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EASTERN NORTH PACIFIC GRAY WHALE CALF PRODUCTION 1994-2024

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Eastern North Pacific gray whale calf production 1994-2024

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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; evenings, weekends, and bad weather days). Here we provide estimates of calf production for the 1994-2024 period using the Bayesian approach.

METHODS

Data for this analysis were collected between 1994-2024 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 prior to analysis was updated. The results were similar between the previously used versus the revised data extraction method, but some inconsistencies were identified. In particular, the previously used data extraction method assumed that the earliest start of an observer shift

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[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 at 7:00 am. The revised protocol allowed for earlier start times, which occurred occasionally. The revised data extraction method also calculated effort more accurately in cases where the sighting conditions changed in the middle of a given shift. Only the results using the revised method are reported in the main text, but a comparison of the results using the previous and updated data extraction protocols is shown in the Appendix.

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 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 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 (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.

To further evaluate patterns in calf production over the time series, we compared estimated calf production with estimated abundance of gray whales. Calf production is limited by the number of sexually mature females available during the primary breeding period, which occurs during a 3-week period from late November to early December (Rice & Wolman 1971). Gestation in gray whales lasts approximately 13 months (Rice and Wolman 1971). Since the proportion of sexually mature females in the ENP gray whale population is not known, we used a ratio based on the calf production estimate for a given year (e.g., spring 2023) divided by the estimated abundance based on counts of southbound migrating whales in the winter approximately a year and a half prior to that calf count (e.g., winter 2021/2022) as a measure of per capita calf production.

RESULTS and DISCUSSION

From 25 March 2024 to 24 May 2024, 404 hours of survey effort were completed. Daily survey effort ranged from zero to 12 hours. A total of 40 gray whale mother-calf pairs were counted. The highest daily count was 5 pairs over 12 effort hours on 02 April 2024, while the day with the highest sighting rate (0.889 pairs per effort hour) occurred on 18 April 2024 (Figure 1). The estimated number of mother-calf pairs during the 2024 migration season was 220.7 (95%CI = 161 - 295) (Table 1, Figure 2). This number is among the lowest of the time series that started since 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 27,450 whales (95% Credible Interval = 24,884.8 - 30,180.0) in 2015/2016 to 14,530 whales (95% Credible Interval = 13,234.8 - 15,960.0) in 2022/2023.

While the 2023 estimate of calf production was low (414.3, 95%CI = 322 - 522), it was nearly twice as high as that in 2022 (214.3, 95%CI = 156 - 290; Eguchi et al. 2023), which represented the lowest estimate of the time series. Abundance also increased in 2023/2024 and was estimated to be between 17,400 and 21,300 (Eguchi et al. 2024). These increases contrast with the decline in calf production seen between 2023 and 2024. Observations of mother-calf pairs using the Mexican wintering lagoons also showed a decrease; in the winter of 2023/2024 the number of mother-calf pairs using San Ignacio Lagoon was the lowest observed since surveys started in 2006 (Urbán et al. 2024).

When patterns in calf production over the time series were evaluated based on the per capita calf production ratios, the ratio calculated for 2024 (0.015) was the lowest of the time series and similar to that estimated for 2022 (Table 2). Mean per capita calf production over the time series was 0.041, while the maximum was 0.079 in the spring of 1997. If it is assumed that within the ENP population the proportion of females is 50% and the percent of mature whales is between 47 and 60% (as estimated in Taylor et al. 2007 for a growing and stable population, respectively), the ratio of calves produced per sexually mature female would range from 0.051 to 0.34.

Variation in gray whale calf production has been linked to sea ice cover in the Bering and Chukchi Seas during early gestation 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). Two previous periods of low calf production have occurred since monitoring began in 1994. One of these overlapped in part

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

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 (1674, 95% CI = 1419 - 2001). 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 heavy sea ice extent (Stewart et al. 2023), suggesting that while calf production was impacted, survival was not.

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 (e.g., Perryman and Lynn 2002; Perryman et al. 2002, 2021; Eguchi et al. 2023, 2024) in order to provide the best scientific information available regarding the status of the population.

