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ABUNDANCE OF EASTERN NORTH PACIFIC GRAY WHALES 2022/2023

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Abundance of eastern North Pacific gray whales 2022/2023

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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). The estimated abundance in the 2015/2016 season was 26,960 whales (95%CI[1] = 24,420-29,830; Table 1), indicating that the population had roughly doubled since 1967, when it was estimated at 13,426 whales (95% CI = 10,952-15,900; CV = 0.094). Since 2015/2016, however, the population declined to 20,580 whales (95% CI = 18,700-22,870) in 2019/2020 (Stewart and Weller 2021a) and 16,650 (95% CI = 15,170 - 18,335) in 2021/2022 (Eguchi et al. 2022a). This report presents a new estimate of abundance for ENP gray whales migrating southward off the central California coast between December 2022 and February 2023[2].

Methods

Data for this updated abundance estimate were collected during the 2022/2023 southward ENP gray whale migration between 29 December 2022 and 24 February 2023. 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. Each survey day was split into six 90-minute observation shifts. As is the case for the Bayesian analytical approach used since 2006/2007, only shifts with at least 85 minutes of survey effort were included in the final data set. Some shifts were less than 85 minutes due to poor weather and/or visibility (e.g., Beaufort sea state greater than 4 or dense fog). Sampling and analytical methods are described in a previous publication (Durban et al. 2015).

The estimate of abundance reported here was computed using the N-mixture modeling approach used previously by SWFSC for surveys conducted between 2006/2007 and 2021/2022 (Durban et al. 2015, 2017; Stewart and Weller 2021a; Eguchi et al. 2022a). In

[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. Estimates based on both approaches are reported for 2006/2007. Uncertainties in point estimates are provided in either confidence intervals (non-Bayesian) or credible intervals (Bayesian), both of which are abbreviated as CI.

[2] The 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 2022 and completed in February of 2023 and is denoted as the 2022/2023 season. This same convention is applied to previous surveys.

this approach, the sighting probability of whales by shore-based observers is estimated using data from replicate surveys (i.e., data collected simultaneously by two independent observer teams) that were completed in 2009/2010 and 2010/2011 and covariates that affect sighting probabilities (i.e., visibility, sea state, and observers). These sighting probability estimates allowed 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.

In the analysis, 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 set at zero. The daily count data are assumed to be random deviates from binomial distributions with the estimated sighting probability and the true but unknown 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 with the peak in the daily number of whales passing occurring 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 estimated total number of whales passing the survey area each day, with a correction factor applied to account for those that migrate through the study area at night (Perryman et al. 1999). The modeling approach is described in detail in Durban et al. (2015; 2017).

Because the N-mixture modeling approach uses all data since 2006/2007 to estimate parameters that are shared among yearly datasets, annual estimates change as more data are added to the analysis. To be consistent, the estimates from previous years, as originally reported, are reported in this update.

Similar to the analysis reported in Eguchi et al. (2022a), we examined the annual median migration date, which was defined previously (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 (Figure 1). Therefore, we use the date when 50% of the whale sightings had been recorded as the median date.

Linear models were fitted to the relationship between median dates and year. In order to estimate change points, if one or more exists, we fitted segmented linear models using the *segmented* package (v. 1.6.0, Muggeo 2017). All statistical analyses were conducted within the R statistical environment (v. 4.2.1, R Core Team 2022).

Results and Discussion

Abundance estimates

From 29 December 2022 to 24 February 2023, 18 trained observers completed 268.5 hours of survey effort over 37 survey days. This effort resulted in 238.4 hours of data retained for further analyses. A total of 1659 gray whales were counted during sufficiently good conditions, with the highest daily count of 156 whales on 20 January and 27 January 2023 (Figure 1). Estimated total abundance of gray whales during the 2022/2023 southbound migration was 14,526 (95% CI=13,195 - 16,040, CV = 0.0492, 20th-percentile = 13,190). This estimate includes the multiplicative correction factor for nighttime passage (mean = 1.0875, SD = 0.03625; Perryman et al. 1999) and represents a 12.8% decline from the previous estimate of 16,650 for the 2021/2022 season (Table 1). Considering the 23.7% decline in abundance from 2015/2016 to 2019/2020 (Stewart and Weller 2021a) and the 19.1% decline from 2019/2020 to 2020/2021 (Eguchi et al. 2022a), a continued decrease in the numbers of ENP gray whales occurred since 2016 (Figure 2).

