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Update on gray whale status since 2020 implementation review

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Introduction

The Scientific Committee (SC) of the International Whaling Commission (IWC) conducts regular reviews (termed *Implementation Reviews*) of the biology, removals, and status of whale species subject to aboriginal subsistence whale (ASW) hunts, with reviews normally occurring every six years (International Whaling Commission, 2019). The SC can call for a special *Implementation Review* to occur sooner than every six years if new information on the biology, removals, or status of the species gives the SC concern about the sustainability of ASW hunts (International Whaling Commission, 2019). For instance, in 2010 the SC called for a special implementation review for gray whales because a newly published study reported on genetic differences between Pacific Coast Feeding Group (PCFG) whales and other gray whales of the Eastern North Pacific breeding stock (EBS) (International Whaling Commission, 2011). This created a concern that the proposed hunt by the Makah Tribe could have disproportionate impacts on the PCFG. The most recent gray whale *Implementation Review* (IR) was completed in 2020 utilizing a modeling structure developed during the Rangewide Review of Gray Whale Stock Structure and Status (RRGW) (International Whaling Commission, 2018, 2020). The exact values of many parameters needed to model and forecast the abundance of gray whales are not known with precision. This is particularly true for models that forecast future conditions. During IRs, a range of conditions is tested using evaluation and robustness trials to assess the effectiveness of the gray whale S*trike Limit Algorithm* (*SLA*) and the Makah hunt management plan in terms of its performance in meeting management objectives (International Whaling Commission, 1995), specifically ensuring that risks to extinction are not seriously increased, maintaining or recovering stocks to levels at or above MSYL, and satisfying aboriginal subsistence need to the greatest extent possible while meeting conservation targets maintaining the conservation objectives. The 2020 IR found that the *Gray Whale SLA* and Makah whaling management plan remain the appropriate basis for the provision of advice on the Chukotkan (Russia) and proposed Makah (USA) hunts (International Whaling Commission, 2020).

Gray whales have experienced two documented unusual mortality events (UMEs) since monitoring of their abundance began in the 1960s, one from 1999/2000 and another that started in 2019 and has continued into 2023 (Raverty et al., 2020; Fauquier et al., 2022). The current UME is characterized by elevated occurrence of strandings (Fauquier et al., 2022), low calf counts in 2019 through 2022 (Eguchi et al. 2022a), and a 38% decline in estimated abundance from 26,960 whales in 2015/2016 prior to the event to 16,650 whales in 2021/2022 overlapping the event (Eguchi et al., 2022b). As discussed below, the UME appears to be affecting the Northern Feeding Group (NFG), but not the Pacific Coast Feeding Group (PCFG), Western Feeding Group (WFG), or Western Breeding Stock (WBS).

Given these recent events, the objective of this paper is to provide a review of recent observations on the biology and status of gray whales to help evaluate if a special IR is needed.

Stock structure hypotheses

Understanding stock structure is important in terms of managing human-caused mortality, especially in those cases where anthropogenic mortality may otherwise 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 RRGW meetings (International Whaling Commission, 2015, 2016, 2017, 2018a, 2018b) and agreed that two of the hypotheses (3a and 5a) should be considered highly plausible, while trials to evaluate stock status would also be conducted for four additional stock structure hypotheses or variants (3b, 3c, 3e and 6b). In 2020, the SC reviewed new genetic studies and agreed that hypotheses 4a and 7a should replace hypotheses 3a and 5a as high plausibility stock structure hypotheses and hypotheses 4b, 4c, and 4e should replace 3b, 3c, and 3e. The hypotheses should be modeled in trials during IRs (International Whaling Commission, 2020). The replacement stock structure hypotheses (4a, 4b, 4c, 4e, and 7a) all consider the WFG a unique breeding stock that utilizes the wintering grounds of Mexico rather than a feeding group of EBS gray whales (as is the case for hypotheses 3a, 3b, 3c, 3e, and 5a). The new hypotheses were equivalent for the purposes of modeling so these changes did not lead to the need for additional trials. In 2020, the SC agreed that changes in stock structure plausibility would not alter its existing advice with respect to the suitability of the either the *Gray Whale SLA* or the Makah Management Plan for the provision of advice on the Chukotkan and proposed Makah hunts (International Whaling Commission, 2020). 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. Full descriptions and diagrams of the stock structure hypotheses are presented in Annex G of the 2021 Scientific Committee report (International Whaling Commission, 2021).

Gray whale health and strandings

Gray whale strandings

Gray whales are known to strand throughout their range (Brownell et al., 2007; Kato et al., 2016; Lowry et al., 2018; Martínez-Aguilar et al., 2020; Fauquier et al., 2022). Monitoring of marine mammal strandings has been rather consistently conducted along the United States west coast (California, Oregon, and Washington) since the early 1980s and since 2000 in Alaska. Reviewing stranding data collected in the United States, UMEs are recognizable by periods of elevated reports of strandings, as seen in 1999/2000 and in 2019-present for data compiled in the US National Stranding Database (Figure 1).

The time series of gray whale abundance estimates illustrated in Figure 2 shows a large reduction in the estimated abundance of gray whales between surveys conducted during the winter of 1987/1988 and 1992/1993. The time series of strandings from the US National Stranding Database shows a slightly elevated number of strandings along the US west coast of North America during that time, but not to the magnitude of the 1999/2000 UME or the current UME (Figure 1). However, survey effort to detect strandings and related reporting structures were expanded and improved significantly beginning 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 US west coast, and Alaska starting in the mid-1970s and includes many stranding records that are not included in the US National Stranding Database. Brownell et al. (2007) found that during the three-year period of 1989, 1990 and 1991, the number of strandings was 265 whales. In the three-year periods before 1989 and three years after 1991 the total number of strandings were much less, 105 and 125 whales respectively, suggesting that a mortality event occurred during the years 1989-1991, but the event was not to the magnitude of the 1999/2000 UME (Brownell et al. 2007).

