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EASTERN NORTH PACIFIC GRAY WHALE CALF PRODUCTION 1994-2022

Tomoharu Eguchi, Aimée R. Lang, and David W. Weller

NOAA Fisheries, SWFSC Marine Mammal and Turtle Division
8901 La Jolla Shores Drive, La Jolla, California

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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 use the protected lagoons in Baja California Sur, Mexico, during the winter 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. Survey methods were evaluated in detail at the outset of the study (Perryman et al. 2002) and have remained consistent since 1994 (Perryman et al. 2021, Stewart and Weller 2021a).

The analytical approach used to estimate total annual calf production remained consistent through the 2019 survey (see Weller and Perryman 2019). The annual survey was not conducted in 2020 due to COVID-19. In 2021, a new Bayesian modeling approach to estimate annual calf production of ENP gray whales was used by Stewart and Weller (2021a). This method accounted for uncertainty during unsampled periods (i.e., evenings, weekends and during periods of unworkable weather). Here we provide estimates of calf production for the 1994-2022 period using the Bayesian approach.

METHODS

Data for this analysis were collected between 1994-2022 using standardized methods and processed to be consistent with previous analyses (Perryman et al. 2002, Weller and Perryman 2019, Perryman et al. 2021, Stewart and Weller 2021a). Briefly, a rotating team of four observers conducted counts of mother-calf pairs from a shore station during a watch period of a maximum of 12 hours per day. Watches were terminated by inclement weather (e.g., rain, fog, wind, etc.), poor visibility or rough sea conditions, resulting in total daily effort frequently below the maximum of 12 hours.

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. Staffing limitations also resulted in one week of the 2022 survey being restricted to a three-person team. 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 12 hours for a four-person rotation.

The previous analyses using the method of Perryman et al. (2002) were based on the following observations and assumptions: (a) the number of calves passing offshore and outside of the range of shore-based observers was negligible (based on data from aerial surveys) and (b) the passage rates of mother-calf pairs were consistent between daytime and nighttime periods (based on recordings from infrared sensors). Independent replicate counts from two different shore-based observation stations conducted over seven consecutive years (1994-2000) suggested a detection probability of 0.889 (SE = 0.06375) (Perryman et al. 2002). All of these assumptions were maintained for the method used by Stewart and Weller (2021a) and the study presented here.

Raw data were processed to reflect the total number of calves passing within four 3-hour periods per day and the total survey effort per 3-hour period following Weller and Perryman (2019). The method of Perryman et al. (2002) used direct corrections for detection probability and effort to generate total calf production estimates. For example, if 2 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 (12-16 April). This number (22) 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 (2021a), a Bayesian model was developed to account for uncertainty associated with detection probability, effort and unsampled periods. In addition, an estimate of a passage rate that varies by week was used to help 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;

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

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

where $\hat{p}$ is the estimated detection probability in Perryman et al. (2002), and E_i is the number of hours of reported effort in each 3-hour survey period i. $N(\mu, \sigma)$ indicates the normal distribution with mean μ and standard deviation σ. 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 were 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 approximately 0.889 * 1.5/3 = 0.4445. Similarly, nights and weekends were broken into 3-hour periods, each of which had 0 sightings and 0 effort. Any missing watch periods, either due to inclement weather conditions or observer limitations (i.e., the use of three-person watch teams), were also recorded as having 0 sightings and 0 effort. The detection probability during unobserved periods was therefore 0. Finally, we used a Poisson distribution to model the mean passage rate of whales within each 3-hour period during a given week,

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

where λ_{w_i} is the mean passage rate for 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 was 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, an annual 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. For these years, the number of weeks surveyed were not consistent across years because of the differences in migration end dates but were instead designed to capture the full northbound migration from start to finish.

As reported by Stewart and Weller (2021a), the Bayesian approach used here resulted in generally greater estimates than the earlier method by Perryman et al. (2002) (Fig. 1). The estimator in Perryman et al. (2002) was negatively biased because it did not account for whales that were not sighted when no whales were observed. Because the observed number of whales was divided by the sighting probability (0.889) to calculate “corrected” number of whales, when no whales (zero whales) were observed, the correction resulted in zero, even though it was possible that the observers missed one or more whales. The Bayesian approach somewhat alleviated the problem by assuming the binomial likelihood of observation.