The most recent estimate of 14,526 in 2022/2023 is comparable to those from 1968-1970 (Figure 2), which are among the lowest in the time series. The new estimate comes during a multi-year unusual mortality event (UME)[3], which was declared in 2019 by NOAA's National Marine Fisheries Service. During the current UME since 2019, a total of 633 stranded whales have been recorded in Mexico, US, and Canada (216 in 2019, 172 in 2020, 115 in 2021, 105 in 2022, and 32 in 2023 up to 18 April)[4]. Overlapping the 2019-present UME are the three declines in abundance reported here: (a) 23.7% decline from 2016 to 2020, (b) 19.6% decline between 2020 and 2022 and (c) 12.8% decline from 2022 to 2023. These three declines, in combination, represent a 46% decline from 2016 to 2023 that is greater than that seen between 1987/1988 and 1992/1993 when the estimated abundance had fallen approximately 40% (Figure 2). Based on the available records, this 40% decline was not associated with a marked increase in the number of stranded whales, as was the case in the 1999-2000 and 2019-present UMEs.

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. The observed declines in abundance may 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 population has recovered (Figure 2). The year over year decline in abundance between 2016 and 2023, however, represents a novel pattern that requires continued regular monitoring to determine when the population trajectory levels off and, in turn, again

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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

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 & Lynn 2002; Durban et al. 2015; Stewart & Weller 2021a; 2021b; Perryman et al. 2021; Eguchi et al. 2022a; 2022b). The results of these research efforts will continue to provide the best scientific information available regarding the status of the population.

Migration phenology

As reported previously (Eguchi et al. 2022a), timing of migration, measured by the median migration date, has changed significantly over the survey period (Figure 3). From the beginning of the survey in 1967 through the 1970s, median migration dates were generally earlier than 10 January (i.e., Day 40). They linearly increased over the 1980s, 1990s, and early 2000s. Since the mid-2000s, there was a linear decline. Estimated change points were 1976 (SE = 3.63) and 2008 (SE = 3.84). The estimated slopes for the three segments were 0.13 (SE = 0.361), 0.468 (SE = 0.077), and -0.238 (SE = 0.221), respectively. The median migration date for the 2022/2023 season was Day 53, which was 6 days later than the 2021/2022 season. The biological and ecological significance of this difference is unknown. Studies on body conditions, environmental fluctuations, and health conditions of gray whales may provide information on possible mechanisms of changes in the migration timing of gray whales.

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Tables and figures

*Table 1: Estimated abundance (Nhat) and 95% lower (LCL) and upper (UCL) confidence limits of gray whales from the visual surveys off Granite Canyon, CA. Estimates up to the 2006/2007 season from Laake et al. (2012) are reported, where confidence limits were computed using SE * 1.96. For the 2006/2007 through 2022/2023 seasons, the method of Durban et al. (2016) was used[5].*

Season	Nhat	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

[5] For the 2006/2007 season, estimates based on both the non-Bayesian (Laake et al. 2012) and Bayesian (Durban et al. 2015, 2017) approaches are reported.

Season	Nhat	LCL	UCL	Method
2006/2007	19,126	16,464.4	21,787.6	Laake
2006/2007	20,750	18,860.0	23,320.0	Durban
2007/2008	17,820	16,150.0	19,920.0	Durban
2009/2010	21,210	19,420.0	23,250.0	Durban
2010/2011	20,990	19,230.0	22,900.0	Durban
2014/2015	28,790	23,620.0	39,210.0	Durban
2015/2016	26,960	24,420.0	29,830.0	Durban
2019/2020	20,580	18,700.0	22,870.0	Durban
2021/2022	16,650	15,170.0	18,335.0	Durban
2022/2023	14,526	13,194.8	16,040.0	Durban