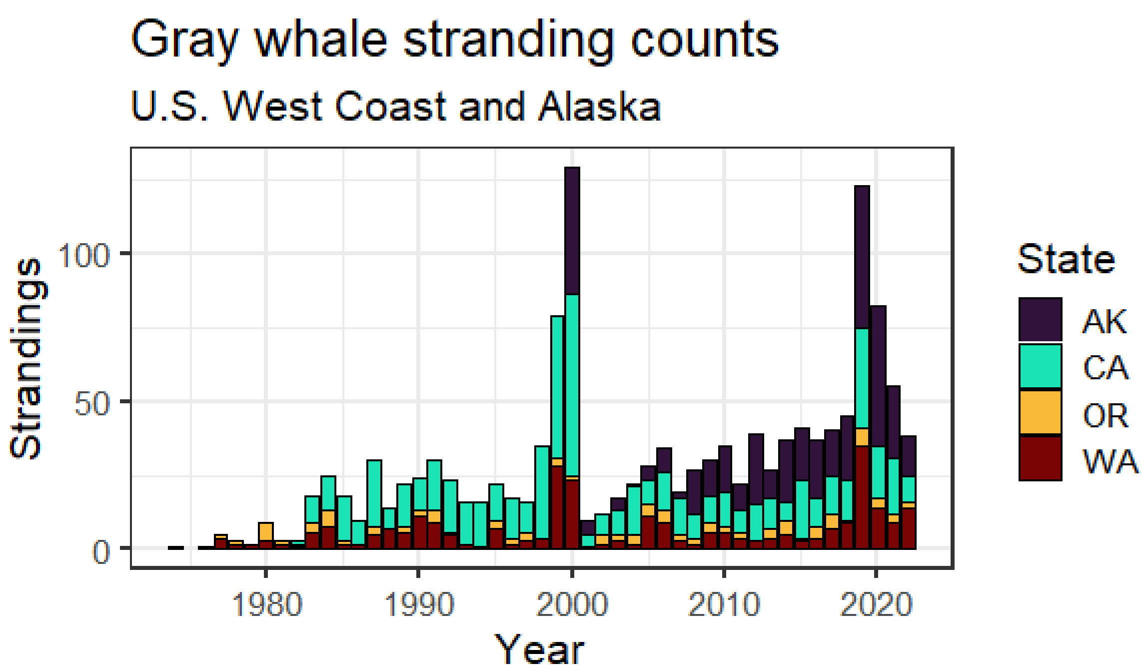

Figure 1. Reports of gray whale strandings along the US west coast from 1980-2022 and in Alaska from 2000-2022.

Observations of gray whale body condition

Gray whale body condition is a useful indicator of gray whales foraging success and health. 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 in northern Washington and southern Vancouver Island, British Columbia from 1996-2013 using boat-based photographs of whales following the approach developed by Bradford et al. (2012). They found that body condition is variable by year and that body condition improves through the feeding season, but not at the same rate in 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. Soledade Lemos et al. (2020) evaluated the body condition of PCFG whales observed off the central Oregon coast from 2016 to 2018 using aerial drone photogrammetry. Like Akmajian et al. (2021), they found that body condition improved through the feeding season and was variable by year. Soledade Lemos et al. (2020) hypothesized that significantly greater upwelling observed on the Oregon coast during 2013-2015, compared to upwelling during 2016-2018, led to greater prey availability and better body condition in 2016 than in 2017 and 2018. Torres et al. (2022) evaluated the body condition of PCFG gray whales observed off Oregon and EBS gray whales at San Ignacio Lagoon and in the Northeastern Chukchi Sea near Utqiagvik, Alaska. This study found that PCFG body condition observed off Oregon improved each year from 2017 to 2019, and hypothesized that the improving trend in body condition was the recovery of prey resources following a marine heatwave that affected the region during 2014-2016 (Peterson et al., 2017; Jones et al., 2018; Thompson et al., 2018). The conclusions of Soledade Lemos et al. (2020) and Torres et al. (2022) are slightly at odds given that Torres et al. (2022) imply that environmental conditions were worse for gray whales prior to 2017 due to the marine heat wave whereas Soledade Lemos et al. (2020) documented that conditions were better in 2016 than in 2017 and 2018 in the same study area used by Torres et al. (2022). Regardless of the causal mechanism, the three studies of body condition of PCFG gray whales showed that body condition is annually variable, that body condition improves through the feeding season but not at the same rate in each year, and that body condition is linked to environmental variables that likely govern the productivity of their prey base.

Studies of gray whale body condition in the wintering lagoons of Baja Mexico have documented a significant decline in body condition coincident with the start of the UME in 2019 (Ronzón-Contreras et al., 2019, 2020; Christiansen et al., 2021; Ronzon-Contreras et al., 2021; Valerio-Conchas et al., 2022; Torres et al., 2022). Aerial photogrammetry showed that body condition was significantly worse during 2018 and 2019 than during 2017 (Christiansen et al., 2021). Using the methods developed by Bradford et al. (2012) for analyzing boat-based photographs, Valerio-Conchas et al. (2022) documented that the proportion of whales in poor and fair condition was much greater during the UME than in years prior to it. Ronzón-Contreras et al. (2021) reported that during 2008-2011 that the percent of single whales observed in poor body condition ranged from 4.9 to 7.6%; during 2019-2021, the proportion of single whales in poor body condition ranged from 23.6% to 30.0%. In 2022, the proportion of whales in good and fair body condition was higher, and the proportion that were in poor body condition declined to 19.5%. These patterns in body condition during 2022 may signal that the effects of the 2019-2022+ UME are starting to abate, although they appear to still be affecting population abundance and calf production (Eguchi et al. 2022a, 2022b).

Christiansen et al. (2021) concluded that the poor body condition of gray whales during the UME was likely to result in reduced reproductive outputs by increasing the post-weaning recovery time of reproductive females. Rice and Wolman (1971) estimated that gray whales lose between 11 and 29% of their body weight during the southbound and northbound migrations, combined. The occurrence of whales in poor body condition on the wintering grounds off Mexico may result in individuals crossing below the threshold for survival during the northward migration (Christiansen et al., 2021).

Bradford et al. (2012) studied gray whale body condition at Sakhalin Island, Russia, from 1997 to 2007. They found that gray whale body condition improved through the feeding season and that some years had significantly better or worse overall body condition. No newer studies on body condition of gray whales at Sakhalin Island or Kamchatka, overlapping the 2019-2022+ UME in the eastern North Pacific, have been conducted.

