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ABUNDANCE AND MIGRATORY PHENOLOGY OF EASTERN NORTH PACIFIC GRAY WHALES 2021/2022

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ABUNDANCE AND MIGRATORY PHENOLOGY OF EASTERN NORTH PACIFIC GRAY WHALES 2021/2022

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Introduction

The Southwest Fisheries Science Center (SWFSC) regularly conducts shore-based surveys of eastern North Pacific (ENP) gray whales (*Eschrichtius robustus*) to estimate abundance. These estimates are obtained from visual survey data collected off central California between December and February during the gray whale southward migration and provide regular updates to a time series of abundance estimates that began in 1967 (Laake et al. 2012; Durban et al. 2015, 2017; Stewart and Weller 2021a). In 2016, abundance was estimated at 26,960 (95% Credible Interval[1] = 24,420-29,830) whales, indicating that the population had roughly doubled since 1967 when it was estimated at 13,426 whales (95% Confidence Interval = 10,952-15,900; Table 1). Since 2016, however, the population declined to 20,580 whales (95% Credible Interval = 18,700-22,870) in 2020 (Stewart and Weller 2021a). This report presents a new estimate of abundance for ENP gray whales migrating southward off the central California coast between December and February 2021/2022[2].

Methods

Data for this updated abundance estimate were collected during the southward ENP gray whale migration between 28 December 2021 and 18 February 2022. Counts were made from a shore-based watch station at Granite Canyon, California, by a rotation of three observers working together in teams of two. This effort was part of the long-term gray whale abundance survey, which started in 1967 (Laake et al. 2012). These surveys were designed to target the main migration period from late December to mid-February and do not typically cover the early onset or late offset of the migration when few whales are observed. Sampling and analytical methods are described in detail elsewhere (Durban et al. 2015), and these same approaches were followed here.

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[1] In this report, results from non-Bayesian (up to the 2006/2007 season; Laake et al. 2012) and Bayesian (since 2006/2007 season; Durban et al. 2015) approaches are included. Uncertainties in point estimates are provided in either confidence intervals (non-Bayesian) or credible intervals (Bayesian).

[2] Gray whale southward migration spans two calendar years, starting in the final quarter of one year and extending into the first quarter of the following year. For example, the survey reported here started in December of 2021 and completed in February of 2022 and is denoted as the 2021/2022 season. This same convention is applied to previous surveys.

The estimates of abundance produced by SWFSC are generated using the N-mixture modeling approach used previously for surveys conducted between 2006 and 2020 (Durban et al. 2015, 2017; Stewart and Weller 2021a). In this approach, the sighting probability of shore-based observers is estimated by using data from replicate surveys (i.e., data collected simultaneously by two independent observer teams) that were completed in 2009/2010 and 2010/2011. These sighting probability estimates allow the total number of whales passing through the survey area during a watch period to be estimated from the observed number of whales, even in years when replicate surveys were not conducted.

For the analysis of data, the start date of the southward migration for the Granite Canyon study site is fixed at 1 December and the end date at 28 February, where the number of whales passing the watch station on those two dates is assumed to be zero. The daily count data are assumed to be random deviates from binomial distributions with the estimated sighting probability from replicate surveys and the true number of whales in the sampling area, which is assumed to change as a function of the number of days since 1 December. The model fits two possible functions to the daily counts of whales and selects a function that fits better for each count. These functions are (a) a normal distribution where the peak in the daily number of whales passing occurs at the midpoint of the migration and (b) a spline fit that allows the overall migration curve to flexibly match the observed daily counts without expectations about the shape of the curve. The model then internally selects which of these two candidate migration curves best matches the daily number of observed whales. The final abundance estimate is the sum of the total number of whales passing the survey area each day (i.e., both observed whales and the estimated number of unobserved whales), with a correction factor applied to account for a small number of whales that may pass too far offshore to be observed by shore-based observers and those that migrate through the study area at night. The modeling approach is described in detail in Durban et al. (2015).