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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	Method
1994	1,009.3	999.5	95.0	851.0	1,222.5	Stewart&Weller
1995	656.0	652.0	69.5	534.0	804.0	Stewart&Weller
1996	1,271.2	1,261.0	113.6	1,077.0	1,509.5	Stewart&Weller
1997	1,660.1	1,648.0	148.6	1,400.0	1,992.0	Stewart&Weller
1998	1,514.3	1,503.0	137.0	1,283.0	1,813.5	Stewart&Weller
1999	468.7	467.0	51.9	374.0	582.1	Stewart&Weller
2000	318.8	315.0	38.8	251.0	403.0	Stewart&Weller
2001	308.4	305.0	38.4	244.5	392.0	Stewart&Weller
2002	912.8	908.0	84.7	762.0	1,097.0	Stewart&Weller
2003	879.7	873.0	84.0	735.0	1,060.0	Stewart&Weller
2004	1,673.8	1,659.5	153.1	1,419.0	2,001.0	Stewart&Weller
2005	1,003.3	996.0	90.4	847.0	1,207.0	Stewart&Weller
2006	1,131.9	1,123.0	109.2	947.0	1,369.0	Stewart&Weller
2007	460.8	458.0	52.9	369.0	572.0	Stewart&Weller
2008	616.0	610.0	64.0	509.0	759.0	Stewart&Weller
2009	353.3	350.0	45.1	274.5	448.5	Stewart&Weller
2010	281.9	278.0	37.3	218.0	362.0	Stewart&Weller
2011	961.0	952.0	97.0	802.0	1,177.6	Stewart&Weller
2012	1,249.6	1,240.5	114.3	1,056.0	1,505.1	Stewart&Weller
2013	1,223.7	1,214.0	112.5	1,027.0	1,470.0	Stewart&Weller
2014	1,616.7	1,608.0	143.8	1,364.0	1,940.0	Stewart&Weller
2015	1,558.3	1,544.0	141.3	1,312.5	1,856.0	Stewart&Weller
2016	1,453.0	1,445.0	132.3	1,230.0	1,734.1	Stewart&Weller
2017	1,079.7	1,073.0	99.6	909.0	1,295.1	Stewart&Weller
2018	948.0	938.0	90.8	796.0	1,152.5	Stewart&Weller
2019	342.4	340.0	43.4	266.0	440.0	Stewart&Weller
2021	380.5	377.0	48.2	300.0	486.0	Stewart&Weller
2022	214.3	212.0	33.9	156.0	290.0	Stewart&Weller
2023	414.3	410.0	51.9	322.0	522.0	Stewart&Weller
2024	220.7	218.0	34.1	161.0	295.0	Stewart&Weller

Table 2: Estimates and 95% lower (LCL) and upper (UCL) confidence limits of gray whale total abundance and mother-calf pairs. Season corresponds to the winter that the abundance survey was conducted while Year corresponds to the spring in which the calf production survey was conducted. prop_MC is the proportion of mother-calf pairs for the Year to the total abundance estimated for the Season.

Season	Abundance	LCL_N	UCL_N	Year	Calf	LCL_MC	UCL_MC	prop_MC
1992/1993	15,762	13,661.2	17,862.8	1994	1,009.3	851.0	1,222.5	0.064
1993/1994	20,103	17,935.9	22,270.1	1995	656.0	534.0	804.0	0.033
1995/1996	20,944	18,439.9	23,448.1	1997	1,660.1	1,400.0	1,992.0	0.079
1997/1998	21,135	18,318.1	23,951.9	1999	468.7	374.0	582.1	0.022
2000/2001	16,369	14,411.9	18,326.1	2002	912.8	762.0	1,097.0	0.056
2001/2002	16,033	13,864.7	18,201.3	2003	879.7	735.0	1,060.0	0.055
2006/2007	19,126	16,644.2	21,977.8	2008	616.0	509.0	759.0	0.032
2006/2007	20,640	18,569.0	23,985.8	2008	616.0	509.0	759.0	0.030
2007/2008	18,450	16,414.8	21,490.0	2009	353.3	274.5	448.5	0.019
2009/2010	20,960	19,200.0	23,060.0	2011	961.0	802.0	1,177.6	0.046
2010/2011	20,820	19,040.0	22,710.0	2012	1,249.6	1,056.0	1,505.1	0.060
2014/2015	23,440	21,264.8	26,055.8	2016	1,453.0	1,230.0	1,734.1	0.062
2015/2016	27,450	24,884.8	30,180.0	2017	1,079.7	909.0	1,295.1	0.039
2019/2020	20,630	18,840.0	22,710.5	2021	380.5	300.0	486.0	0.018
2021/2022	17,430	15,800.0	19,220.0	2023	414.3	322.0	522.0	0.024
2022/2023	14,530	13,234.8	15,960.0	2024	220.7	161.0	295.0	0.015