Comparisons of gray whale body condition as a function of feeding region (PCFG vs. Sakhalin) 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) improvement in body condition during the feeding season was much greater for whales feeding at Sakhalin than for PCFG whales, suggesting better prey availability/quality at Sakhalin than in the PCFG feeding area. Torres et al. (2022) compared the body condition of PCFG whales to whales that were photographed at either San Ignacio Lagoon and in the Northwestern Chukchi Sea and concluded that PCFG whales had significantly worse body condition than other EBS whales in most years. The body condition of PCFG whales was not comparable to San Ignacio Lagoon whales until 2019, when the UME was affecting the body condition of whales at San Ignacio Lagoon (Christiansen et al., 2021).

Stinky whales in Chukotka

The occurrence of stinky whales has been known since the 1960s, with increased reporting of these whales starting in the late 1990s (Rowles & Ilyashenko, 2007). Many hypotheses have been proposed for the source of the strong medicinal odor and concern that the smell was due to anthropogenic sources. A new analysis by Polyakova et al. (2022) determined that the strong medicinal smell in stinky 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 the conclusion that the strong medicinal smell in gray whales was due to a natural source, specifically the proportion of polychaetes in the diet of stinky whales. The finding that the strong medicinal smell is from 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 UME.

Post-mortem examinations of gray whales during recent unusual mortality event

To date, post-mortem examinations have not found a definitive cause for any of the gray whale unusual mortality events. It is thought that these events are likely due to multifactorial drivers leading to killer whale predation, ship strikes and entanglements, and poor nutritive condition (Raverty et al., 2020; Fauquier et al., 2022). During the 2019-2022+ UME, the majority of whales examined in 2019 (72%) were in poor body condition (Raverty et al., 2020). In 2019, 19 of 50 examined whales (38%) showed evidence of killer whale predation and 8 of the 50 had signs of blunt force trauma consistent with ship strikes and an additional 2 whales with signs of propeller strikes resulting in a total of 20% of examined whales having evidence of ship strike. Causes of deaths are difficult to determine because of fast decomposition of internal tissues and lack of fresh carcasses, which prevent collection of tissues suitable for histopathology. PCR examination of tissue samples from 25 gray whales tested negative for morbillivirus, influenza viruses, and coronaviruses (Fauquier et al., 2022).

The high occurrence of poor body condition and emaciation among stranded whales suggest that starvation could be a cause for the elevated strandings. However, similarly to the 1999-2000 event, the underlying cause of poor body condition and potentially of starvation is not known (Gulland et al., 2005). Raverty et al. (2020) speculated that the population could have abruptly reached or exceeded carrying capacity, or experienced a sudden environmentally driven shift in prey availability citing Moore et al. (2022)’s findings of significant changes in prey availability and environmental processes in the sub-Arctic and Arctic feeding grounds of gray whales coincident with the start of the UME. Stewart et al (in prep) found strong correlations between gray whale abundance/vital rates and Arctic crustacean biomass, further supporting evidence of periodic prey limitation as a main driver of NFG gray whale abundance, reproduction, mortality, and condition fluctuations.

New results on post-mortem examinations will be presented to the IWC Scientific Committee this year. Results of the analysis are very similar to the previous conclusions presented above (Deborah Fauquier, NOAA, personal communication).

Gray whale health in summary

The large, ongoing UME of EBS gray whales is of concern and appears to be impacting the NFG. To date, there is no evidence that the UME is affecting WBS, WFG, or PCFG whales, noting that the PCFG has experienced a lesser decline in abundance than the larger EBS (Harris et al., 2022). The leading hypothesis for the current UME is that shifts in ecosystem productivity on the northern feeding grounds have led to increased 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 previous UME documented in 1999 and 2000 of ecosystem shifts leading to poor feeding conditions for gray whales (Le Boeuf et al., 2000; Gulland et al., 2005; Gulland, 2013). Supporting this hypothesis are two research projects. Moore et al. (2022) documented shifts in gray whale distributions in the Arctic in response to climatic and sea ice changes that led to shifts in prey production. Second, Stewart et al. (in prep) conducted an integrated analysis of gray whale population dynamics and found that the Arctic ecosystem has annual variability in how many gray whales it can support and that during the recent UME the ecosystem was not able to support the full abundance of the population.

The current event may not be affecting the entire Arctic feeding grounds equally. Sidorov et al. (2022) reported no observable changes in gray whale abundance and condition around Chukotka suggesting the hypothesis that the conditions causing the UME may not be affecting the Chukotkan hunt area. This hypothesis is further supported by studies that have found that gray whales show fidelity to the coast of Chukotka (Heide-Jørgensen et al., 2012; Filatova et al., 2022) and are thus most likely to be affected by environmental conditions in that region.

Human removals

Aboriginal harvest

The United States and Russia Federation share a catch limit of 140 gray whale strikes per year and a total of 980 strikes for the 6-year block management period. Currently hunts are only conducted in Russia. The proposed Makah hunt, requiring a waiver of the US Marine Mammal Protection Act, is being considered by the US government.

Hunting in Russia is conducted by Chukotkan natives along the shores of the Chukotka Peninsula. From 2017 through 2021, Chukotkan hunts averaged 126 strikes of gray whales per year with an average of 60 males and 66 females struck per year (Sidorov et al., 2022). The Aboriginal Whaling Scheme allows unused portions of the catch limit to be carried forward and used in a future year and this scheme was tested for gray whale hunts in Chukotka (International Whaling Commission, 2020; Punt, 2020).

The Makah Tribe reserved their right to harvest whales in the 1855 Treaty of Neah Bay with the US government. The Tribe utilized its 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 and delisting of the gray whale from the US endangered species list. The Makah Tribe had hunts permitted by the US and the IWC in 1999 and 2000 with one successful whale hunt in 1999. In 2000, hunting activities were stopped while a US court of law reviewed the hunt. A final ruling was made in 2004 that required the Tribe to apply for a waiver of the moratorium on takes imposed by the US Marine Mammal Protection Act before it could resume hunting. The Tribe submitted an application for a waiver in 2005 and the US government is still in the process of reviewing the request. NOAA has indicated that it anticipates completing the final environmental review document (FEIS) in Summer 2023 and, after a mandatory waiting period, making a final decision on the Tribe's waiver request in Summer 2023. If a waiver is approved, the Tribe would still need to obtain a permit from NOAA before it could resume hunting. Details on the waiver application and the review by the US government are available at https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/makah-tribal-whale-hunt.