RESULTS and DISCUSSION

Calf production

From 28 March 2022 to 27 May 2022, 391 hours of survey effort were completed. Daily survey effort ranged from zero to 12 hours. A total of 41 gray whale mother-calf pairs were counted, with the highest daily count of 6 pairs on 20 April 2022, which equated to 0.5 pairs per hour when adjusted for survey effort (Fig. 2).

The estimate of total calf production in 2022 was 216.7 (SE = 33.4, 95% CI = 159 – 290, Table 1), which was the lowest estimate since the survey started in 1994 (Fig. 3). Reproductive rates of ENP gray whales have been very low for the last few years, with the calf production estimates in 2019 (356; 95% CI 283-450) and 2021 (383; 95% CI 300-481) also being some of the lowest in the time series (Fig. 3). Two previous periods of low calf production also lasted for 3-4 years each (1999-2001 and 2007-2010, Fig. 3). Two of the three recorded periods of low calf production have coincided with Unusual Mortality Events (UMEs; 1999-2000 and 2019-2022) and corresponding declines in abundance (Stewart and Weller 2021b, Eguchi et al. 2022). Furthermore, there was a linear relationship between estimated abundance and estimated calf production (Fig. 4). The estimated abundance for ENP gray whales between 1994 and 2022 ranged from 16,033 in 2002 to 26,960 in 2016 (Table 2; Eguchi et al. 2022). The proportion of mother-calf pairs to total abundance ranged from 0.013 in 2022 to 0.068 in 1998 (Table 2). This pattern suggests that the factors driving or mediating rates of ENP gray whale fecundity and mortality may be similar.

While ENP gray whales have shown long-term resilience to fluctuations in abundance for which a direct cause has yet to be determined, NOAA/NMFS/SWFSC continues 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. 2020, Stewart and Weller 2021a, Stewart and Weller 2021b, Eguchi et al. 2022). The results of these research efforts will continue to provide the best scientific information available regarding the status of the population.

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LITERATURE CITED

Durban, J.W., Weller, D.W., Lang, A.R. and Perryman, W.L. (2015) Estimating gray whale abundance from shore-based Counts using a multilevel Bayesian model. J Cetacean Res Manag 15:61–67.

Durban, J., Weller, D. and Perryman, W. (2017). Gray whale abundance estimates from shore-based counts off California in 2014/15 and 2015/16. Paper SC/A17/GW/06 presented to the International Whaling Commission.

Eguchi, T., Lang, A. and Weller, D.W. (2022). Abundance and migratory phenology of eastern North Pacific gray whales 2021/2022. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-668. https://doi.org/10.25923/x88y-8p07

Perryman, W.L., and Lynn, M.S. (2002). Evaluation of nutritive condition and reproductive status of migrating gray whales (*Eschrichtius robustus*) based on analysis of photogrammetric data. J Cetacean Res Manag 2: 155–164.

Perryman, W.L., Donahue, M.A., Perkins, P.C. and Reilly, S.B. (2002) Gray whale calf production 1994-2000: Are observed fluctuations related to changes in seasonal ice cover? Mar Mammal Sci 18:121–144. doi: 10.1111/j.1748-7692.2002.tb01023.x

Perryman, W.L., Joyce, T., Weller, D.W. and Durban, J.W. (2021) Environmental factors influencing eastern North Pacific gray whale calf production 1994–2016. Mar Mammal Sci 37:448-62.

Rice, D.W. and Wolman, A.A. (1971) Life history and ecology of the gray whale (*Eschrichtius robustus*). Am Soc Mammal (special issue) 3:1–142.

