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EASTERN NORTH PACIFIC GRAY WHALE CALF PRODUCTION 1994-2025

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Eastern North Pacific gray whale calf production 1994-2025

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INTRODUCTION

Eastern North Pacific (ENP) gray whales (*Eschrichtius robustus*) migrate annually between foraging grounds in the Arctic and wintering grounds in Baja California (Rice and Wolman 1971). Females give birth in protected lagoons in Baja California Sur, Mexico, and migrate north with their calves in the spring of each year. Shore-based counts of female gray whales accompanying their calves (i.e., mother-calf pairs) have been conducted annually from the Piedras Blancas Lighthouse Station in central California since 1994[1]. Survey methods were evaluated in detail at the outset of the study (Perryman et al. 2002) and have remained consistent since 1994 (Weller and Perryman 2019, Stewart and Weller 2021).

In 2021, Stewart and Weller (2021) presented a new Bayesian modeling approach to estimate annual calf production of ENP gray whales. Their approach accounted for uncertainty during unsampled periods (i.e., when there was no sampling effort; nights, weekends, and bad weather days). Here we provide estimates of calf production for the 1994-2025 period using the Bayesian approach.

METHODS

Data for this analysis were collected between 1994 and 2025 using standardized methods (Perryman et al. 2002, Weller and Perryman 2019, Stewart and Weller 2021). Briefly, a rotating pair of observers conducted counts of mother-calf pairs from a shore station during a 12-hour watch period per day. Watches were terminated by poor weather (e.g., rain or fog), visibility or sea conditions, resulting in total daily effort frequently below the maximum of 12 hours.

The protocol for processing the raw data prior to analysis was similar to that in Stewart and Weller (2021). However, the data extraction method used to format the raw data was updated in 2024 to accomodate start times before 7:00 am and to calculate effort more accurately when sighting conditions change mid-shift (see Lang et al. 2024 for details).

The previous analysis using the method of Perryman et al. (2002) was based on the following observations and assumptions. Perryman et al. (2002) determined that: (a) the number of calves passing offshore and beyond the visual range of shore-based observers

[1] The annual survey was not conducted in 2020 due to COVID-19. In 2021, the survey was completed under COVID-related staffing restrictions, which included a three-person rather than four-person observer rotation during some weeks to reduce the number of people in close proximity. During periods when the three-person rotation was in place, the maximum survey effort in a given day was limited to 9 hours rather than the typical 12 hours for a four-person rotation.

was negligible (data from aerial surveys) and (b) the passage rates of mother-calf pairs were consistent between daytime and nighttime periods (based on recording from infrared sensors). Independent replicate counts from two different shore-based observation stations conducted over seven consecutive years (1994-2000) reported a detection probability of 0.889 (SE 0.06375) (Perryman et al. 2002). All of these assumptions were maintained for the method of Stewart and Weller (2021).

The method of Perryman et al. (2002) used direct corrections for detection probability and effort to generate total calf production estimates. For example, if two calves were observed passing during a 3-hour period, that would be corrected for detection probability by dividing the total observed calves by 0.889, for a total estimate of 2.247 calves for that 3-hour period. The detection probability-corrected calf counts were then summed for each 1-week period. Then, to account for both the portions of 3-hour watches that were terminated by poor conditions, and the unobserved night and weekend periods, the weekly total counts were multiplied by the number of hours in a week (168) divided by the total weekly effort. In 2016, for example, 22 calves were counted during the third week of survey effort (April 12-16). This was corrected to 24.747 calves to account for detection probability. There were 39.6 total hours of survey effort during that week, so the final estimate was 24.747 * (168/39.6) = 104.99. The same calculation was made for each week of the survey, and summed across weeks for a total calf estimate. Variance was incorporated via Taylor series expansion from the variance in estimated detection probability, the number of survey days, and the variance in the corrected total number of animals passing per 3-hour period (Weller and Perryman 2019).

In Stewart and Weller (2021), a Bayesian model was developed to account for uncertainty associated with detection probability, effort and unsampled periods. In addition, we estimate a passage rate that varies by week, which then helps inform the undetected calf estimates from unsampled periods. The model is based on a binomial sampling process,

$$O_i \sim BIN(T_i, p_i)$$

where O_i is the number of calves observed during each 3-hour survey period i (including unobserved nights and weekends), T_i is the number of calves that actually passed the study area during each 3-hour survey period i, and p_i is the effort-corrected detection probability for each survey period. We calculated p_i as,