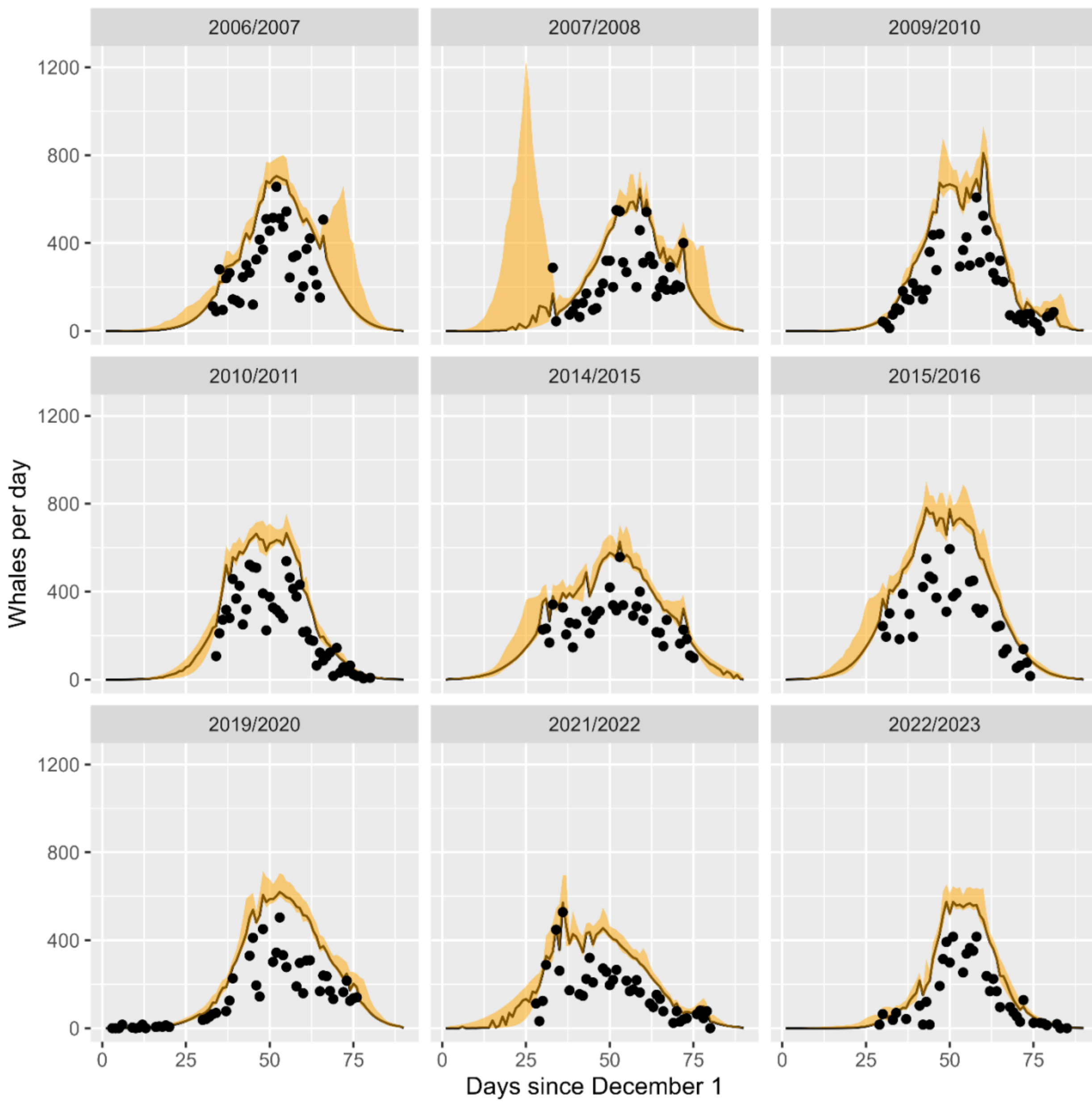

Figure 1: Daily estimated numbers of gray whales migrating through the sampling area off Granite Canyon. Black lines are medians and orange bands indicate 95% credible intervals from the method of Durban et al. (2015). Solid circles indicate observed counts corrected for the daily survey effort.

