the Gray Whale SLA and Makah Management Plan remain the appropriate basis for the provision of advice on the Chukotkan (Russia) and proposed Makah (USA) hunts (IWC, 2021).

Gray whales have experienced two documented episodic mortality events (EMEs) since abundance monitoring began in the 1960s, the first during 1999/2000, and the second starting in 2019, which has continued into 2023, albeit at a reduced rate (Raverty *et al*., 2020; Fauquier *et al*., 2022, 2023). The USA has designated both of these EMEs as 'unusual mortality events' under criteria established by the Marine Mammal Protection Act (Fauquier *et al*., 2022). The current EME is characterised by elevated occurrences of strandings (Fauquier *et al*., 2023), low calf production (Eguchi *et al*., 2022a), and a year-to-year decline in abundance estimates from 26,960 whales (95% CI 24,420-29,830) in 2015/16 to 16,650 whales (95% CI 15,170-18,335) in 2021/22 (Eguchi *et al*., 2022b). As discussed below, this EME appears to be affecting the Northern Feeding Group (NFG) of the EBS, but not the PCFG, Western Feeding Group (WFG) or Western Breeding Stock (WBS). Given these recent events, the purpose of this paper is to review recent observations of the biology and status of gray whales to evaluate whether a special IR is needed before the next scheduled IR in 2026.

## STOCK STRUCTURE HYPOTHESES

Understanding stock structure is important for evaluating and managing human-caused mortality, especially in cases where this mortality may disproportionately deplete smaller stocks or feeding groups. The SC thoroughly reviewed available data and alternative stock structure hypotheses for gray whales in the North Pacific Ocean during five range-wide review of gray whale stock structure and status meetings (IWC, 2015, 2016, 2017, 2018, 2019b).[14] These stock structure hypotheses include three feeding groups or aggregations: the PCFG, which includes whales that are photo-identified in more than one feeding season (June to November) in the region extending between 41°N and 52°N, excluding Puget Sound; the WFG, which includes the whales photo-identified

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[13] For gray whales, this objective has been interpreted at the feeding group level, e.g., to ensure that risks of extirpation of the PCFG and Western Feeding Group (WFG) are not seriously increased.

[14] Full descriptions and diagrams of the stock structure hypotheses are presented in Annex G of the 2021 Scientific Committee Report (IWC, 2022).

off Sakhalin Island, Russia; and the NFG, which includes whales found in other feeding areas, including the Beaufort, Bering and Chukchi Seas, where photo-identification and genetic data are sparse. Up to three extant breeding stocks are considered under these hypotheses: the WBS, EBS, and a third unnamed stock which includes WFG whales that interbreed while migrating to the wintering grounds off Mexico.

The SC agreed that two stock structure hypotheses for gray whales are highly plausible: (1) Hypothesis 3a, in which a single EBS exists, comprised of three feeding groups (NFG, PCFG and WFG), with the WBS no longer considered extant; and (2) Hypothesis 5a, in which two breeding stocks exist (EBS and WBS), with the EBS consisting of the PCFG, NFG and some of the WFG whales, all of which overwinter in Mexican waters, and the WBS consisting of whales that feed in the western North Pacific (Sakhalin Island, southern Kamchatka and the northern Kuril Islands, and other areas of the Okhotsk Sea) and overwinter in the South China Sea and Vietnam. The SC also identified four additional stock structure hypotheses or variants of medium plausibility (3b, 3c, 3e and 6b) to be considered when evaluating stock status – see IWC (2021) Annex G for details.

In 2020, the SC reviewed new genetic studies and agreed that: (a) hypotheses 4a and 7a should replace hypotheses 3a and 5a as high-plausibility stock structure hypotheses; and (b) hypotheses 4b, 4c, and 4e should replace 3b, 3c and 3e as medium-plausibility hypotheses during IRs (IWC, 2022). While hypotheses 3a (and variants) and 5a consider the WFG whales that migrate to Mexico to be a feeding group of the EBS, the replacement stock structure hypotheses (4a, 4b, 4c, 4e and 7a) all consider the WFG as a separate breeding stock which uses the wintering grounds of Mexico. Given this approach does not model gene flow, the replacement hypotheses were equivalent to those previously considered highly plausible for the purposes of modeling, and thus these changes did not lead to the need for additional simulation trials in 2020. Overall, the SC agreed that these changes in stock structure plausibility would not alter its existing advice with respect to the suitability of either the Gray Whale SLA or Makah Management Plan for the provision of advice on the Chukotkan hunt and proposed Makah hunt (IWC, 2021). There have been no additional changes to gray whale stock structure hypotheses and no new studies showing a need for changes since the 2020 IR.

## UPDATES ON GRAY WHALE ABUNDANCE AND CALF COUNTS

### Eastern breeding stock

The Southwest Fisheries Science Center (SWFSC) of NOAA (USA) conducts periodic surveys of the abundance of gray whales during their southbound migration off central California. It is worth noting that this survey includes the NFG, PCFG and either some or all of the WFG (depending on stock structure hypothesis). Surveys have been conducted since the winter of 1967/68, providing a long-term dataset for evaluating EME trends and magnitude (Fig. 1). The SWFSC has produced two new abundance estimates (Stewart and Weller, 2021; Eguchi *et al.*, 2022b) since the last IR, which coincide with the current EME. Prior to the EME, the most recent abundance estimate was 26,960 (95% CI 24,420-29,830) during 2015/16 (Durban *et al*., 2017). Estimates during the EME declined to 20,580 (95% credible interval 18,700–22,870) during 2019/20 (Stewart and Weller, 2021). The 2021/22 survey showed further decline with an estimate of 16,650 (95% credible interval 15,170–18,335)[15] (Eguchi *et al.*, 2022b). The median of the calculated decline between the 2015/16 and 2021/22 estimates from posterior samples was 37.4% (95% credible interval 33.1–41.7% decline). The mean decline was 37.3%.[16] The population dynamics model presented in Stewart *et al*. (2023), integrating all available abundance and vital rate time series, estimates a recent abundance high of 23,619 (95% credible interval 22,830–24,429) in 2018 and a low of 18,027 (95% credible interval 16,942–19,074) in 2023, corresponding to a 23.7% (95% credible interval 20.3–27.2%) decrease in abundance.

The EBS has experienced at least one previous EME in 1999/2000 (Gulland *et al.*, 2005). This EME resulted in a 22.6% decline in median abundance estimates from shore-based surveys conducted during the southward migration of gray whales in 1997/98 and 2000/01 (Eguchi *et al*., 2022b). The Stewart *et al.* (2023) population

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[15] NOAA SWFSC conducted a survey of gray whale abundance during the winter of 2022/23 (Eguchi *et al.*, 2023). This work was published after this paper was prepared and conclusions were agreed by co-authors.

[16] Each successive survey uses the abundance estimation technique developed by Durban *et al.* (2015) to update the parameters in previous estimates. The resultant revised abundance estimate for 2015/16 was 26,640 (95% CI = 24,310–29,161), compared to 26,960 (95% CI = 24,420–29,830) as reported in Eguchi *et al.* (2022b), which kept the estimates for previous years the same as in past reports.