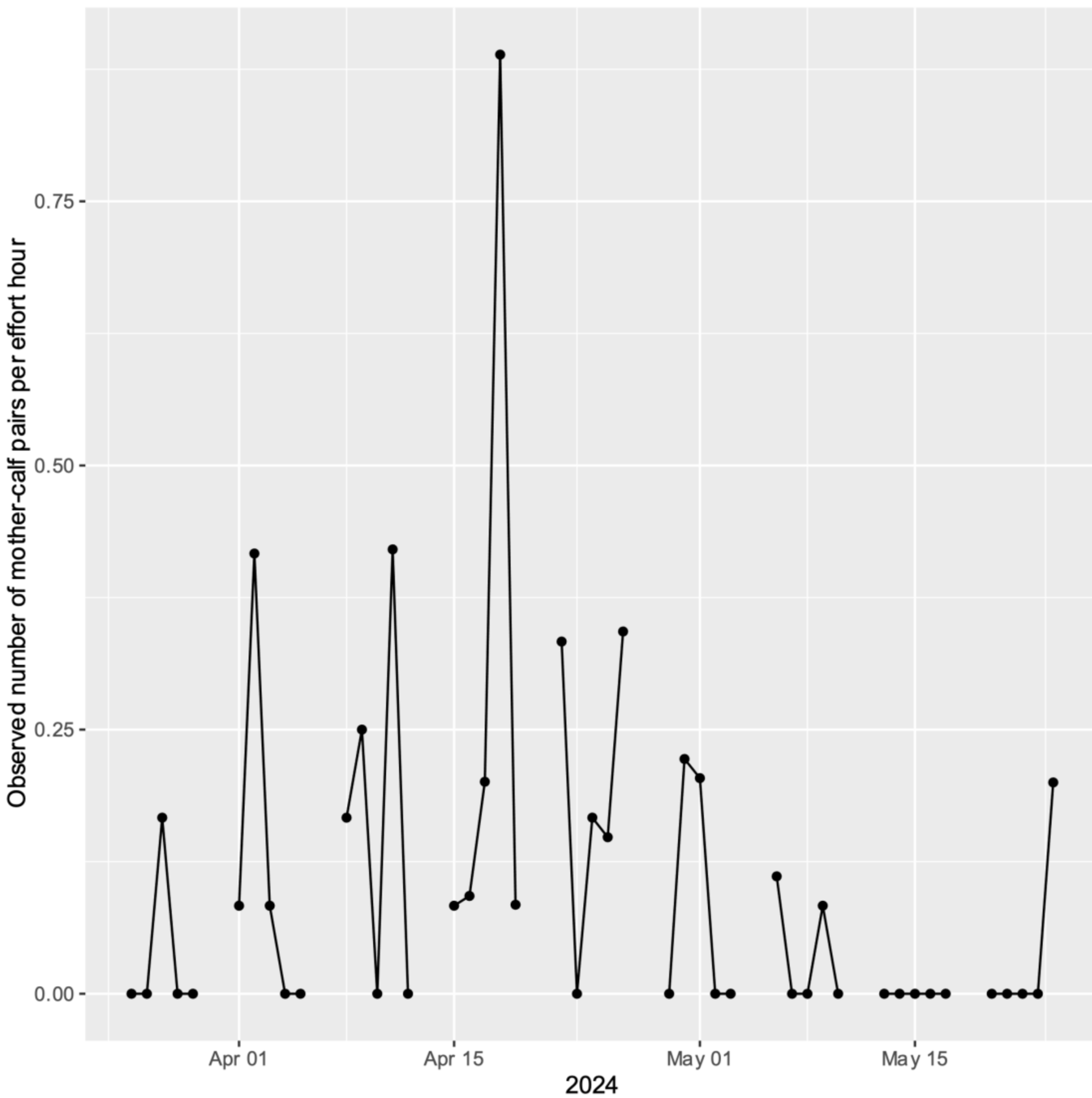

Figure 1: Observation rate (numbers per hour of survey effort) of mother-calf pairs of gray whales migrating through the sampling area off Piedras Blancas during the 2024 survey period.