The N-mixture modeling approach uses all data since 2006/2007 to estimate parameters that are shared among yearly datasets. Consequently, analysis of the previously collected data (2006/2007 through 2020/2021) with the 2021/2022 data resulted in annual estimates that were slightly different from those provided in previous reports. These differences, however, were negligible. Therefore, for the sake of consistency, the estimates for previous years, as originally reported, were used in this update.

To determine possible changes in migration timing, we examined the annual median migration date (AMMD), which was defined in Rugh et al. (2001) as "the date when 50% of the whale sightings had been recorded at a research site or (if data were not available for calculating the median) the date corresponding with the apex of a unimodal sighting curve." Using the first definition, these dates are determined using sightings rather than estimated abundances. The latter definition, however, is applicable for estimated numbers if the model has a unimodal distribution. In our approach, the model selected a better function between the normal and spline fits for each day. Consequently, the results are not unimodal for some years (Fig. 1). Therefore, the date when 50% of the whale sightings had been recorded was used as the AMMD.

Linear models were fitted to the relationship between the AMMD and year. In order to estimate change points, if any existed, we fitted segmented linear models using the *segmented* package (v. 1.6.0, Muggeo 2017). All statistical analyses were conducted in the R statistical environment (v. 4.1.2, R Core Team 2021).

Results and Discussion

Abundance estimates

From 28 December 2021 to 18 February 2022, 13 trained observers completed 255 hours of survey effort over 39 survey days. A total of 853 groups of 1689 gray whales were counted, with the highest daily count of 112 whales on 03 January 2022 (Fig. 1). Estimated total abundance of gray whales during the 2021/2022 southbound migration was 16,650 (95% Credible Interval: 15,170 - 18,335, CV = 0.0485, 20th-percentile = 16,050). This estimate includes the multiplicative correction factor for nighttime passage (mean = 1.0875, SD = 0.03625) and represents a 19.6% decline from the previous survey in 2019/2020 when abundance was estimated at 20,580 (Table 1, Fig. 2). Considering the 23.7% decline in abundance from 2016 to 2020 (Stewart and Weller 2021a), a continued decrease in the numbers of ENP gray whales has occurred since 2016: 26,960 whales in 2015/2016, 20,580 in 2019/2020 and 16,650 in 2021/2022 (Fig. 2).

The most recent estimate of 16,650 in 2021/2022 is comparable to those from 2000/2001 and 2001/2002 (Fig. 2). Those earlier survey years coincided with an unusual mortality event (UME)[3] that occurred in 1999 and 2000 when higher than usual strandings and deaths of gray whales were observed along the west coast of Mexico, the United States, and Canada. In total, 651 dead gray whales were reported, with 283 observed in 1999 and 368 in 2000 (Gulland et al. 2005). While the cause of this UME was not determined, some stranded whales were in poor body condition leading to questions about whether the population of ENP gray whales had reached the limit of what the Arctic feeding ground habitat could support (Moore et al. 2001). However, the population subsequently increased and in 2016 the abundance was estimated at an all-time high of nearly 27,000 whales.

In 2019, NOAA's National Marine Fisheries Service declared the most recent UME for ENP gray whales[4]. As of June 3, 2022, 578 stranded whales were recorded with 216 in 2019, 172 in 2020, 114 in 2021 and 76 in 2022. While this UME appeared to be at a slightly reduced level compared to the 1999-2000 UME, it overlaps with the observed 23.7% decline in abundance from 2016 to 2020 and the 19.6% decline in abundance that occurred between 2020 and 2022. Given the increased number of strandings in 2019 that triggered the designation of a UME and the lower number of reported strandings since that time, it is

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[3] Under the Marine Mammal Protection Act (MMPA), an unusual mortality event (UME) is defined as "a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response"

[4] https://www.fisheries.noaa.gov/national/marine-life-distress/2019-2022-gray-whale-unusual-mortality-event-along-west-coast-and

likely that the majority of this decline occurred in 2019. This decline is comparable to that seen between 1987/1988, when the ENP gray whale population reached what was then its highest estimated abundance (26,916 whales) of the time series, and 1992/1993, when the estimated abundance had fallen approximately 40% over the course of four years. Based on the available records, this decline was not associated with a marked increase in the number of stranded whales, as was the case in 1999-2000 and 2019-present. However, by 1993/1994 abundance had increased to over 20,000 and remained stable at near that level until the 1999-2000 UME.