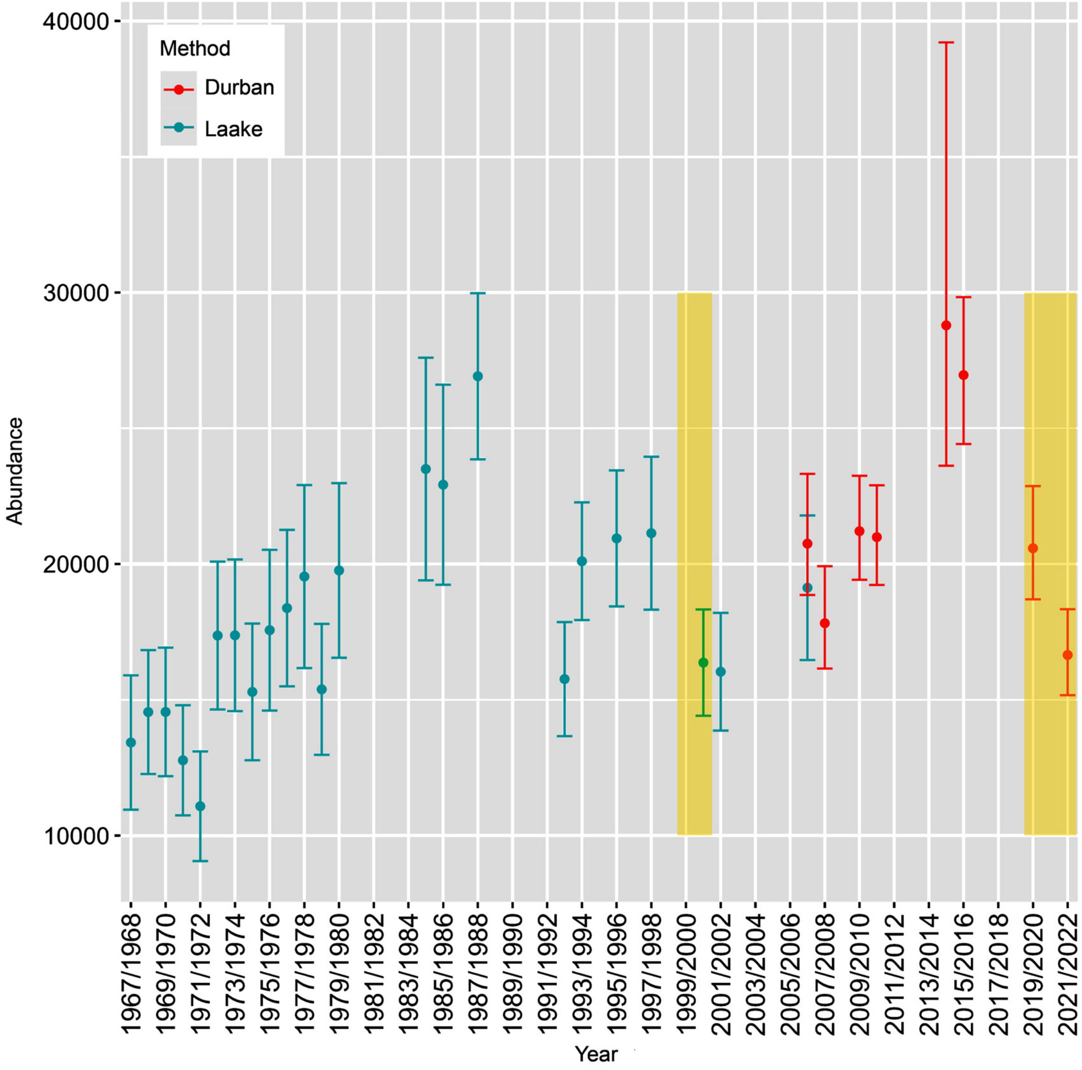

Fig. 1. Time series of abundance estimates of EBS gray whales informed by counts conducted at Granite Canyon, California, during the southbound migration. Highlighted counts show the documented EMEs during 1999–2000 and 2019–present. Estimates in blue are from Laake *et al*. (2012) and report 95% confidence intervals, and estimates in red use methods developed by Durban *et al*. (2015) and present 95% credible intervals. (Adapted from Eguchi *et al*., 2023).

dynamics model estimated a slightly smaller decline of 16.1% (95% credible interval 13.3–18.9%). Examining the time series of abundance estimates (Fig. 1), an EME could also have occurred between 1987/88 and 1992/93 when the population is estimated to have declined 41.5% from an estimated abundance of 26,916 (95% confidence limit 23,856–29,976) to 15,762 (95% confidence limits 13,661–17,863). The Stewart *et al*. (2023) model estimated a smaller but still substantial decline of 19.1% (95% credible interval 14.0–24.3%) between 1987 and 1990. As noted below, elevated numbers of reported strandings of gray whales along the USA's West Coast were not reported concurrent with this decline.

The estimate of abundance in 1993/94 was 20,100 (greater than the upper 95% confidence interval for the 1992/93 estimate). This rapid recovery seems implausible based on known population processes and observed gray whale reproductive output. Some other underlying process(es) may therefore be leading to interannual variability that is insufficiently captured by the abundance survey, such as variability in the proportion of the gray whale population that annually migrates past and close enough to the counting station at Granite Canyon, California. Indeed, the SC has long recognised the likely existence of extra variation ('process error') in the time series of abundance estimates, which has presented challenges to population dynamics modeling, despite efforts to address this aspect of the data (Punt and Wade, 2012). This variation is accounted for in the integrated analysis presented in Stewart *et al*. (2023), which generally estimates less extreme abundance values that are informed by both the Granite Canyon abundance surveys and other time series of vital rates. It should be noted that gray whale abundance quickly recovered following each of the large declines documented between 1987–1993 and 1997–2001, showing the resilience of the gray whale population to past EME events (Stewart *et al*., 2023).

The SWFSC has conducted annual surveys to count the number of mother-calf pairs on their northward migration at Piedras Blancas, California, since 1994, except in 2020 due to the COVID-19 pandemic (Eguchi *et al*., 2022a). During the recent EME, the estimated numbers of calves were some of the lowest in the time series, including 2022 which was the lowest on record. Christiansen *et al*. (2021) hypothesised that the poor body condition of EBS gray whales during the current EME has likely resulted in reduced reproductive output by increasing the post-weaning recovery time of reproductive females. The time series also shows low EBS calf production in the past during the 1999/2000 EME, corroborating the hypothesis of Christiansen *et al.* (2021). However, the time series also shows low EBS calf production during 2007 through 2010, a period not associated with any EME (Fig. 2).

## Pacific Coast feeding group

Several independent researchers provide photographs of gray whales collected along the Pacific Ocean coastlines of the USA and Canada to compare with Cascadia Research Collective's catalogue of known PCFG whales. The