Stewart, J.D. and Weller, D.W. (2021a). Estimates of eastern North Pacific gray whale calf production 1994-2021. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-653. https://doi.org/10.25923/jebs-9k39

Stewart, J.D. and Weller, D.W. (2021b) Abundance of eastern North Pacific gray whales 2019/2020. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-639. https://doi.org/10.25923/bmam-pe91

Weller, D.W. and Perryman, W.L. (2019) Eastern North Pacific gray whale calf production estimates 1994-2018. Paper SC/68a/CMP17 presented to International Whaling Commission Scientific Committee.

Table 1: Eastern North Pacific gray whale calf production 1994-2022 with Mean, Median, SE, 95% lower (LCL) and upper (UCL) confidence limits. Years with unusual mortality events are highlighted in gray.

Year	Mean	Median	SE	LCL	UCL
1994	1,038.9	1,027.0	99.0	873.5	1,254.5
1995	656.3	652.0	69.4	538.5	809.0
1996	1,195.1	1,184.0	108.0	1,016.0	1,420.5
1997	1,632.8	1,619.0	142.6	1,394.0	1,938.0
1998	1,435.6	1,419.0	117.3	1,253.5	1,697.0
1999	484.0	481.0	52.8	395.0	595.0
2000	318.0	315.0	36.9	254.0	403.0
2001	300.8	299.0	36.3	235.5	375.0
2002	922.3	918.0	84.3	771.5	1,105.0
2003	845.2	839.0	77.6	710.5	1,013.6
2004	1,643.4	1,636.0	145.5	1,388.5	1,958.6
2005	1,014.4	1,008.0	93.5	859.5	1,215.0
2006	1,137.6	1,132.0	106.8	958.5	1,373.5
2007	453.9	451.0	50.7	364.0	568.0
2008	612.1	608.0	62.2	501.5	750.5
2009	360.1	356.0	43.4	286.0	455.5
2010	295.3	293.0	37.4	228.5	375.0
2011	931.7	924.0	88.5	784.5	1,123.5
2012	1,266.9	1,259.0	113.4	1,067.0	1,505.5
2013	1,229.3	1,220.5	114.6	1,036.5	1,481.0
2014	1,606.7	1,589.0	142.8	1,367.0	1,912.0
2015	1,558.0	1,542.5	141.6	1,318.9	1,889.6
2016	1,458.3	1,446.5	132.4	1,236.5	1,753.5
2017	1,143.3	1,133.0	105.2	965.5	1,371.0
2018	950.2	944.0	89.6	800.5	1,152.5
2019	356.5	353.0	43.2	282.0	452.0
2021	382.3	380.0	48.1	295.0	488.0
2022	216.7	214.0	33.4	159.0	290.0

Table 2: Estimates of gray whale abundance (N) and calf production (C) with 95% lower (LCL) and upper (UCL) confidence limits; prop_C is the proportion of calves to the total abundance. The years bounding unusual mortality events are highlighted in gray.

Season	N	LCL_N	UCL_N	C	LCL_C	UCL_C	prop_C
1993/1994	20,103	17,935.9	22,270.1	1,032.3	859.5	1,238.5	0.051
1995/1996	20,944	18,439.9	23,448.1	1,199.5	1,010.0	1,439.5	0.057
1997/1998	21,135	18,318.1	23,951.9	1,445.3	1,259.0	1,701.0	0.068
2000/2001	16,369	14,411.9	18,326.1	302.0	238.0	383.0	0.018
2001/2002	16,033	13,864.7	18,201.3	925.1	783.5	1,100.5	0.058
2006/2007	20,750	18,860.0	23,320.0	457.6	370.0	567.0	0.022
2007/2008	17,820	16,150.0	19,920.0	611.0	509.0	739.0	0.034
2009/2010	21,210	19,420.0	23,250.0	294.6	228.0	379.5	0.014
2010/2011	20,990	19,230.0	22,900.0	933.7	776.0	1,132.5	0.044
2014/2015	23,530	21,270.0	25,945.0	1,563.7	1,327.5	1,873.7	0.066
2015/2016	26,960	24,420.0	29,830.0	1,465.3	1,239.5	1,759.0	0.054
2021/2022	16,650	15,170.0	18,335.0	216.7	159.0	290.0	0.013

Figure 1: Differences in estimated calf production between the methods of Perryman et al. (2002) and Stewart and Weller (2021a). Yellow vertical bars indicate unusual mortality events.