Non-hunting Human-caused Mortality

The primary sources of NHHCM are ship 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 NHHCM from 1924 through 2018 based on data from national stranding databases, national bycatch and ship strike databases, published reports and manuscripts, national reports to the IWC, and from newspaper articles available on newspapers.com. The previous *Implementation Review* in 2020 utilized the data from Scordino et al. (2020) to inform the number of NHHCM (termed 'bycatch' in the modeling) by area and year throughout the gray whale range. The SC recognized that the data compiled by Scordino et al. (2020) were an underestimate of the true mortality of gray whales due to NHHCM because of under-reporting, e.g., cryptic mortality. To address this, the base case of the model multiplied all known mortalities due to NHHCM by a factor of 4. The factor of 4 was chosen using estimated recovery rates for coastal bottlenose dolphins (Carretta et al., 2016) as a model because both species spend most of their time close to shore. The SC also evaluated adding together prorated mortalities from serious injuries with observed mortalities, a multiplier of 10x observed NHHCM mortalities, and a multiplier of 20x observed NHHCM mortalities. The 10x and 20x trials were based on the finding in Punt and Wade (2012) that an estimated 3.9 - 13.0% of whales dying during the 1999/2000 UME were observed during stranding response and documented by Gulland et al. (2005). Trials with a multiplier of 20x observed NHHCM mortalities resulted in model results that were not consistent with observations, and these trials were therefore considered to have low plausibility (IWC 2018).

Scordino et al. (2023) provide an update on NHHCM since the last implementation review with new data from 2019-2021. Contributions to this effort were provided by scientists from the US, Japan, Korea, Canada, and Mexico. Table 2 includes the annual average NHHCM deaths from 2009-2018 by region used in the last IR and the new data from 2019-2021 for comparison. The average number of observed mortalities per year due to NHHCM has increased during the period of 2019-2021 in the North Pacific as compared to the previous ten years of data collection (2009-2018) from 3.9 to 6.7 per year. The change was driven by increased numbers of whale mortalities reported in CA and NBNC. The average annual number of observed dead whales plus prorated serious injuries for the North Pacific were very similar between the periods 2009-2018 and 2019-2021, 11.03 and 11.69 respectively.

Table 2: Observed non-hunting human-caused mortalities and mortalities plus prorated serious injuries by region for 2009-2018 and 2019-2021 reported in Scordino et al. (2023).

	Observed Dead		Dead + Serious Injury	
Region	2009-2018	2019-2021	2009-2018	2019-2021
AK	0	0	0	0
CA	12	21	68.55	20.25
EJPJ	0	0	0	0
FN	0	1	4.25	0
K	0	0	0	0
M	0	0	2.25	0
NBNC	7	13	27.27	11.75
PS	1	2	2.75	1.56
SEAK	0	0	3.25	1.5
SI	0	1	1	0
VSCS	0	1	1	0
Avg/year	6.67	3.9	11.03	11.69

As noted above, the base case for the last IR assumed that bycatch and ship strikes were under reported and multiplied observations of mortalities due to bycatch and ship strike by 4 to provide an estimate of total non-hunting human-caused mortalities. That IR also tested a range of other methods to account for under reporting of ship strike and bycatch related mortalities. Based on the new data collected since the previous IR (Table 2; Scordino et al., 2023), there is no evidence that recent levels of bycatch and ship strikes are outside the parameter space modeled in the 2020 IR.

Updates on gray whale abundance and calf counts

Eastern Breeding Stock

The Southwest Fisheries Science Center (SWFSC) of NOAA conducts periodic surveys of the abundance of gray whales during their southbound migration off central California. It is worth noting that this survey also includes the NFG, PCFG, and some fraction of the WFG (WFG is either a feeding group of EBS or a breeding stock depending on stock structure hypothesis). Surveys have been conducted since the winter of 1967/1968 providing a long-term dataset for evaluating trends and magnitude of events. Since the last IR, the SWFSC has produced two new abundance estimates (Stewart and Weller, 2021; Eguchi et al., 2022b) that coincided with the current UME. Prior to the UME, the most recent abundance estimate was 26,960 (95% credible interval 24,420-29,830) in 2015/2016 (Durban et al., 2017). Estimates during the UME declined to 20,580 (95% credible interval 18,700-22,870) in 2019/2020 (Stewart and Weller, 2021) and scheduled surveys for 2020/2021 were postponed until 2021/2022 due to the covid pandemic. The 2021/2022 survey showed further decline with an estimate of 16,650 (95% credible interval 15,170-18,335), representing a 38% decline from the 2015/2016 estimate from prior to the UME (Eguchi et al. 2022b). The SWFSC conducted a new survey during 2022/2023 and they hope to analyze their data prior to the 2024 IWC meeting.

The EBS has experienced at least one previous UME in 1999/2000 (Gulland et al., 2005). The 1999/2000 event resulted in a 22.6% decline due to the two-year event between median abundance estimates from surveys in 1997/1998 and in 2000/2001 (Eguchi et al., 2022b). Punt and Wade (2012) conducted population modeling and estimated that the decline in abundance due to the 1999/2000 UME was 28%. Examining the time series of abundance estimates (Figure 2), it appears that a UME could have occurred between 1987/1988 and 1992/1993 when the population is estimated to have declined 41.5% from an estimated abundance of 26,916 (95% confidence limits 23,856-29,976) to an estimated abundance of 15,762 (95% confidence limits 13,661-17,863). As noted above, there were not elevated numbers of strandings of gray whales along the US west coast concurrent with the decline in abundance from 1987 to 1993 and the estimate of abundance in 1993/1994 was 20,100 (greater than the upper 95% confidence interval for the 1992/1993 estimate). These types of patterns in the time series of abundance estimates are consistent with some underlying process(es) leading to interannual variability between counts that is not fully captured in the confidence intervals (e.g., interannual differences in the proportion of the population available to be counted between survey seasons). It is noteworthy that following each of the large declines documented between 1987 and 1993 and between 1997 and 2001 that the gray whale abundance estimates recovered.