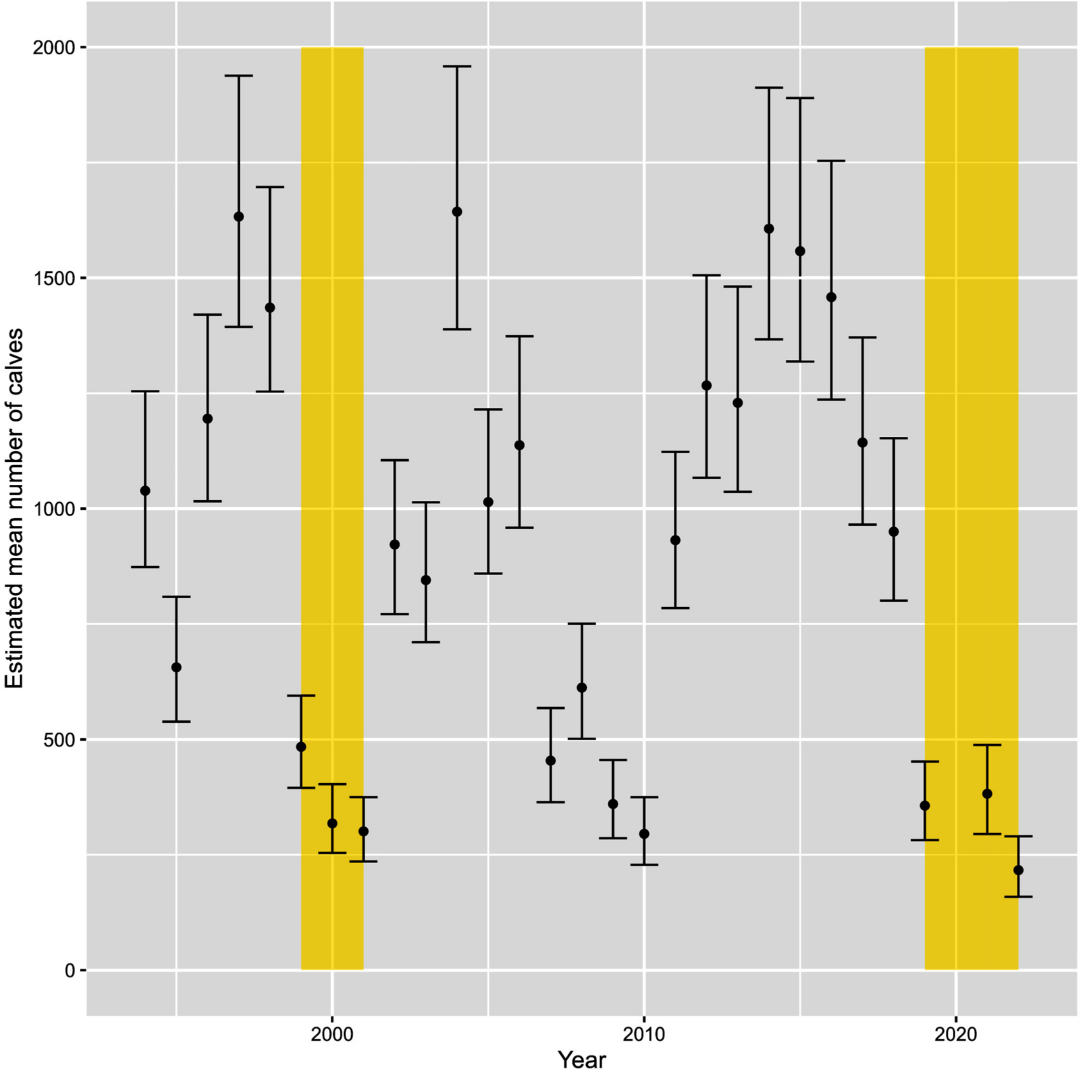

Fig. 2. Annual estimates of EBS gray whale calf production with associated 95% confidence intervals. Yellow vertical bars indicate documented EMEs. (Source: Eguchi *et al*., 2022a).

resulting photo ID-capture histories inform PCFG annual mark-recapture abundance estimates calculated by NOAA's Alaska Fisheries Science Centre. The most recent update on PCFG abundance was provided by Harris *et al*. (2022) using survey data from 1996-2020. Abundance estimates from 1996 and 1997 are known to be biased due to the rapid discovery of 'new' individuals that were likely long-term members of the feeding group. Thus, only estimates from 1998 onward are considered for management purposes (Laake, 2012). The PCFG time series of abundance estimates peaked in 2015 at 257 (standard error (SE) = 17.9), before declining to the most recent estimate of 212 (SE = 17.9) in 2020, an estimated 17.5% reduction in abundance (Fig. 3; Harris *et al*., 2022).

The start of this decline in PCFG abundance preceded the current EME of EBS gray whales and may show the PCFG response to the 2014–2016 marine heatwave (Peterson *et al*., 2017; Khangaonkar *et al*., 2021; Maniscalco, 2023). The marine heatwave has also been implicated in affecting the ecology of kelp forests, in part through the rapid increase in purple urchin populations (Rogers-Bennett and Catton, 2019; McPherson *et al*., 2021). Kelp canopy cover is positively correlated with gray whale body condition in Washington (Akmajian *et al*., 2021). One hypothesis is that the decline of kelp forests due to the marine heat wave and the increase in urchin populations could potentially have been a detriment to prey populations of PCFG gray whales. Alternatively, given that the PCFG abundance estimate is based on a mark-recapture approach, it is possible that recent declines of abundance

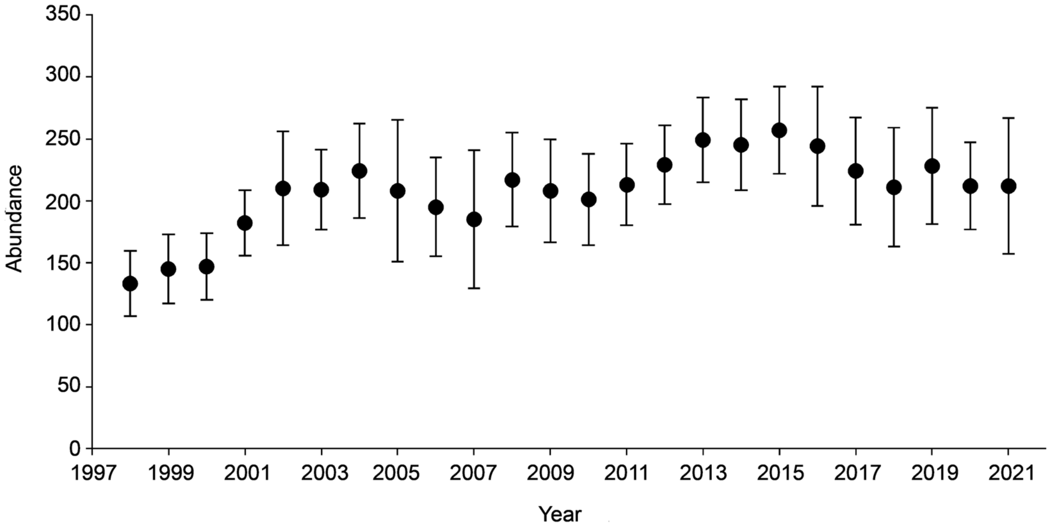

Fig. 3. Time series of model-averaged estimates of PCFG whale abundance from a modified Jolly-Seber mark-recapture population estimator. Error bars are 95% confidence intervals. Figure adapted from Harris *et al*. (2022).

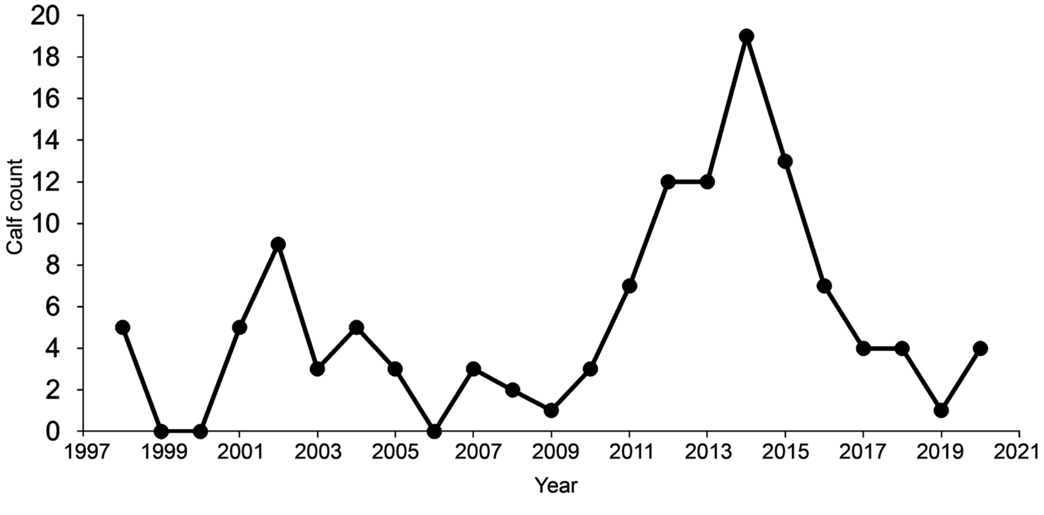

Fig. 4. Annual number of calves observed in the PCFG range during the feeding season of June through November. Figure adapted from Harris *et al*. (2022).

were an artefact of reduced spatial coverage of surveys, particularly in the northern portion of the PCFG range, or perhaps due to a different spatial arrangement of whales as compared with the past.