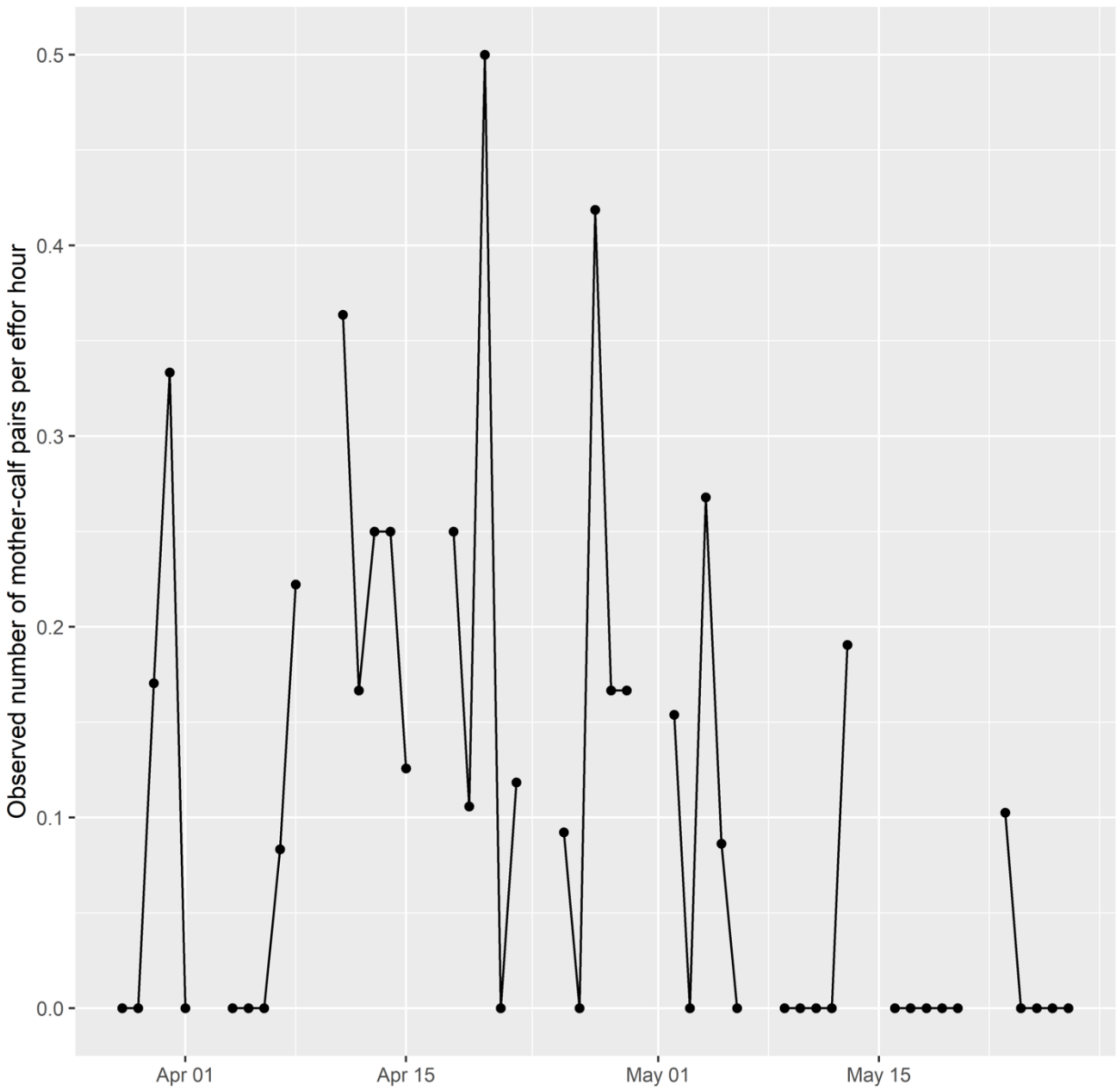

Figure 2: Observation rate (numbers per hour of survey effort) of mother-calf pairs migrating through the sampling area during the 2022 survey period.