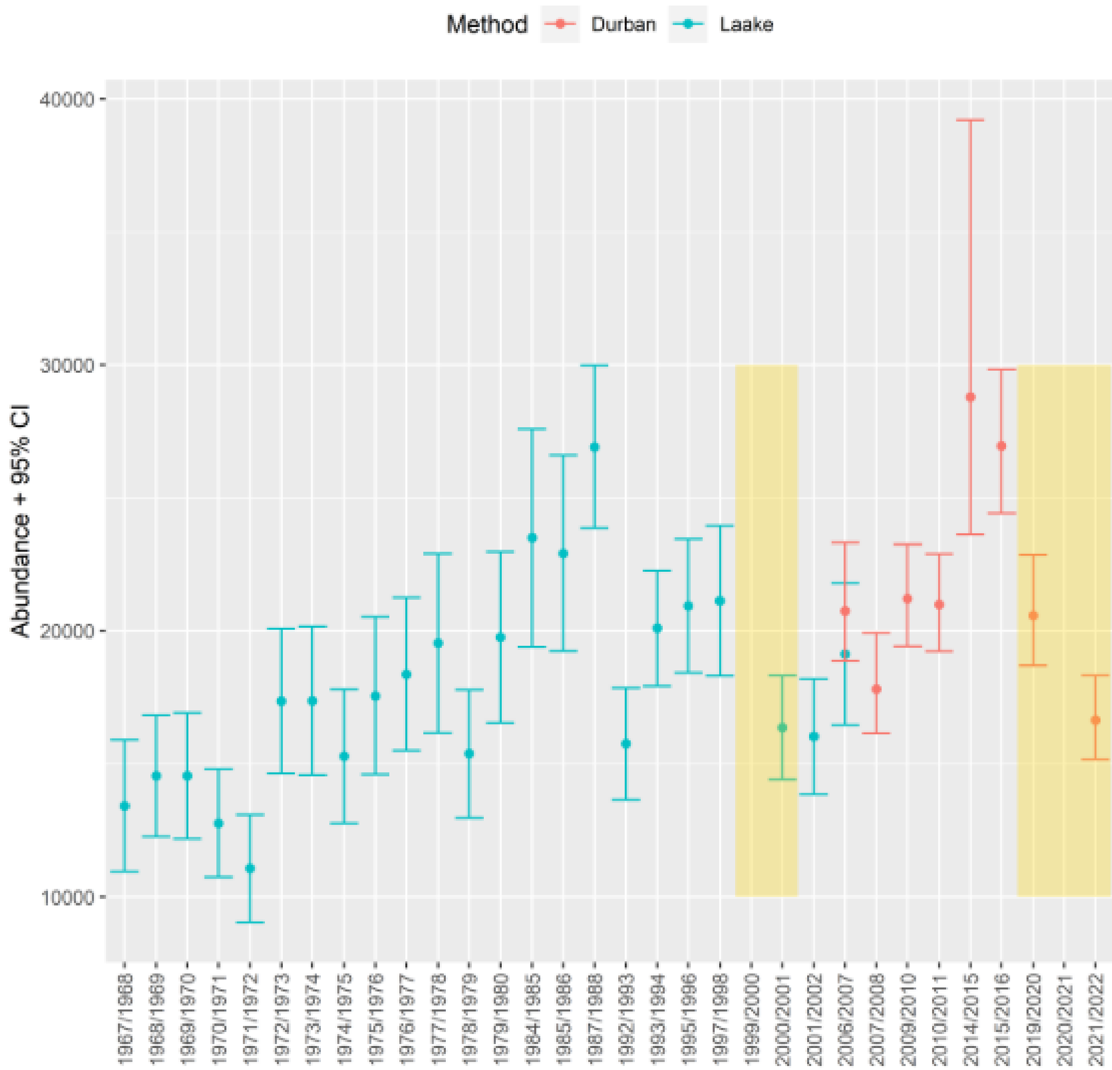

Figure 2: Time series of abundance estimates of EBS gray whales informed by counts conducted at Granite Canyon, California during the southbound migration. Highlighted counts show the documented UMEs in 1999-2000 and 2019-present. Estimates in blue report 95% confidence intervals and estimates in red present 95% credible intervals. Figure copied from Eguchi et al. (2022b).

The SWFSC has conducted surveys of mother-calf pairs on their northward migration at Piedras Blancas, California annually since 1994 in all years except 2020 due to the covid pandemic (Eguchi et al., 2022a). During the recent UME, the estimated number of calves were some of the lowest in the time series, including 2022 which was the lowest. The time series of EBS calf estimates shows low calf production in the past including during the 1999/2000 UME and between 2007 and 2010 which was not associated with a UME (Figure 3).