Researchers record observations of calves during surveys of the PCFG. Discriminating between gray whale calves and juveniles while on the feeding grounds can be difficult, particularly once independent of their mother (Bradford *et al*., 2011). As a result, observations of calves likely underestimate the number born into the PCFG each year. Uncorrected calf counts from PCFG surveys show a spike of calf production from 2012-2015 and indicate that calf production was relatively constant during the rest of the time series (Fig. 4). Recent calf counts have been low but are similar to counts during 1998–2010. The periods of high and low calf counts are similar between the PCFG and the broader EBS.

## Western feeding group and Western breeding stock

Cooke (2018) produced abundance estimates for gray whales observed in the area around Sakhalin Island and Kamchatka organised by stock structure hypothesis (Fig. 5). No new abundance estimates are available to assess whether the WFG or WBS have been affected by the current EME. Reports by researchers at Sakhalin Island and Kamchatka show that calf counts were high during the years of the current EME, including the highest calf count on record (since 1994, when the study began) in 2019 and the second highest in 2021 (Fig. 6; Burdin *et al*., 2023). The high occurrence of calves is in stark contrast to the low calf estimates in the EBS during similar years, suggesting that the WBS/WFG are not affected by the current EME. However, the number of gray whales observed at Sakhalin Island during surveys in 2023 was much reduced compared to previous years (Burdin *et al*., 2023). Continued monitoring is essential.

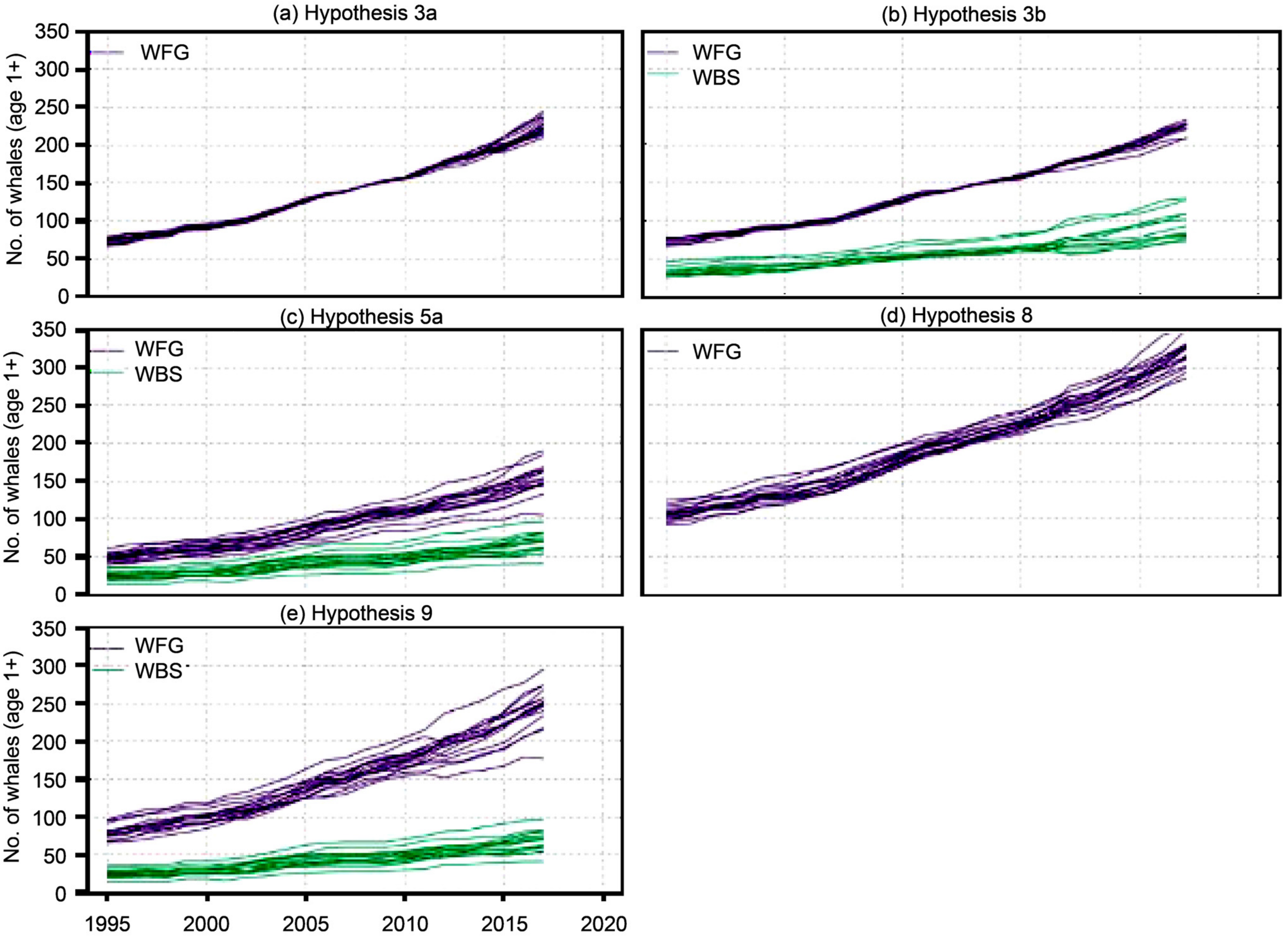

Fig. 5. Posterior samples of population trajectories for the WFG (purple lines) and WBS (green lines) by stock structure hypothesis as calculated by Cooke (2018). Note: hypothesis 3a would have the same population trajectory as 4a, 3b as 4b, and 5a as 7a. (Source: Cooke, 2018).

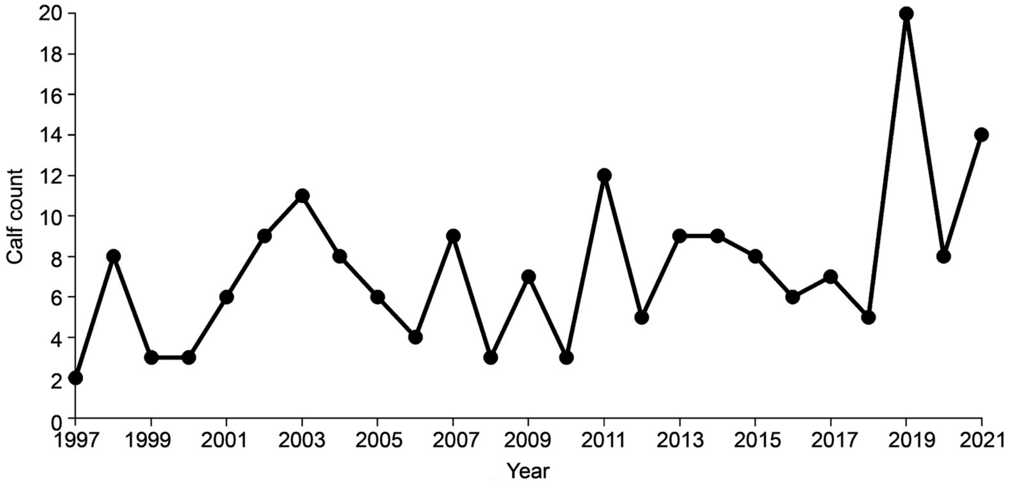

Fig. 6. Annual number of calves observed at Sakhalin Island. Figure adapted from Burdin *et al*. (2023).