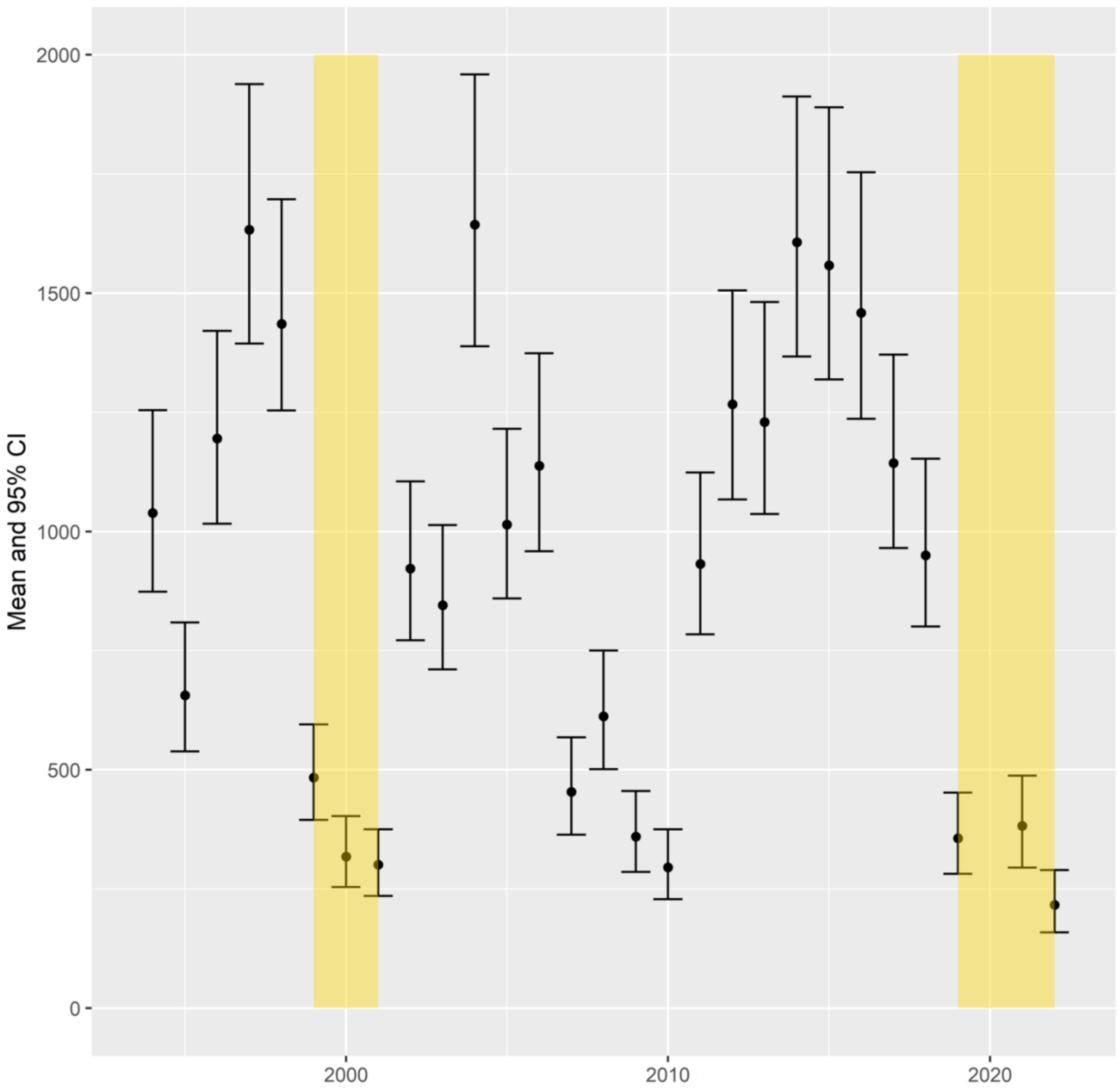

Figure 3: Annual estimates of eastern North Pacific gray whale calf production with associated 95% CIs. Yellow vertical bars indicate unusual mortality events.