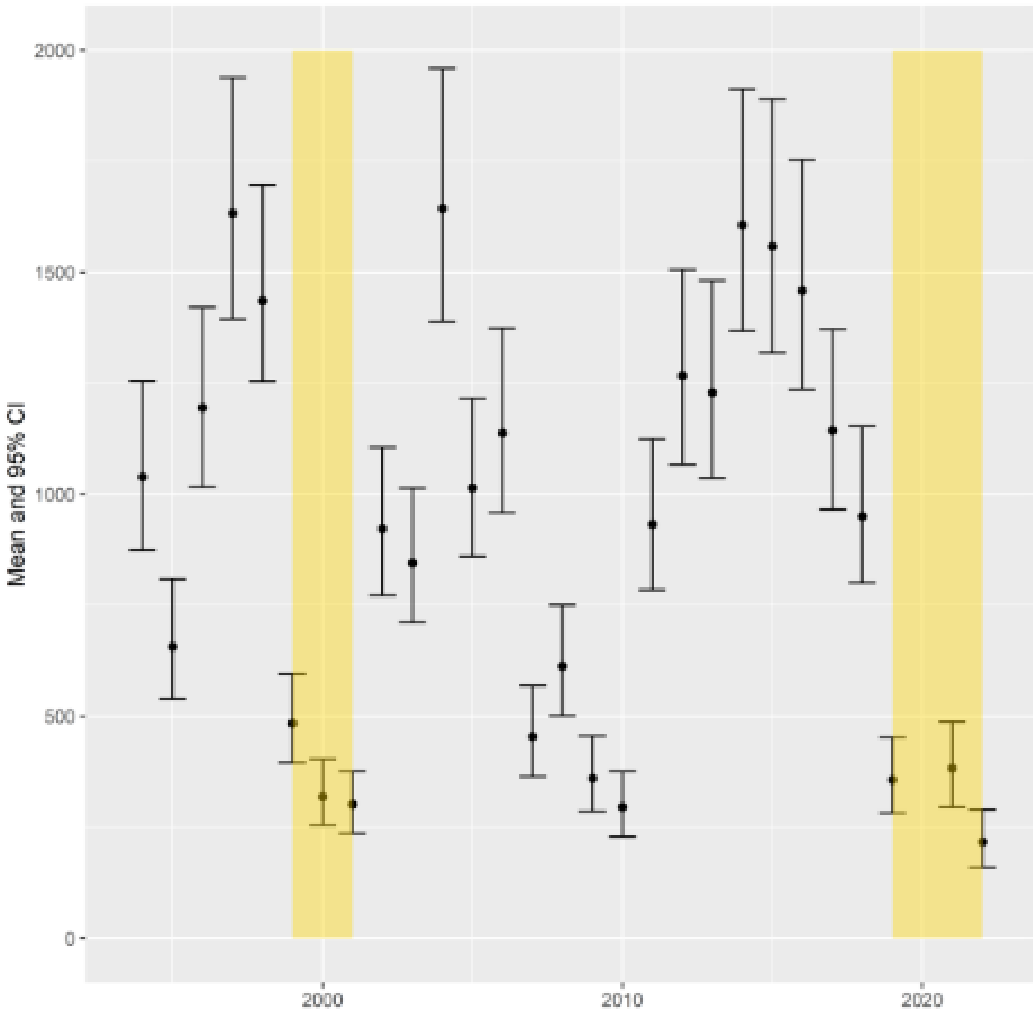

Figure 3: Annual estimates of EBS gray whale calf production with associated 95% CIs. Yellow vertical bars indicate UMEs. This figure was copied from Eguchi et al. (2022a).

PCFG abundance estimates

*S*everal independent researchers provide photographs of gray whales to Cascadia Research Collective to compare to their catalog of known PCFG whales to inform annual abundance estimates calculated by NOAA's Marine Mammal Laboratory. The most recent update on PCFG abundance was provided by Harris et al. (2022) using survey data from 1996 through 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 and only estimates from 1998 on are considered for management purposes (Laake, 2012). The PCFG time series of abundance estimates peaked in 2015 at 257 (standard error (SE) = 17.9) and then declined to the most recent estimate of 212 (SE = 17.9) in 2020, an estimated 28% reduction in abundance (Figure 4; Harris et al., 2022). The start of the decline in PCFG abundance preceded the current UME of EBS gray whales and may show the PCFG response to the 2014-2016 marine heatwave that affected the region (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) and the decline in kelp forests due to the marine heat wave and the increase in urchin populations may be to the detriment of PCFG whales. Also, given that the PCFG abundance estimate is formed by mark-recapture estimates, it is possible that the recent declines of abundance were an artifact of reduced spatial coverage of surveys as compared to the past particularly in the northern portion of the PCFG range, or, alternatively, a different spatial arrangement of whales leading to reduced probability of photographically capturing them.

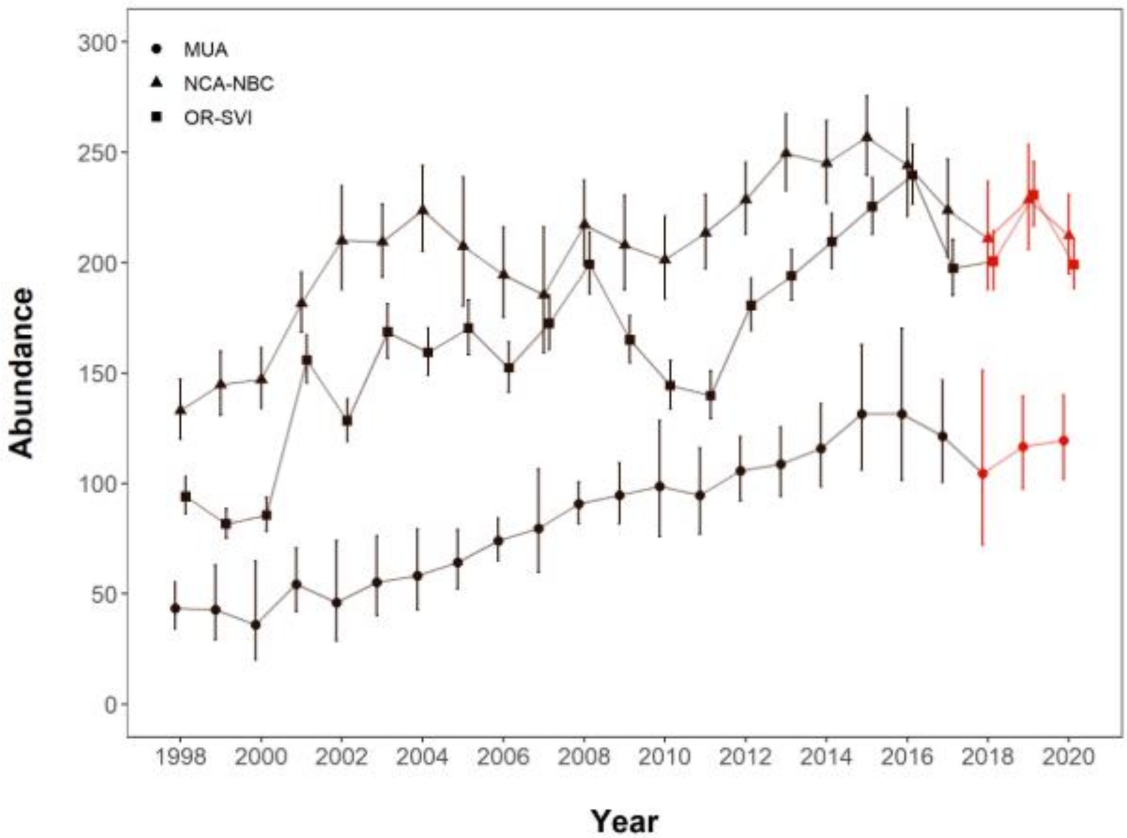

Figure 4: Time series of PCFG whale abundance estimates. The NCA-NBC area corresponds with the area used by the IWC for defining the PCFG range for abundance estimates (International Whaling Commission, 2015). Values in red are the most recent abundance estimates added to the time series. Confidence intervals are +/- 1 SE. Figure is copied from Harris et al. (2022).