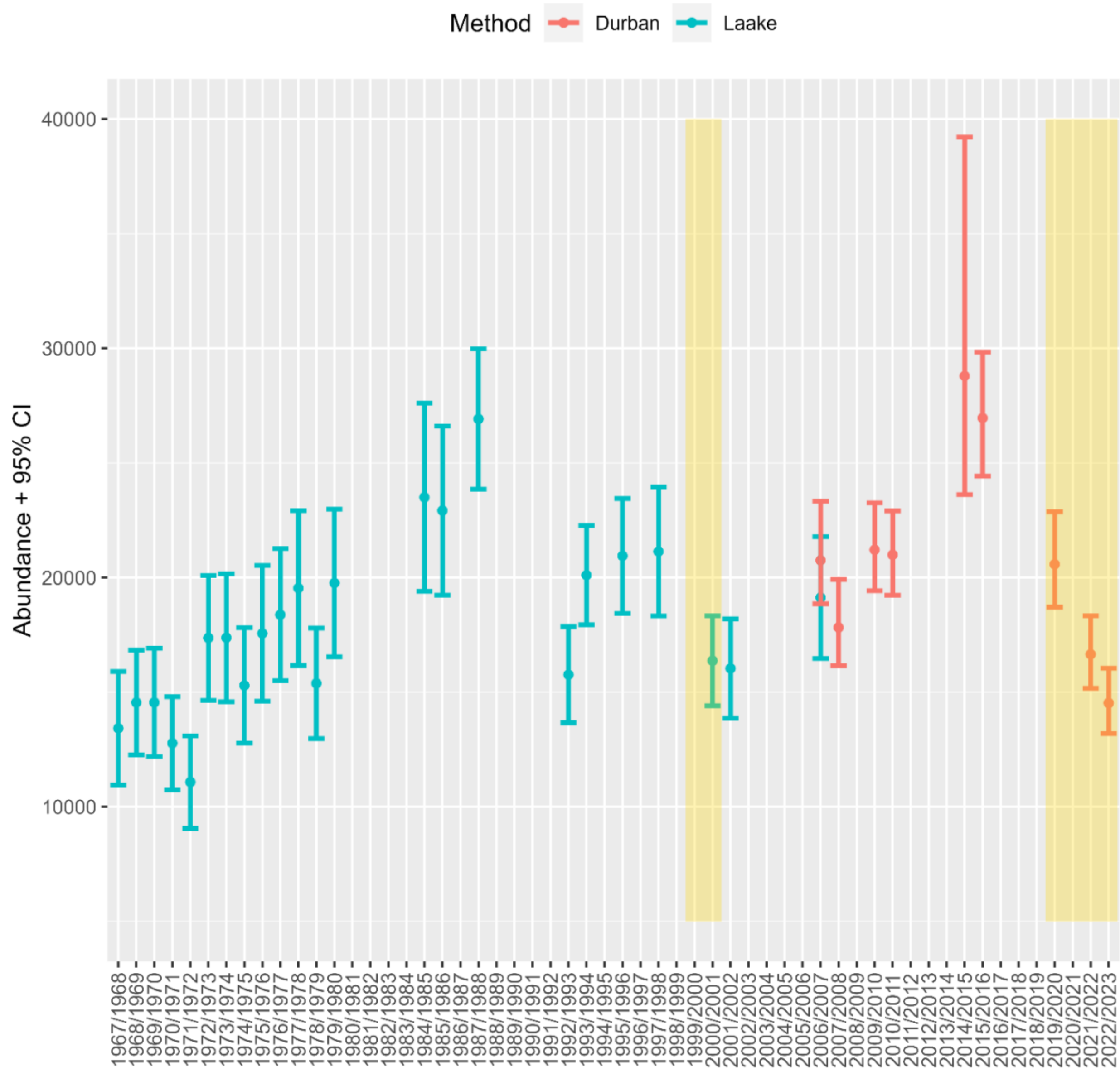

Figure 2: Estimated abundance and 95% CIs (confidence intervals for the method of Laake et al. and credible intervals for the method of Durban et al.) of gray whales from the visual surveys off Granite Canyon, CA, between the 1967/1968 and 2022/2023 seasons. Estimates in blue indicate those from Laake et al. (2012). Estimates in red (from the 2006/2007 season) indicate those obtained using the method in Durban et al. (2016). Yellow boxes represent the designated unusual mortality events.