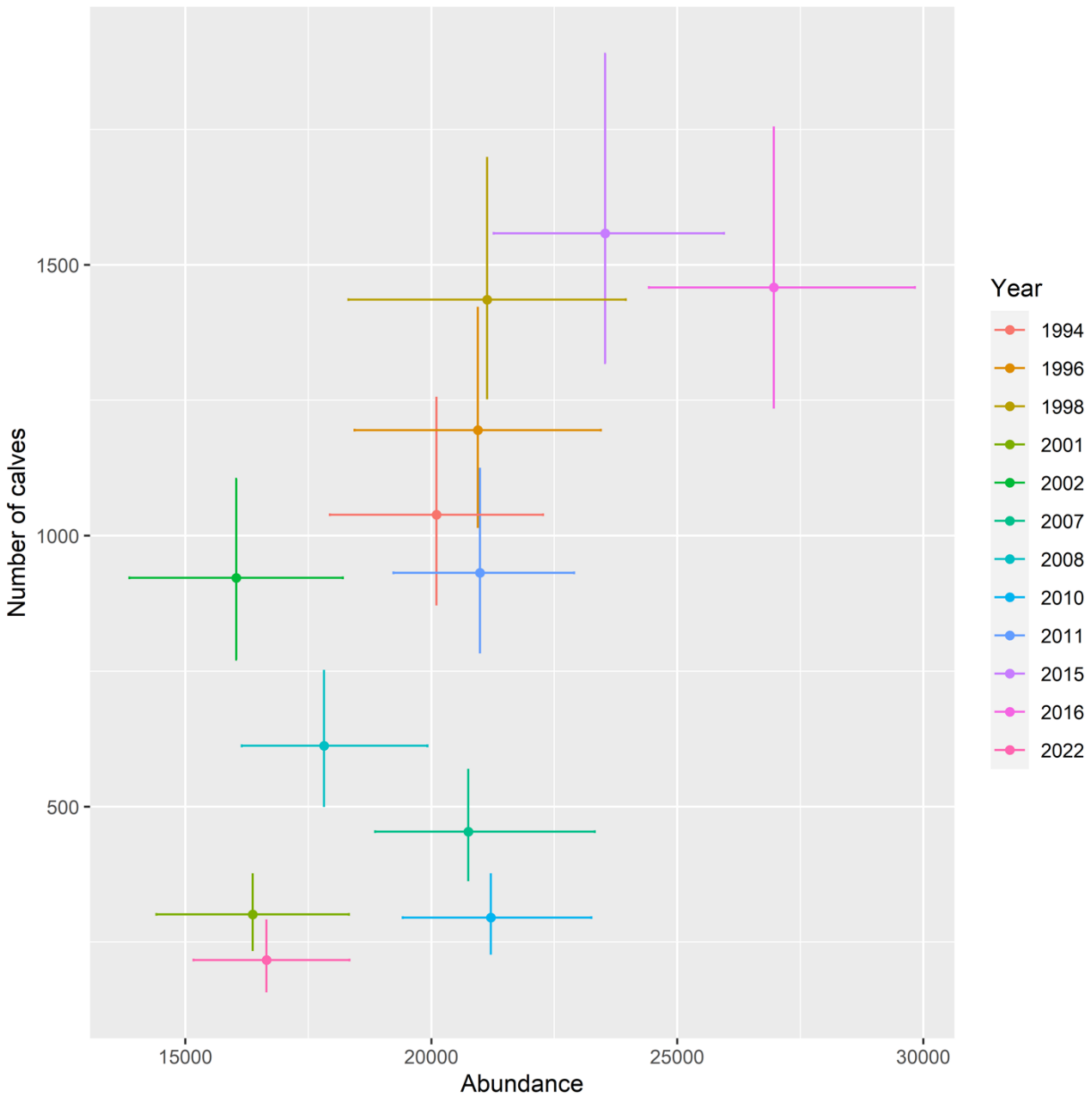

Figure 4: The relationship between estimated abundance and estimated calf production.