$$p_i = \hat{p} \times \frac{E_i}{3}$$

$$\hat{p} \sim N(0.889, 0.06375)$$

where $\hat{p}$ is the detection probability estimated by Perryman et al. (2002), and E_i is the number of hours of reported effort in each 3-hour survey period i. Detection probability is therefore scaled by the proportion of time within a 3-hour survey period that observers were on watch. We make the assumption that, for example, if observers are only on watch for 1.5 out of 3 hours, then the probability of detecting a whale that passes during the 3-hour period is 0.889 * 1.5/3 = 0.4445. Similarly, nights and weekends are broken into 3-hour periods, each of which has 0 sightings and 0 effort. Any missing watch periods, either due to poor conditions or observer limitations during the 2021 survey that was impacted by COVID, were also logged as having 0 sightings and 0 effort. The detection probability during unobserved periods is therefore 0. Finally, we use a Poisson distribution to estimate the mean passage rate of whales within each 3-hour period during a given week,

$$T_i \sim POI(\lambda_{w_i})$$

where λ is the mean passage rate for each week, and w_i is the week during which survey period i occurred. This allows the estimated true number of whales passing during an unobserved 3-hour period to be informed by the mean passage rate during observed periods within the same week, with associated uncertainty. Finally, the total number of calves throughout the study period is calculated as

$$N = \sum_i T_i$$

or the estimated true number of calves passing in each 3-hour period, summed across all periods i.

In some years, a survey was concluded mid-week after three consecutive days of 0 sightings of calves. In these cases, we populated the remainder of the final week with 0 sighting and 0 effort survey periods to maintain consistency across weeks. Migration start and end dates differed across years, and therefore the number of weeks surveyed were not consistent across years, but were instead designed to capture the full northbound migration from start to finish.

RESULTS and DISCUSSION

From 31 March 2025 to 23 May 2025, 399 hours of survey effort were completed. Daily survey effort ranged from zero to 12 hours. The total number of gray whale mother-calf pairs counted during the survey was 17. The highest daily count was 3 pairs over 12 effort hours on both 22 April 2025 and 01 May 2025, while the day with the highest sighting rate (0.317 pairs per effort hour) occurred on 29 April 2025 (Figure 1). The estimated number of mother-calf pairs during the 2025 migration season was 84.62 (95% CI = 55.48 - 293.5) (Table 1, Figure 1). This number is the lowest of the time series that started in 1994.

Total calf production of ENP gray whales has been notably low since 2019 (Table 1, Figure 2), which marked the start of an Unusual Mortality Event (UME) for gray whales on the west coast of North America. This event extended from 17 December 2018 through 9 November 2023, during which time 690 gray whales stranded, including 347 in the United States, 316 in Mexico, and 27 in Canada[2]. During this event, abundance, which is estimated using data collected during shore-based counts of southbound migrating gray whales off central California, declined from a pre-UME peak of 27,430 whales (95% CI = 24,930 - 30,180) in 2015/2016 to 14,770 whales (95% CI = 13,410 - 16,250) in 2022/2023. While

[2] https://www.fisheries.noaa.gov/national/marine-life-distress/2019-2023-eastern-north-pacific-gray-whale-ume-closed

the 2023/2024 estimate of abundance of ENP gray whales showed an apparent increase to 19,730 whales (95% CI = 17,580 - 21,850), the estimate for 2024/2025, which was 12,950 whales (95% CI = 11,690.0 - 14,450.2), was the third lowest in the time series, which began in 1967/1968. This most recent abundance estimate is consistent with the low calf production that has occurred since the start of the UME, suggesting that the observed 2023/2024 increase may have been biased due to mismatches between analytical assumptions, including sampling and modeling, and the migratory behavior of whales (Eguchi et al. 2025).

Variation in gray whale calf production has been linked to sea ice cover in the Bering and Chukchi Seas as well as to broad-scale environmental indices of North Pacific climate, including the Pacific Decadal Oscillation and the North Pacific Index (Perryman et al. 2002, 2021; Joyce et al. 2023; Stewart et al. 2023). Two previous periods of low calf production have occurred since monitoring began in 1994. One of these overlapped in part with the first documented UME for gray whales (1999-2000), during which time ENP gray whales experienced a corresponding decline in abundance. Similar to the pattern seen in 2024, calf production remained low in the year (2001) following the UME closure. Estimated calf production increased to moderate levels by 2002 and remained moderate to high through 2006, reaching the highest estimate of the time series in 2004 (1678, 95% CI = 1425 - 1999). The second period of low calf production occurred over a four-year period between 2007 and 2010. This period did not overlap with a UME, and there was no indication that abundance declined. Population modeling that integrated the abundance, calf production and stranding time series with measures of sea ice extent and benthic biomass indicated that both UMEs corresponded with periods of high sea ice extent and low benthic biomass (Stewart et al. 2023). However, the 2007-2010 period of low calf production coincided with low benthic biomass but not with heavy sea ice extent (Stewart et al. 2023), suggesting that while calf production was impacted, survival was not.