The pattern of population growth and decline represented in the time series of abundance estimates for ENP gray whales suggests that large-scale fluctuations of this nature are not rare (Fig. 2). The observed declines in abundance appear to represent short-term events that have not resulted in any detectable longer-term impacts on the population. That is, despite occasional declines in abundance since the time-series of data began in 1967, the overall trend had remained positive. That being said, the year over year decline in abundance between 2016 and 2022 represents a pattern that requires further regular monitoring to determine when the population trajectory levels off and, in turn, again becomes positive.

While ENP gray whales have shown long-term resilience to population fluctuations for which a direct cause has yet to be determined, NOAA/NMFS continue to closely monitor the population with regular surveys to estimate abundance, calf production and body condition (e.g., Perryman and Lynn 2002, Durban et al. 2015; 2017, Perryman et al. 2021, Stewart and Weller 2021a, Stewart and Weller 2021b). The results of these research efforts will continue to provide the best scientific information available regarding the status of the population.

Migration phenology

Timing of migration, measured by the annual median migration date (AMMD), changed significantly over the survey period (Fig. 3). From the beginning of the survey (1967) through the 1970s, the AMMDs were generally earlier than 10 January (i.e., Day 40). This pattern changed in the 1980s, 1990s and early 2000s when the AMMD shifted to later in the migration period. Since the mid-2000s, there was a linear decline in ADDM but it has nevertheless remained above the pattern observed prior to 1980. Estimated change points were 1976 (SE = 3.52) and 2007 (SE = 2.86). The estimated slopes (in the unit of days per year) for the three segments were -0.073 (SE = 0.282), 0.500 (SE = 0.076), and -0.406 (SE = 0.241). The linear decline in the median southbound migration date since 2007 was not apparent in the northbound ADDM date of mother-calf pairs off Piedras Blancas, California, which increased (i.e., became later) by approximately one week when recent data (through 2016) was compared to those collected in the mid-1990s (Perryman et al. 2021).

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*Table 1: Estimated abundance (N) and 95% lower (LCL) and upper (UCL) confidence (Laake) and credible (Durban) limits of gray whales from the visual surveys off Granite Canyon, CA. Estimates prior to the 2006/2007 season are from Laake et al. (2012), where confidence limits were computed using +/- SE * 1.96. For the 2006/2007 through 2021/2022 seasons, the method of Durban et al. (2015) was used. The method of Durban et al. (2015) updates all estimates when new data are added. To keep the consistency in abundance estimates, values in previous publications are reported within this table.*

Season	N	LCL	UCL	Method
1967/1968	13,426	10,952.4	15,899.6	Laake
1968/1969	14,548	12,266.9	16,829.1	Laake
1969/1970	14,553	12,185.5	16,920.5	Laake
1970/1971	12,771	10,743.5	14,798.5	Laake
1971/1972	11,079	9,059.5	13,098.5	Laake
1972/1973	17,365	14,642.2	20,087.8	Laake
1973/1974	17,375	14,582.5	20,167.5	Laake
1974/1975	15,290	12,772.7	17,807.3	Laake
1975/1976	17,564	14,603.4	20,524.6	Laake
1976/1977	18,377	15,495.5	21,258.5	Laake
1977/1978	19,538	16,168.1	22,907.9	Laake
1978/1979	15,384	12,971.8	17,796.2	Laake
1979/1980	19,763	16,548.0	22,978.0	Laake
1984/1985	23,499	19,399.8	27,598.2	Laake
1985/1986	22,921	19,237.1	26,604.9	Laake
1987/1988	26,916	23,856.2	29,975.8	Laake
1992/1993	15,762	13,661.2	17,862.8	Laake
1993/1994	20,103	17,935.9	22,270.1	Laake
1995/1996	20,944	18,439.9	23,448.1	Laake
1997/1998	21,135	18,318.1	23,951.9	Laake
2000/2001	16,369	14,411.9	18,326.1	Laake
2001/2002	16,033	13,864.7	18,201.3	Laake
2006/2007	19,126	16,464.4	21,787.6	Laake
2006/2007	20,750	18,860	23,320	Durban
2007/2008	17,820	16,150	19,920	Durban
2009/2010	21,210	19,420	23,250	Durban
2010/2011	20,990	19,230	22,900	Durban
2014/2015	28,790	23,620	39,210	Durban
2015/2016	26,960	24,420	29,830	Durban
2019/2020	20,580	18,700	22,870	Durban
2021/2022	16,650	15,170	18,335	Durban