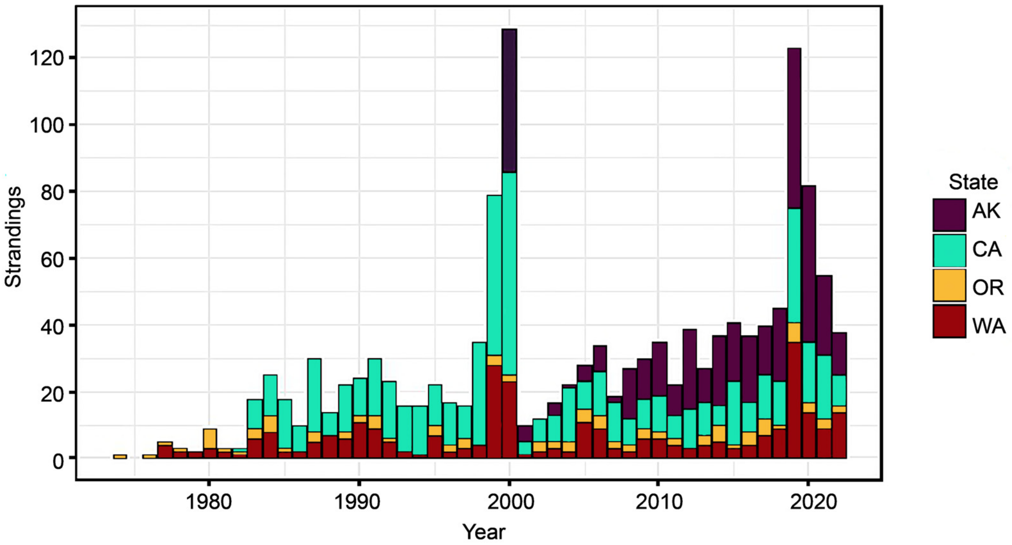

Fig. 7. Reports of gray whale strandings along the USA west coast from 1980-2022 and off Alaska during 2000–22 according to data in the USA National Stranding Database.

# GRAY WHALE HEALTH AND STRANDINGS

## Gray whale strandings

Gray whales strand throughout their range (Brownell *et al*., 2007; Kato *et al*., 2016; Lowry *et al*., 2018; Martínez-Aguilar *et al*., 2023; Fauquier *et al*., 2023). Monitoring of marine mammal strandings has been consistently conducted along the USA's West Coast (California, Oregon and Washington) since the early 1980s and since 2000 off Alaska. In reviewing stranding data collected in the USA, EMEs were recognisable by periods of elevated reports of strandings, as seen during 1999/2000 and during 2019–present for data compiled in the USA National Stranding Database (Fig. 7).

The time series of abundance estimates also shows a large reduction in the estimated abundance of gray whales between surveys conducted during the winter of 1987/88 and 1992/93 (Fig. 1). The time series of strandings from the USA National Stranding Database shows a slightly elevated number of strandings along the USA West Coast of North America during that time, but not to the magnitude observed during the 1999/2000 EME or the current EME (Fig. 7). However, survey effort to detect strandings and related reporting structures were expanded and improved markedly in 1990, indicating that stranding rates pre-1990 may not be comparable to post-1990.

Another dataset, compiled by Brownell *et al*. (2007), incorporates stranding records from Mexico, the USA West Coast and Alaska starting in the mid-1970s and includes many reports that are not included in the USA National Stranding Database. Brownell *et al*. (2007) found that the number of strandings was 265 whales during the three-year period of 1989, 1990 and 1991. The total number of strandings was much fewer during the three-year period before 1989 (n = 105) and after 1991 (n = 125), suggesting that a mortality event occurred during the years 1989–1991. Despite the elevated number of strandings between 1989–1991 relative to adjacent three-year periods, the magnitude of elevation was not as large as observed during the 1999/2000 EME (Brownell *et al*., 2007). In addition, the population dynamics model for EBS gray whales presented by Stewart *et al*. (2023) estimates a significant population decline starting in 1989, similar in magnitude to the 1999 and 2019 EMEs and reflected in declines in both abundance and body condition.

Examinations of strandings at the wintering lagoons in Mexico have documented an overall increase in strandings during the recent EME, as well as a change in the age composition of stranded whales (Martínez-Aguilar *et al*., 2023). During 2019 and 2020, the number of stranded gray whales was substantially elevated, roughly three-fold, compared with the numbers observed in 2017 and 2018 prior to the 2019 EME. The number of stranded whales remained elevated during 2021 and 2022, but to a lesser degree than was observed during 2019 and 2020. The number of stranded whales observed during 2023 was similar to the number of strandings observed during 2017 and 2018. Between 2019–22, the majority of stranded whales were sub-adult or adult whales. During 2023, calves were the most common age group of stranded whales, which is the typical age class of stranded whales in non-EME years (Martínez-Aguilar *et al*., 2023).

## Observations of gray whale body condition

Body condition is a useful indicator of foraging success and health in whales (Lockyer, 1986; George *et al*., 2015; Pettis *et al*., 2017; Stewart *et al*., 2021). Numerous studies have been conducted on the body condition of gray whales of the EBS. Akmajian *et al*. (2021) evaluated the body condition of PCFG gray whales observed off northern Washington and southern Vancouver Island, British Columbia, between 1996–2013, using boat-based photographs of whales, following the approach developed by Bradford *et al*. (2012). Body condition was found to be variable by year and improves through the feeding season, but not at the same rate every year. Accounting for the impact of environmental factors, particularly the Pacific Decadal Oscillation, significantly improved the ability of regression models to predict body condition in a given year. Lemos *et al*. (2020) evaluated the body condition of PCFG whales observed off the central Oregon coast between 2016–18 using aerial drone photogrammetry. Like Akmajian *et al*. (2021), they found that body condition improved through the feeding season and was variable by year. Lemos *et al*. (2020) hypothesised that significantly greater upwelling observed on the Oregon coast between 2013–15, compared with observations of upwelling during 2016–2018, led to greater prey availability and better body condition in 2016 than between 2017–18. Torres *et al*. (2022) also evaluated the drone-derived body condition of PCFG gray whales observed off Oregon and found that their body condition improved each year from 2017 to 2019. The authors hypothesised that the improving trend in body condition was related to the recovery of prey resources following a marine heatwave that affected the region during 2014–16 (Peterson *et al*., 2017; Jones *et al*., 2018; Thompson *et al*., 2018). The conclusions of Lemos *et al*. (2020) and Torres *et al*. (2022) are somewhat conflicting, with the latter implying that environmental conditions (namely the marine heat wave) were worse for gray whales prior to 2017, whereas the former reported that upwelling conditions were better for whales in the same area in 2016 than 2017-18. Regardless of the causal mechanism, the three studies on PCFG gray whales showed that body condition is annually variable, improves through the feeding season, but not at the same rate each year, and is likely linked to environmental variables that govern productivity of the prey base.