The duration and extent of the decline in calf production that occurred during and following the 2019-2023 UME exceed those of other periods of low calf production and suggest that the population may be adjusting to previously unencountered shifts in the Arctic ecosystem (Stewart et al. In press). These results highlight the value of long-term monitoring in elucidating factors influencing the population dynamics of ENP gray whales. NOAA/NMFS/SWFSC continues to closely monitor ENP gray whales with regular surveys to estimate abundance, calf production and body condition in order to provide the best scientific information available regarding the status of the population (e.g., Perryman and Lynn 2002; Perryman et al. 2002, 2021; Eguchi et al. 2023, 2024, 2025; Lang et al. 2024).

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Perryman pioneered this study in 1994 and lead the field effort for more than 20 years. His contributions to the science and fun of the project have everything to do with its enduring quality and success.

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Tables and Figures

Table 1: Estimated abundance (Mean and Median), standard error (SE), and 95% lower (LCL) and upper (UCL) confidence limits of gray whale mother-calf pairs migrating north off the Piedras Blancas Lighthouse Station, CA. Years when the population was experiencing a UME are highlighted in yellow.

Year	Mean	Median	SE	LCL	UCL
1994	987.6	978.5	91.7	833.0	1,193.5
1995	616.8	613.0	61.9	507.9	745.0
1996	1,231.1	1,222.0	112.0	1,034.5	1,486.1
1997	1,658.4	1,647.0	144.4	1,407.5	1,960.1
1998	1,461.2	1,448.0	128.6	1,237.0	1,749.5
1999	468.8	466.0	50.4	379.0	573.0
2000	316.0	313.0	37.1	252.0	396.5
2001	298.3	296.0	34.9	235.5	374.0
2002	894.4	887.0	84.2	754.0	1,080.1
2003	840.1	835.0	78.5	700.5	1,008.0
2004	1,677.6	1,665.0	147.2	1,425.5	1,998.5
2005	1,007.5	998.5	91.7	852.0	1,211.5
2006	1,101.1	1,094.0	104.5	926.0	1,327.5
2007	466.0	463.5	51.4	374.5	573.5
2008	609.6	604.0	62.4	504.0	742.5
2009	342.2	340.0	40.9	271.0	430.0
2010	282.8	280.0	35.5	222.0	359.0
2011	914.5	907.0	87.2	763.5	1,108.0
2012	1,264.1	1,254.0	115.7	1,065.5	1,511.6
2013	1,215.3	1,206.0	112.4	1,021.5	1,461.5
2014	1,607.0	1,596.0	139.8	1,365.5	1,913.0
2015	1,560.4	1,548.0	138.7	1,325.0	1,860.5
2016	1,451.3	1,442.0	128.5	1,233.0	1,725.0
2017	1,093.9	1,086.0	102.6	913.0	1,315.0
2018	942.4	936.0	89.3	791.0	1,137.0
2019	340.2	337.0	42.9	267.0	433.0
2021	387.7	384.0	49.1	299.0	489.5

2022	210.8	208.0	32.9	154.0	282.0
2023	428.4	425.0	54.6	335.5	550.0
2024	217.2	215.0	35.0	158.0	293.5
2025	84.6	84.0	16.8	55.5	120.0