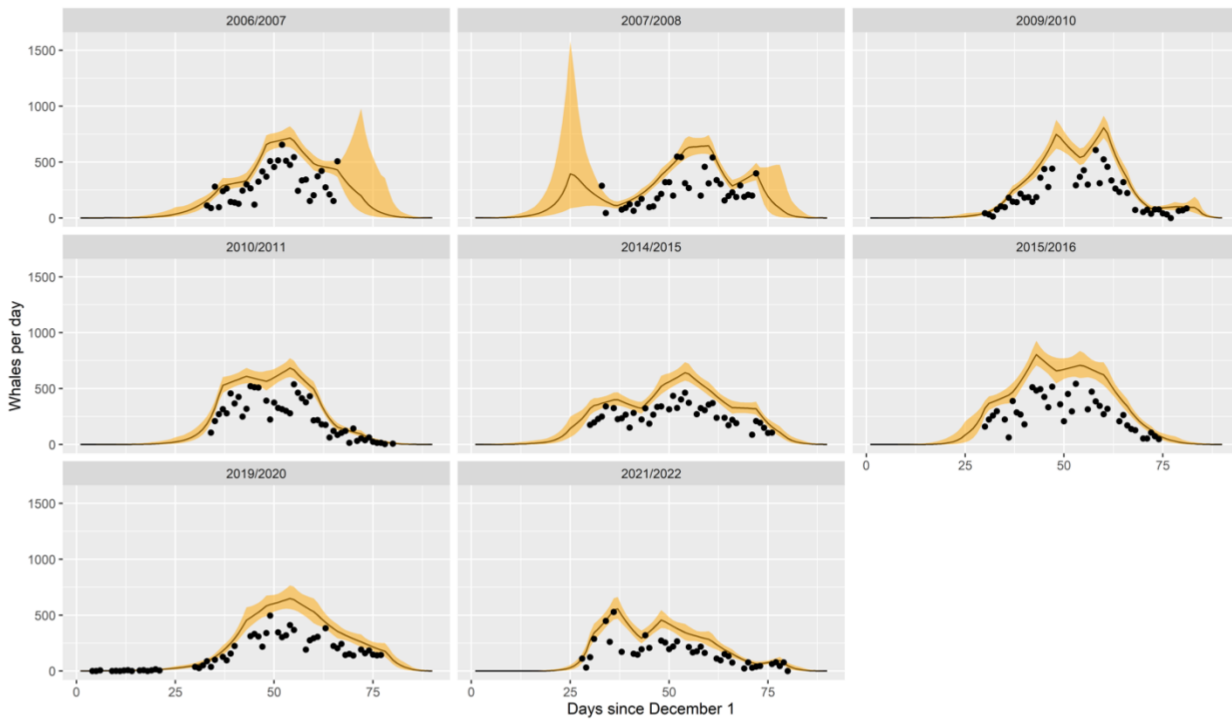

Figure 1: Daily estimated numbers of gray whales migrating through the sampling area off Granite Canyon, CA. Black lines are medians and orange bands indicate 95% credible intervals. Solid circles indicate observed counts. The estimated numbers and their 95% credible intervals are slightly different from those shown in previous reports because of the hierarchical nature of the model that includes shared parameters among years, whose posterior distributions change with additional data.