Studies of gray whale body condition in the wintering lagoons of Baja California, Mexico, have documented a significant decline in body condition coincident with the start of the EME in 2019 (Ronzón-Contreras *et al*., 2019, 2020, 2021; Christiansen *et al*., 2021; Valerio-Conchas *et al*., 2022, 2023; Torres *et al*., 2022). Aerial drone photogrammetry showed that body condition in this region was significantly worse between 2018–19 than in 2017 (Christiansen *et al*., 2021). Using the methods developed by Bradford *et al*. (2012) for analysing boat-based photographs, Ronzón-Contreras *et al.* (2021) and Valerio-Conchas *et al.* (2022, 2023) documented that the proportion of single whales and lactating females in poor and fair condition was much greater during the EME than in prior years. Ronzón-Contreras *et al*. (2021) reported that the percentage of single whales observed in poor body condition ranged from 4.9–7.6% during 2008–11, prior to the EME, while this percentage ranged from 19.5-30.0% during the 2022 EME years (Valerio-Conchas *et al*., 2022). Observations during 2023 showed marked improvements in body condition, with 70.0% of the single whales observed in good condition and 8.8% in poor condition (Valerio-Conchas *et al*., 2023). There were also roughly twice as many mother-calf pairs observed during 2023 than during any year from 2019 through 2020–22 (Valerio-Conchas *et al*., 2023). The observed patterns of improving body condition during 2023 and increased observations of mother-calf pairs may signal that the effects of the 2019 EME are starting to abate.

Stewart *et al*. (2023) found that fluctuations in the body condition (recorded by aerial photogrammetry) of southbound migrating gray whales were synchronous with changes in calf production rates, strandings rates and changes in abundance. Body condition of northbound migrating gray whales (mostly females with dependent calves) was also largely synchronous with fluctuations in other vital rates but had more deviations from the overall trend than southbound body condition. The two EMEs beginning in 1999 and 2019, and the putative EME beginning in 1987 (Stewart *et al.*, 2023), are all associated with declines in body condition. Body condition declines associated with the first two EMEs were rapid, whereas, in the most recent EME, the body condition decline began several years before major increases in mortality began.

Bradford *et al*. (2012) studied gray whale body condition at Sakhalin Island, Russia, from 1997-2007. They found that gray whale body condition improved through the feeding season and that overall body condition was significantly better or worse in particular years. No new data on the body condition of gray whales at Sakhalin Island or Kamchatka are available.

Comparisons of gray whale body condition as a function of feeding region have produced some insightful results. Akmajian *et al*. (2021) compared their results to Bradford *et al*. (2012) and drew the following conclusions: (1) the years of better and worse body condition were not the same for the two study areas; and (2) the rate of improvement in body condition during the feeding season was much greater for whales feeding at Sakhalin than PCFG whales, suggesting better quality or availability of prey at Sakhalin Island. Torres *et al*. (2022) compared the body condition of PCFG whales with whales photographed in San Ignacio Lagoon and in the north-western Chukchi Sea, concluding that PCFG whales had significantly worse body condition than other EBS whales during most years. The body condition of PCFG whales was worse than San Ignacio Lagoon whales until 2019, when the EME affected the body condition of whales at San Ignacio Lagoon (Christiansen *et al*., 2021).

## Stinky gray whales in Chukotka

The occurrence of stinky whales has been known since the 1960s, with increased reporting of these whales starting during the late 1990s (Rowles and Ilyashenko, 2007). Many hypotheses have been proposed for the source of the strong medicinal odour; there was concern that the smell was due to anthropogenic sources. A new analysis by Polyakova *et al*. (2022) determined that the strong medicinal smell in whales hunted in 2020 was caused by bromophenols, especially 2,6 dibromophenol. The observation that polychaetes have high levels of bromophenols led the authors to conclude that the strong medicinal smell in gray whales was due to a natural source, specifically the proportion of polychaetes in the diet. The finding that the strong medicinal smell is from a natural origin helps eliminate hypotheses of pollution and biotoxins causing the condition and show that the stinky whale phenomenon is not likely linked with conditions causing the past or current EMEs.

## Post-mortem examinations of gray whales during recent EME

To date, post-mortem examinations have not found a definitive cause for any gray whale EMEs. The varied results of necropsy reports suggest that EMEs may be caused by multifactorial drivers that can in some cases lead to increased killer whale predation, vessel strikes, entanglements and poor nutritive condition (Raverty *et al*., 2020; Fauquier *et al*., 2022, 2023). During the current EME, 61 gray whales had a partial or complete post-mortem examination (Fauquier *et al*., 2023). Of the 61 examinations, 33 identified findings that contributed to the whale's death. Of these 33 cases, 16 (48.5%) were associated with emaciation as a contributing factor; 11 cases (33.3%;

two of which were also emaciated) had evidence of a vessel strike, three (9.1%) had evidence of being killed by killer whales, two (6.1%) died due to entanglement, and one (3.0%) died due to entrapment. No cause of death could be determined for 28 cases. Using a proportional hazards model to estimate anthropogenic versus natural mortality rates based on the occurrence of human interactions in stranded EBS gray whales, Stewart *et al*. (2023) estimated low and stable rates of direct anthropogenic mortality from 1967-2022 (i.e., vessel strikes and fishing gear entanglements), and periodic major increases in natural mortality rates during the three EMEs.

Disease and harmful algal bloom toxin screening has largely proved inconclusive when identifying cause of death during EMEs (Fauquier *et al*., 2023). PCR examination of tissue samples from 25 gray whales tested negative for morbillivirus, influenza viruses and coronaviruses. Samples from 13 whales were screened by metagenomic viral sequencing. No known or novel viruses were identified. Nine whales had metagenomic bacterial screening, and three whales tested positive for *Brucella sp*., but none of these whales had lesions identified during necropsy that were consistent with a Brucella infection. Samples from 57 whales were tested for biotoxins from harmful algal blooms. High concentrations (> 1,000 ng/ml) of domoic acid were detected in three of 55 samples (5.5%). However, the toxic threshold of domoic acid in cetaceans is not well known (Lefebvre *et al*., 2016), and it is therefore uncertain if the high concentrations observed contributed to the death of the whales. None of the 35 samples tested for saxitoxin had high concentrations. The largest challenge in identifying diseases in dead gray whales is the rapid decomposition of internal tissues and a general lack of fresh carcasses suitable for histopathology.

The occurrence of poor body condition and emaciation among some stranded whales suggests that starvation could be a partial cause for the elevated numbers of strandings (Fauquier *et al*., 2022, 2023). Similar to the 1999–2000 event, the underlying cause of poor body condition and potential starvation is not known (Gulland *et al*., 2005). However, recent modelling by Stewart *et al*. (2023) found a significant positive relationship between annual carrying capacity and both Arctic crustacean biomass and sea ice-mediated access to foraging areas, suggesting the ability of ENP gray whales to physically access feeding areas, combined with in-situ prey availability, explains fluctuations in body condition, reproduction and mortality.

## Summary of gray whale health

The large EME of gray whales that started in 2019 is of concern and is having observable effects on the number of strandings and body condition of gray whales (Christiansen *et al*., 2021; Fauquier *et al*., 2023; Valerio-Conchas *et al*., 2023). To date, it appears that the EME is only affecting the NFG of the EBS. There is no evidence that the EME is similarly affecting the number of strandings and body condition of PCFG whales. However, the PCFG has experienced a lesser decline in abundance than the larger EBS that is slightly out of phase temporally with the EME (Harris *et al*., 2022; Punt *et al*., 2023). There are no studies reporting observations of strandings or changes in body condition of WBS and/or WFG whales during the years of the current EME making it hard to assess if the EME is affecting the health of WBS and/or WFG whales. However, the record-high calf counts at Sakhalin Island while the EBS was experiencing record low counts is a line of evidence to suggest that the current EME has not affected WBS and/or WFG whales. The leading hypothesis for the current EME is that shifts in ecosystem productivity on the northern feeding grounds have led to increased nutritional stress for whales, making them more vulnerable to other sources of mortality or has directly led to starvation. This hypothesis is very similar to the proposed cause of the 1999/2000 EME of ecosystem shifts leading to poor feeding conditions for gray whales (Le Boeuf *et al*., 2000; Gulland *et al*., 2005; Gulland, 2013). Two studies support this hypothesis: first, Moore *et al*. (2022) documented shifts in gray whale distribution in the Arctic due to climatic and sea ice changes that led to shifts in prey production; and second, Stewart *et al*. (2023) conducted an integrated analysis of gray whale population dynamics and found annual variability in the number of gray whales supported by the Arctic ecosystem, and that the ecosystem was not able to support the full abundance of the population during the current EME.