During surveys of the PCFG, researchers record observations of calves. Gray whales are difficult to identify as a calf, particularly once they are independent of their mother (Bradford et al., 2011). As a result, observations of calves are likely an underreporting of the number born into the PCFG each year. Figure 5 presents a time series of uncorrected calf counts from PCFG surveys showing a spike of calf production from 2012-2015 and that calf production was relatively constant during the rest of the time series. Recent calf counts have been low, but are similar to counts during 1998-2010. Interestingly, the periods of high and low calf counts are similar between the PCFG and the broader EBS.

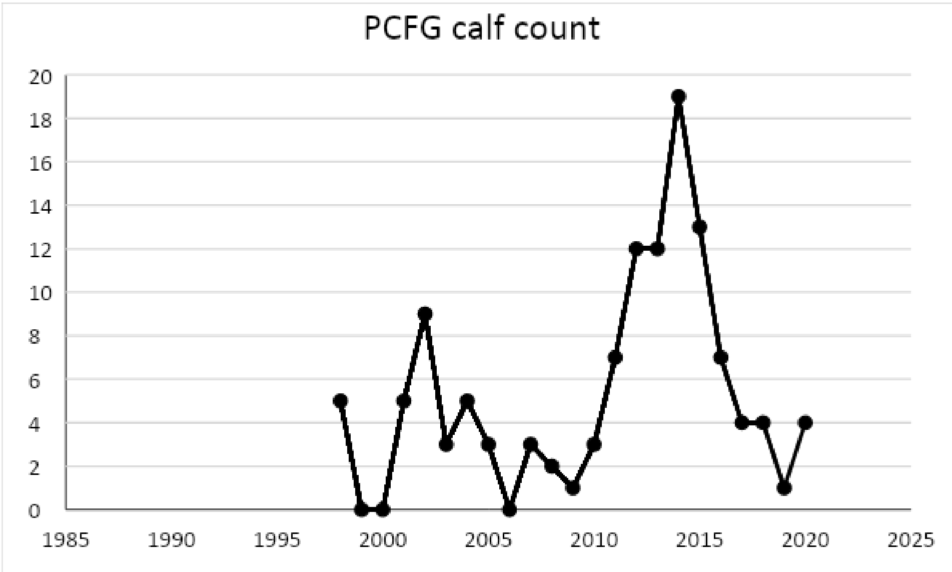

Figure 5: Calf counts in the PCFG range during June through November. Figure adapted from Harris et al. (2022).

WFG/WBS

Cooke (2018) produced abundance estimates for gray whales that utilize Sakhalin Island and Kamchatka by stock structure hypothesis. Figure 6 shows the trends in growth of the modeled feeding groups and breeding stocks. Cooke (2018) estimated the growth rate as 5% per year. No new abundance estimates are available to assess if the WFG or WBS have been affected by the current UME. Reports by researchers at Sakhalin Island and Kamchatka show that calf counts were high during the years of the current UME, including the highest calf count on record since 1994 in 2019. 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 being affected by the current UME for NFG EBS gray whales. However, we strongly encourage that abundance estimates of WFG/WBS whales are updated to more carefully evaluate if either WFG or WBS have been affected by the UME.

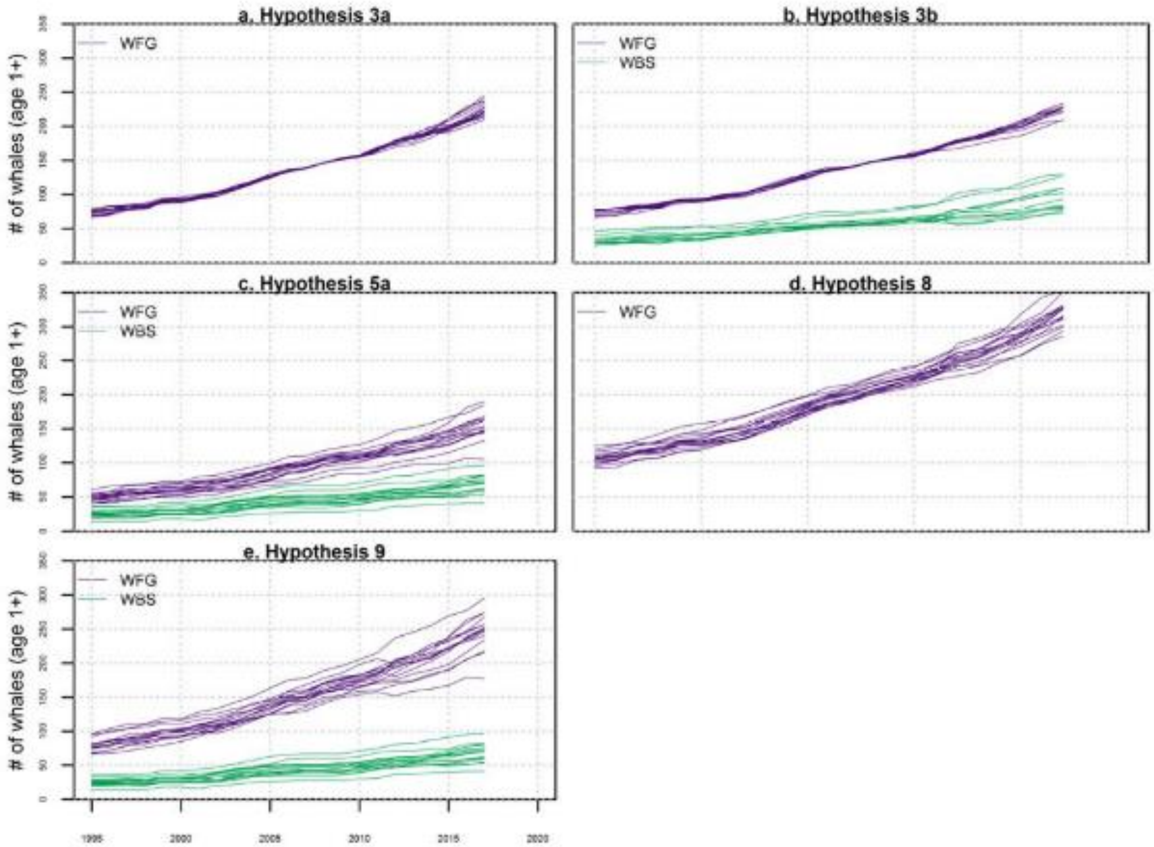

Figure 6: Posterior samples of population trajectories for WFG (purple lines) and WBS (green lines) by stock structure hypothesis as calculated by Cooke (2018). Note that hypothesis 3a would have the same population trajectory as 4a, 3b as 4b, and 5a as 7a. Figure is copied from Cooke (2018).