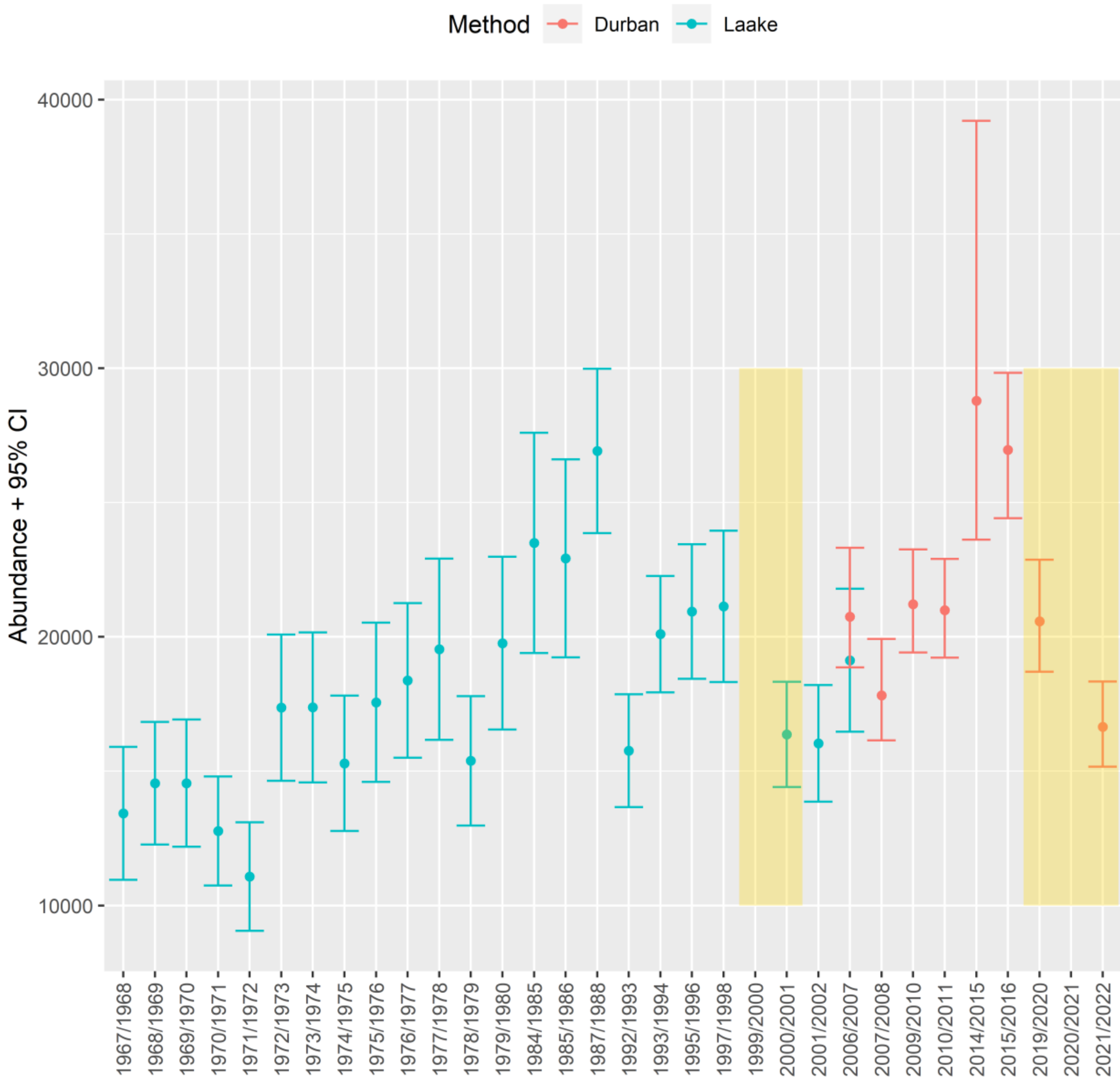

Figure 2: Estimated abundance and approximate 95% confidence (Laake's method) and credible (Durban's method) intervals of gray whales from the visual surveys off Granite Canyon, CA, between the 1967/1968 and 2021/2022 seasons. Estimates in green indicate those from Laake et al. (2012). Estimates in red (from the 2006/2007 season) indicate those obtained using the method in Durban et al. (2015). Yellow boxes represent unusual mortality events.