The current EME may not have affected Arctic feeding areas equally. Sidorov *et al*. (2022) reported no observable changes in gray whale abundance and condition off Chukotka, suggesting that the conditions causing the EME may not be affecting the Chukotkan hunt area in the central/western North Pacific. Support for this hypothesis comes from studies that found some gray whales show fidelity to the coast of Chukotka (Heide-Jørgensen *et al*., 2012; Filatova *et al*., 2022) and are therefore most likely to be affected by environmental conditions in that region.

Observations of improved body condition and reduced strandings in 2023 compared with 2019-22 show promising signs that the most recent EME may be reaching a conclusion. However, continued monitoring is vital for documenting the full temporal extent of the EME and evaluating the recovery and population status of the ENP gray whale population. The relevance of the observations of gray whale health monitoring and EMEs to the gray whale IR is presented below in the section titled 'Future Episodic Mortality Events'.

# HUMAN-CAUSED MORTALITIES

## Aboriginal harvest

Under the IWC, the USA and Russia Federation share a catch limit of 140 gray whale strikes per year and a total of 980 strikes per six-year block management period. Currently, hunts are only conducted in Russia. The proposed Makah hunt, requiring a waiver of the USA Marine Mammal Protection Act, is being considered by the USA Government.

Hunting in Russia is conducted by Chukotkan natives along the shores of the Chukotka Peninsula. From 2018 through 2022, Chukotkan hunts averaged 126.4 strikes (SD = 11.7) of gray whales per year (Zharikov *et al*., 2019; Zharikov *et al*., 2020; Sidorov *et al*., 2021, 2022, 2023). The Aboriginal Whaling Scheme allows unused portions of the catch limit to be carried forward and used in a future year (IWC, 2019c), and this scheme was tested for robustness to gray whale hunts in Chukotka and was found to improve access to whales by Chukotkan hunters while still meeting the IWC's conservation objectives (Punt, 2020; IWC, 2021).

The Makah Tribe reserved their right to harvest whales in the 1855 Treaty of Neah Bay with the USA Government. The Makah Tribe utilised this treaty right and whaled until the 1920s. Whaling activities were suspended around 1929 due to the low abundance of whales caused by unregulated commercial whaling (Renker, 2018). The Makah Tribe asserted its desire to resume whale hunting in the mid-1990s following the recovery of the EBS gray whale population and its delisting from the USA endangered species list in 1994. The Makah Tribe had hunts permitted by the USA and the IWC in 1999 and 2000 and conducted one successful whale hunt in 1999. In 2000, hunting activities were stopped while a USA court of law reviewed the hunt. A final ruling was made in 2004 requiring the Makah Tribe to apply for a waiver of the moratorium on takes imposed by the USA Marine Mammal Protection Act before it could resume hunting. The Makah Tribe submitted an application for a waiver in 2005 and the USA Government is still in the process of reviewing the request. Details on the waiver application and the review by the USA Government are available here.

## Non-hunting human-caused mortality

The primary sources of non-hunting human-caused serious-injury and mortality (NHHCSM) for gray whales are vessel strikes and entanglements in fishing gear, but occasionally entanglements occur in other marine debris or human made structures (Scordino *et al*., 2020). Scordino *et al*. (2020) presented all known cases of gray whale NHHCSM from 1924-2018 in the North Pacific Ocean, based on data from national stranding databases, national bycatch and vessel strike databases, published reports and manuscripts, national reports to the IWC, and newspaper articles. The IR in 2020 used data from Scordino *et al*. (2020) to inform an estimate of NHHCSM (termed 'bycatch' in the model) by area and year throughout the gray whale range. The SC recognised that the data compiled by Scordino *et al*. (2020) were an underestimate of the true mortality of gray whales due to NHHCSM because of under-reporting, e.g., cryptic mortality. To address this, the base case of the model multiplied all known mortalities due to NHHCSM by a factor of four (cases of serious injury were excluded from the analysis). The factor of four was chosen using estimated recovery rates for coastal bottlenose dolphins (Carretta *et al*., 2016) because both species spend most of their time close to shore.

The SC also evaluated three other approaches to account for NHHCSM in modeling for the IR. The approaches were: (1) adding together prorated mortalities from serious injuries with observed mortalities; (2) a multiplier of 10× observed NHHCSM mortalities; and (3) a multiplier of 20× observed NHHCSM mortalities. The 10× and

20× scenarios were based on the finding in Punt and Wade (2012) that an estimated 3.9–13.0% of whales dying during the 1999/2000 EME were observed during stranding response and documented by Gulland *et al*. (2005). Stewart *et al*. (2023) estimated that before 1990, when the reporting structure for stranding records was improved, approximately 1.3% (1.1–1.6%) of gray whales that died were reported as strandings in the USA National Stranding Database. In contrast, after improvements in 1990, they estimated that approximately 4.5% (4.2–5.1%) of whales that died were reported as strandings. The smaller estimated proportion of dead whales recovered as strandings used by Stewart *et al*. (2023) compared to Punt and Wade (2012) is likely because the former only included strandings reported in the USA whereas the latter estimate included strandings from Mexico, the USA and Canada. The Punt and Wade (2012) and Stewart *et al*. (2023) estimates of carcass recovery may not be the best estimates to use for multipliers of cryptic NHHCSM mortality because they are based on single-stock models that do not attempt to model the full range-wide dynamics across western and eastern breeding and feeding groups. Trials with a multiplier of 20x observed NHHCSM resulted in IWC range-wide model results that were not consistent with observations in the multi-stock population dynamics model, and these trials (and the associated multiplier) were therefore considered to have low plausibility (IWC, 2018).

Scordino *et al*. (2023) provided an update on NHHCSM since the last IR with new data from 2019–21. Contributions to this effort were provided by scientists from the USA, Japan, Korea, Canada and Mexico. Table 1 includes the annual average NHHCSM observed mortalities from 2009-18 by region used in the last IR and the new data from 2019-21 for comparison. The average number of observed mortalities per year due to NHHCSM in the North Pacific has increased to 6.7 whales/year during 2019–21, compared with 3.9 whales/year from the previous 10 years of data collection (2009–18). This change was driven by increased numbers of whale mortalities reported for California and across the PCFG range. The average annual number of observed dead whales plus prorated serious injuries for the North Pacific were very similar between the periods 2009–18 and 2019–21, 11.03 and 11.69 whales/year respectively. Based on the new data collected since the previous IR (Table 1; Scordino *et al*., 2023), there is no evidence that recent levels of bycatch and vessel strikes are outside the parameter space modeled in the 2020 IR.