Population growth rates (MSYR)

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 for NFG, PCFG, and WFG 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, and another trial with a common estimated MSYR for all gray whales. MSYR is an important parameter, because it determines the expected resiliency for abundance under long-term average mortality rates.

No new data were collected since the IR to suggest that the estimate of Punt and Wade (2012) needs revision. Cooke (2018) found that WFG and WBS whales were growing at 5% a year. However, a lower MSYR makes the modeling more conservative and it is therefore questionable how much would be gained by increasing the MSYR for the WFG and WBS. 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. The IR included trials with an MSYR of 2% for PCFG which should capture the concerns noted by Torres et al. regarding lower reproductive potential for PCFG whales.

Immigration into the PCFG

The PCFG population dynamics appear to be influenced by both internal recruitment through the birth of calves of members of the feeding group and immigration of older whales likely from the NFG (Lang and Martien, 2012; Weller et al., 2013). In the late 1990s and early 2000s, the PCFG experienced a rapid increase in abundance that is not explainable by survey bias (Laake, 2012) or by calf production alone, and suggests 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 unusual mortality event (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 (International Whaling Commission, 2020).

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 that were not detected in the PCFG during the year of their birth and or were photographed but were not documented as a new calf. Lang and Martien (2012) used computer simulations to evaluate what amounts of immigration are most parsimonious with observed genetic diversity of the PCFG (Lang et al., 2014). They found that an immigration rate of 1 or fewer whales per year would produce genetic diversity and differentiation that is inconsistent with the empirical data. They found that the most parsimonious amount of immigration consistent with data was 4 immigrants per year. The 2020 IR included immigration of 2 whales per year in the base case and evaluated trials with 0, 1, and 4 immigrants per year (International Whaling Commission, 2020).

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

Parameterization of the Makah hunt

There is uncertainty about how the Makah hunt will operate both in terms of hunting efficiency and in how efficient the monitoring of the hunt will be in terms of photographing whales during the hunt and accurately matching the photographs of struck whales to catalogs of PCFG and WNP whales (International Whaling Commission, 2018a). Parameters that needed estimating for the RRGW and the IR included: probability of obtaining a photograph of suitable quality for matching for a struck and lost whale, probability of struck and lost, false positive rate for matching of a PCFG whale (probability of being wrongly identified as a PCFG whale), false negative for matching a PCFG whale (probability a whale is a PCFG but is not matched to the catalog), false positive for WFG, false negative for WFG, 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 (International Whaling Commission, 2018a, 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 for increasing the summer/fall struck and lost rate to 50% from 10% (International Whaling Commission, 2018a, 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 programs.

Future catastrophic events (UMEs)

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

As noted above, there are now two well-documented UMEs that occurred during 1999/2000 and from 2019-present. The 1999/2000 event resulted in an estimated 22.6% decline in the population and the current event resulted in an estimated decline of 38% (as of 2022). It is possible that the current event is having a larger effect as stranding levels are still high despite the reduction in population and that we will not know the full magnitude of the event until the SWFSC provides abundance estimates from the 2022/2023 survey. It is also possible that EBS gray whale experienced a UME between 1987/1988 and 1992/1993 when the observed difference in abundance estimates dropped by 41.5%, however the stranding records for the US west coast do not show supporting evidence for a UME during that time.

The recent observations on the magnitude of the 2019-present UME, and the observation that UMEs 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 UMEs (Punt et al., 2023), and that the current observed magnitude and frequency are outside of the parameter space tested. (Actually, the magnitude is borderline, as it is comparable to at least a few trials, but the frequency does appear greater than previously envisioned.) New models are needed to evaluate more frequent and larger magnitude UME events. Furthermore, more trials should be constructed that involve combining scenarios related to future UMEs with other factors such as stock structure immigration rates, productivity rates, survival rates, rate of immigration into the PCFG and etc., to assess the synergistic impacts of the parameters included in the other evaluation trials with future catastrophic events (UMEs). This sort of combination trial is essential because UMEs no longer appear to be as unusual as initially thought, whereas at the time the Gray Whale SLA was designed, it was uncertain whether another UME would occur anytime soon.

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 UMEs (catastrophic events) were modeled during development of the Gray Whale SLA, testing of the Makah Whaling Management Plan, and all previous IRs, as compared to current observations. The current UME is of greater magnitude and occurring over a longer duration than was considered in the 2020 IR. Furthermore, the observations of UMEs in 1999/2000 and the current event in 2019-present and potentially an event in the late 1980s, suggest that the previous approach of modeling one event every 50 years did not model UMEs occurring as frequently as they appear to actually occur. Preliminary modeling by Punt et al. (2023) includes evaluation trials with two UMEs (catastrophic events) forecasted to occur every 50 years with one event lasting two years (like 1999/2000) and the next lasting 4 years (like the current UME) with the UMEs programmed to replicate the magnitude of the 1999/2000 and the 2019-present events. The preliminary modeling by Punt et al. (2023) also includes trials with decreased productivity in the PCFG in 2016. The preliminary modeling suggests that the performance of the Gray Whale SLA and Makah Whaling Management Plan are likely robust to recent and future UMEs of NFG gray whales and reductions of productivity of the PCFG, at least under the initial parameterizations taken into account in that exploratory modeling.

The Commission requires the SC to provide scientific advice in 2024 to confirm that gray whale subsistence hunting complies with the IWC's conservation standards for ASW hunts, in order for quotas to be renewed. In light of the current UME and related overview on the status of ENP gray whales provided here, a plan is needed regarding what steps (if any) the IWC SC needs to take to be fully confident in the ASW management advice it provides for gray whales in advance of the renewal of the gray whale catch limit quota in 2024.

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