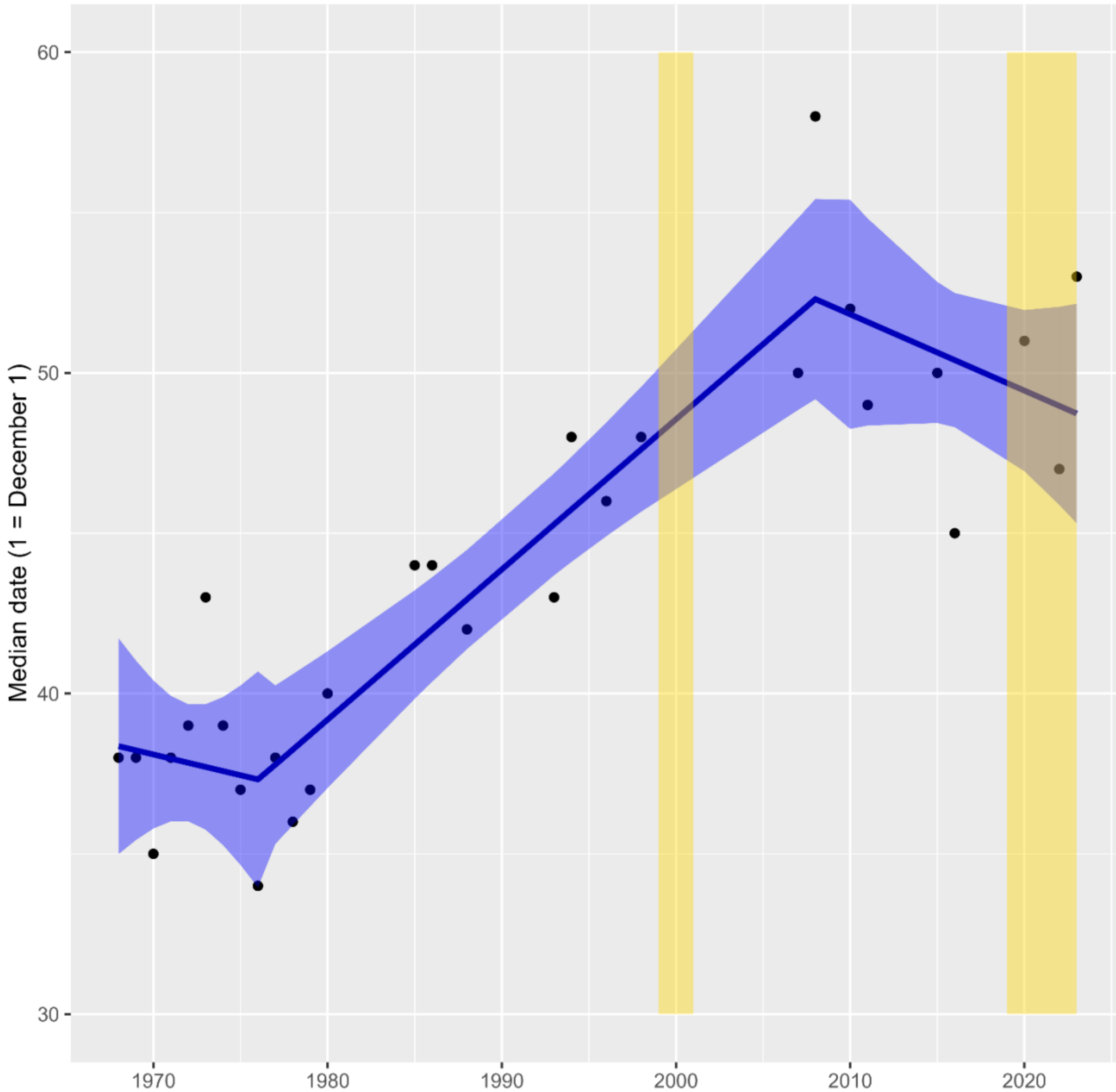

Figure 3: Changes in median date of gray whale migration at the sampling area off Granite Canyon, CA (the date when 50% of the whale sightings had been recorded). December 1 of each year is 1 and January 10 is Day 40. Data before the 2006/2007 sampling season are from Rugh et al. (2001, Table 1). Regression lines are linear models with change points. Yellow boxes indicate the designated unusual mortality events.