Table 1

Observed non-hunting human-caused serious injuries and mortalities by region for gray whales in 2009–18 and 2019–21, reported in Scordino *et al*. (2023).

| | Observed dead | | Dead + serious injury | |
|---|---|---|---|---|
| Region | 2009–18 | 2019–21 | 2009–18 | 2019–21 |
| Alaska | 0 | 0 | 0 | 0 |
| California | 21 | 12 | 68.55 | 20.25 |
| Eastern Sea of Japan and Pacific Coast of Japan | 0 | 0 | 0 | 0 |
| Northern Feeding Grounds | 1 | 0 | 4.25 | 0 |
| Kodiak | 0 | 0 | 0 | 0 |
| Mexico | 0 | 0 | 2.25 | 0 |
| Northern British Columbia-Northern California (PCFG Range) | 13 | 7 | 27.27 | 11.75 |
| Puget Sound | 2 | 1 | 2.75 | 1.56 |
| Southeast Alaska | 0 | 0 | 3.25 | 1.5 |
| Sakhalin Island | 1 | 0 | 1 | 0 |
| Vietnam and South China Sea | 1 | 0 | 1 | 0 |
| Average per year | 6.67 | 3.9 | 11.03 | 11.69 |

## POPULATION GROWTH RATES

Punt and Wade (2012) developed an age- and sex-structured population dynamics model to evaluate the status of EBS gray whales. They found that the best estimate of the maximum sustainable yield rate (MSYR) was 4.6% (posterior 90% interval 2.2–6.4%). Based on the findings of Punt and Wade (2012), the SC chose to use 4.5% as the MSYR for the base case of IR trials in 2020 for NFG, PCFG and WFG gray whales. Evaluation trials included a lower MSYR of 2% and a higher MSYR of 5.5% for PCFG whales. Some evaluation trials used estimates of MSYR by feeding area based on treating MSYR as an estimable parameter, while another trial used a common estimated MSYR for all gray whales.

No new data were collected since the 2020 IR to suggest that the estimate of Punt and Wade (2012) needs revision. Although Torres *et al*. (2022) found that PCFG whales often have poorer body condition than other EBS gray whales and suggested that they have lower reproductive potential, this was already accounted for in the 2020 IR which included trials with an MSYR of 2% for PCFG whales.

## IMMIGRATION INTO THE PCFG

The population dynamics of the PCFG appear to be influenced by both internal recruitment through the addition of calves belonging to members of the feeding group and through immigration of non-calf whales likely from the NFG (Lang and Martien, 2012; Weller *et al*., 2013). The PCFG experienced a rapid increase in abundance during the late 1990s and early 2000s, which is not explainable by survey bias (Laake, 2012) or calf production alone, suggesting a pulse of immigration. This pulse of immigration corresponds with apparent poor feeding conditions on the northern feeding grounds as indicated by the 1999/2000 EME (Gulland *et al*., 2005). The modeling base case for the 2020 IR included a pulse of 20 additional immigrants per year during 1999 and 2000. Evaluation trials were also conducted with 10 and 40 additional immigrants per year (IWC, 2021).

Photo-identification surveys regularly observe new non-calves in the PCFG (Harris *et al*., 2022), which suggests some level of regular immigration into the PCFG. However, some of these new non-calves may be calves that had been born in a previous year to a PCFG female but were not detected in the PCFG during the year of their birth, or they could have been a calf when first detected but not classified as a calf. Lang and Martien (2012) used computer simulations to evaluate what amount of immigration is most consistent with the results of genetic analyses of samples collected from PCFG and NFG whales (Lang *et al*., 2014). They found that an immigration rate of one or fewer whales per year would produce genetic diversity within the PCFG and differentiation between the PCFG and NFG whales inconsistent with the empirical data. They found that an immigration rate of four whales per year was most plausible. The 2020 IR included immigration of two whales per year in the base case and evaluated trials with 0, 1 and 4 immigrants per year (IWC, 2021).

No new data have been collected to suggest that immigration rates modeled for the pulse of immigration between 1999–2000 or the annual immigration of new individuals are outside the parameter space tested during the 2020 IR.

## PARAMATERISATION OF THE MAKAH TRIBE’S GRAY WHALE HUNT

There is uncertainty about how the Makah hunt will operate both in terms of hunting and monitoring efficiency. Monitoring of the hunt for the Makah Management Plan requires photographing whales during the hunt and accurately matching the photographs of struck whales to catalogues of PCFG and WFG whales (IWC, 2019b). Parameters estimated for the range-wide review of gray whale stock structure and status and the 2020 IR included: probability of obtaining a photograph of suitable quality for matching a struck and lost whale; probability of struck and lost whales; false positive rate for matching of a PCFG or WFG whale (probability of being wrongly identified as a PCFG or WFG whale); false negative for matching a PCFG or WFG whale (probability a whale is a PCFG or WFG but is not matched to the respective catalogue); and probability of not assigning the sex of a whale identified as a PCFG whale. Estimates were made for each of these parameters based on expert opinion and review of available data (IWC, 2019b, 2020). Evaluation trials were included in the IR to evaluate false negative reporting rates of 0.1 (base case 0.25) for PCFG whales struck and photographed during the Makah whale hunt, and also for increasing the summer/fall struck-and-lost rate from 10% to 50% (IWC, 2019b, 2020).

Without a hunt occurring in recent history, there are no data to evaluate the assumptions and parameter space tested regarding the performance of the Makah hunt and monitoring programmes.

## FUTURE EPISODIC MORTALITY EVENTS

The 2020 IR included a trial with future EMEs that were scheduled to occur once at a random time in each 50-year time block of the 100-year projection period (IWC, 2021). The forecasted EMEs were simulated to have a similar magnitude of effect as the 1999/2000 event.

Recent observations on the magnitude of the EME that started in 2019, and the observation that EMEs are likely occurring more frequently than once every 50 years, show that the 2020 IR did not include trials that wholly encompassed the potential magnitude and frequency of future EMEs (Punt *et al*., 2023). The current observed EME magnitude and frequency are therefore outside the parameter space tested. Further, Stewart *et al*. (2023) demonstrates a relationship between EMEs, benthic crustacean biomass and access to feeding areas in the Arctic and suggest that benthic crustacean biomass has been in decline over the past 50 years. EMEs may therefore be more frequent in the future, or the average carrying capacity of Arctic feeding may be reduced, limiting the maximum abundance of the EBS gray whales. New model configurations are needed to evaluate more frequent and larger magnitude EMEs and reduced or fluctuating carrying capacities. Furthermore, more trials should be constructed that involve combining scenarios related to future EMEs with other factors, such as stock structure, immigration rates, productivity rates, survival rates, and rate of immigration into the PCFG, to assess the synergistic impacts of the parameters included in the other evaluation trials with future EMEs. Such combination trials are essential because EMEs no longer appear to be as unusual as previously thought, whereas, at the time the Gray Whale SLA was designed, it was uncertain whether another EME would occur (IWC, 2005).

## CONCLUSIONS

This review of newly collected data shows that, in almost all aspects, the current understanding of the biology and status of gray whales is within the parameter space tested in the 2020 IR. The major exception to that conclusion is how EMEs were modeled during development of the Gray Whale SLA, testing of the Makah Management Plan, and all previous IRs, compared with current observations. The EME that started in 2019 is of greater magnitude and longer duration than was considered in the 2020 IR. Furthermore, both the previous EME in 1999/2000 and the potential event during the late 1980s suggest that the previous approach of modeling one event every 50 years was insufficient. In response, preliminary modeling by Punt *et al*. (2023) included evaluation trials with two EMEs occurring every 50 years, with one event lasting two years (e.g., 1999/2000) and the next lasting four years (e.g., 2019-present EME), with the EMEs designed to replicate the magnitude of the 1999/2000 and the 2019-present events. These models suggested that the performances of the Gray Whale SLA and Makah Management Plan are likely robust to recent and future EMEs of NFG gray whales and reductions of productivity of the PCFG, at least under the initial parameterisations taken into account in that exploratory modeling. We conclude that there is no compelling need for a Special Implementation Review for gray whales prior to the regularly scheduled IR in 2026, noting however that additional abundance data for 2022/23 and 2023/24 analysed after drafting this paper could either strengthen or weaken the evidence for this conclusion before 2026. However, as EMEs and fluctuations in the carrying capacity of Arctic feeding may become more frequent in the future, new evaluation and robustness trial configurations are needed in future IRs to evaluate the impacts of these scenarios in combination with other factors, such as stock structure, population dynamics and immigration into the PCFG.

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