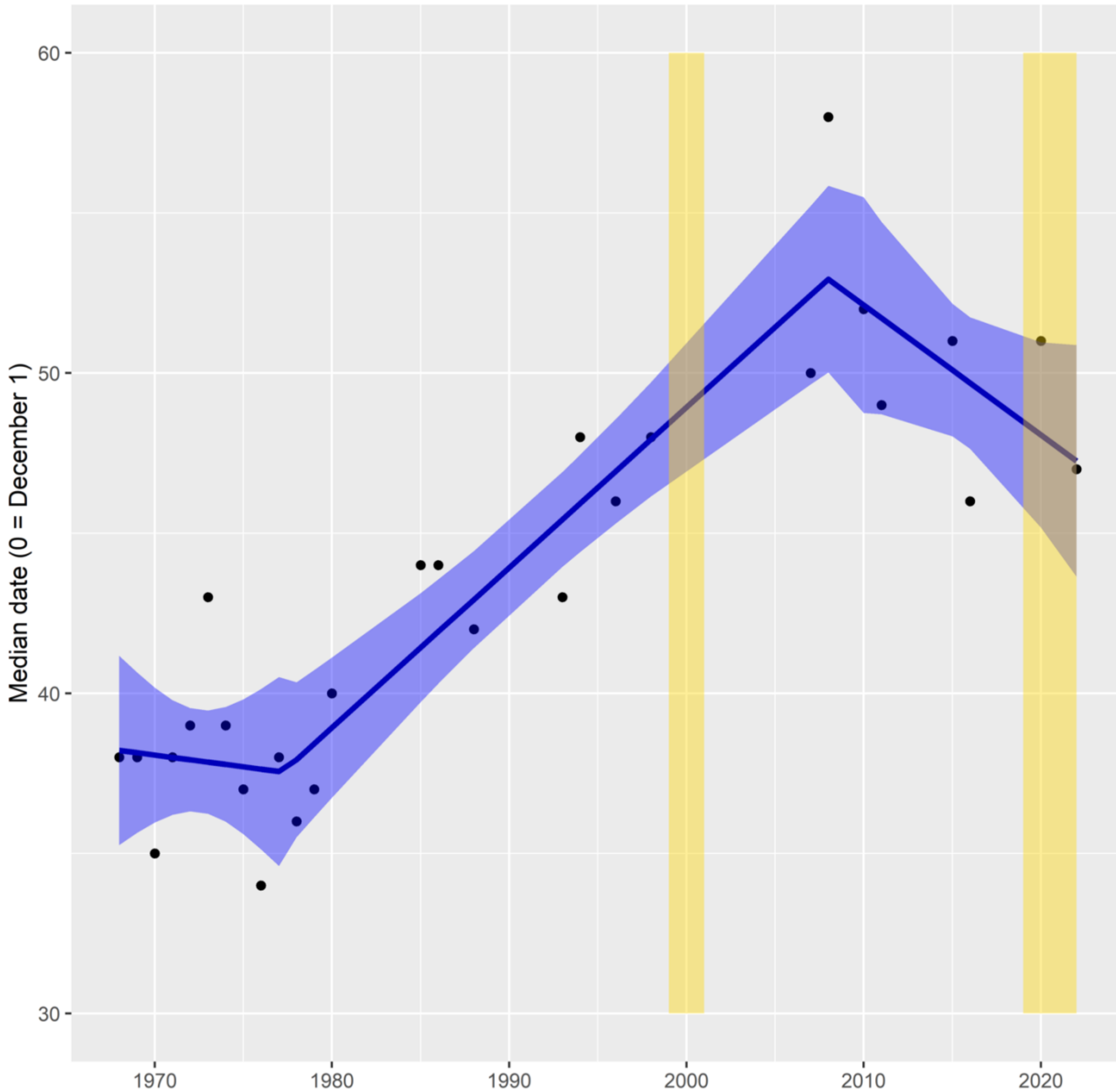

Figure 3: Changes in annual median date of gray whale migration at the sampling area off Granite Canyon, CA (the date when 50% of the whale sightings had been recorded). December 1 of each year is Day 0 and January 10 is Day 40. Data before the 2006/2007 sampling season are from Rugh et al. (2001, Table 1 within). Regression lines are linear models with change points and blue bands indicate approximate 95% confidence intervals. Yellow vertical bars indicate the designated UMEs.