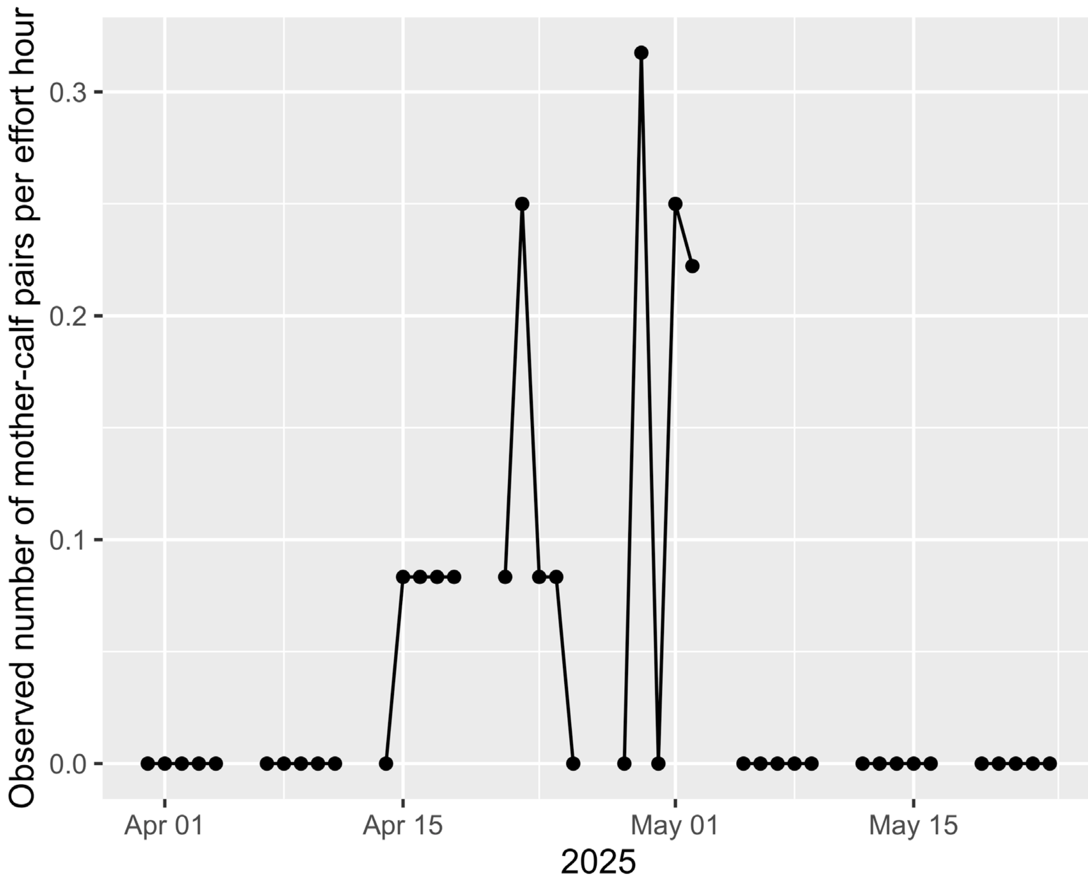

Figure 1: Observation rate (numbers per hour of survey effort) of gray whale mother-calf pairs migrating through the sampling area off Piedras Blancas during the 2025 survey period.

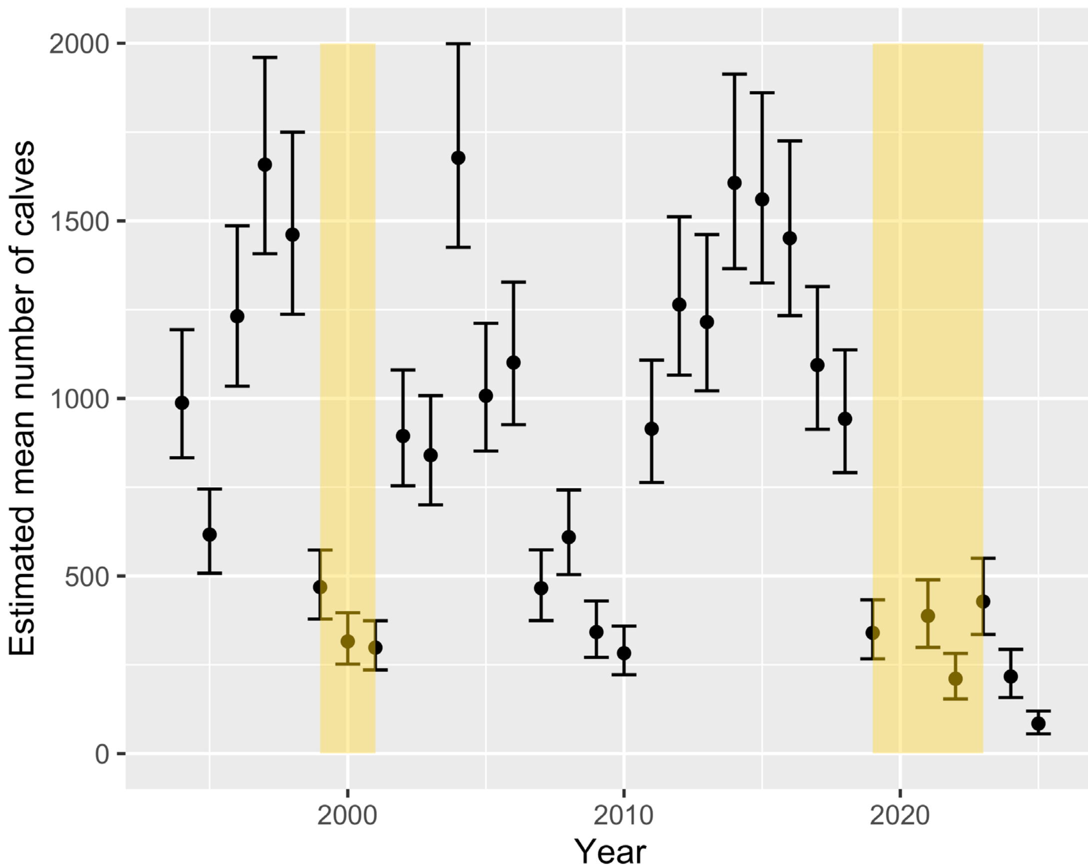

Figure 2: Estimated means and 95% CIs of the number of gray whale mother-calf pairs migrating north off Piedras Blancas between 1994 and 2025. Years when the population was experiencing a UME are highlighted in yellow.