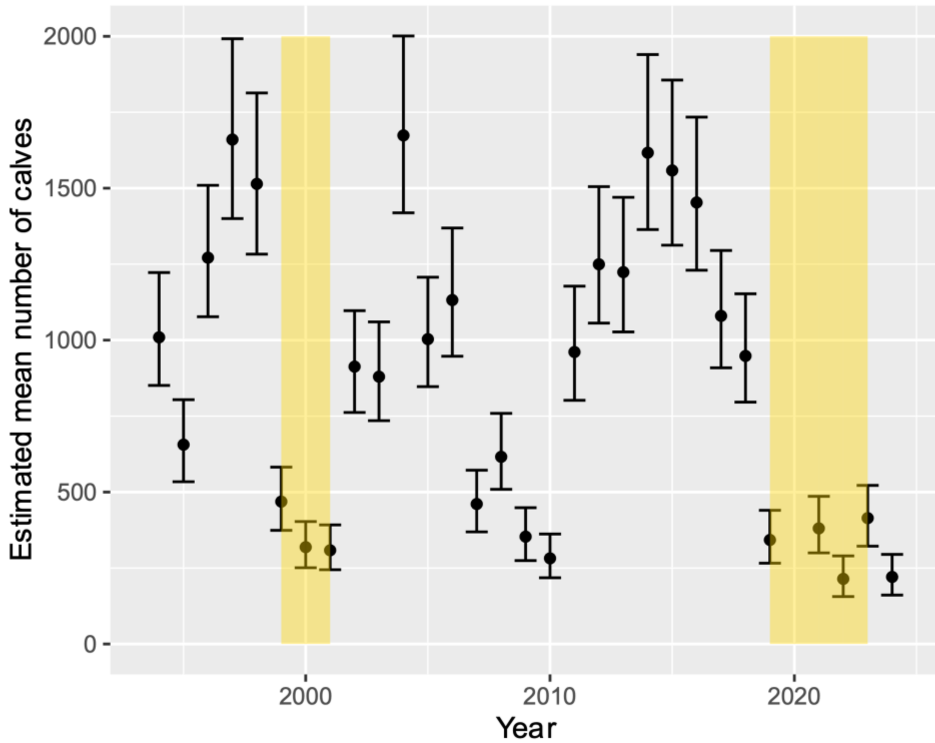

Figure 2: Estimated means and 95% CIs of the number of gray whale mother-calf pairs migrating north off Piedras Blancas between 1994 and 2024. Years when the population was experiencing a UME are highlighted in yellow.

Appendix

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. The estimates presented on the left side of the table reflect the new data extraction method (v3), while those on the right side (v1) represent the estimates using the previous data extraction method. Years when the population was experiencing a UME are highlighted in yellow.

	Updated Method					Previous Method				
Year	Mean.v3	Median.v3	SE.v3	LCL.v3	UCL.v3	Mean.v1	Median.v1	SE.v1	LCL.v1	UCL.v1
1994	1,009.3	999.5	95.0	851.0	1,222.5	1,038.9	1,027.0	99.0	873.5	1,254.5
1995	656.0	652.0	69.5	534.0	804.0	656.3	652.0	69.4	538.5	809.0
1996	1,271.2	1,261.0	113.6	1,077.0	1,509.5	1,195.1	1,184.0	108.0	1,016.0	1,420.5
1997	1,660.1	1,648.0	148.6	1,400.0	1,992.0	1,632.8	1,619.0	142.6	1,394.0	1,938.0
1998	1,514.3	1,503.0	137.0	1,283.0	1,813.5	1,435.6	1,419.0	117.3	1,253.5	1,697.0
1999	468.7	467.0	51.9	374.0	582.1	484.0	481.0	52.8	395.0	595.0
2000	318.8	315.0	38.8	251.0	403.0	318.0	315.0	36.9	254.0	403.0
2001	308.4	305.0	38.4	244.5	392.0	300.8	299.0	36.3	235.5	375.0
2002	912.8	908.0	84.7	762.0	1,097.0	922.3	918.0	84.3	771.5	1,105.0
2003	879.7	873.0	84.0	735.0	1,060.0	845.2	839.0	77.6	710.5	1,013.6
2004	1,673.8	1,659.5	153.1	1,419.0	2,001.0	1,643.4	1,636.0	145.5	1,388.5	1,958.6
2005	1,003.3	996.0	90.4	847.0	1,207.0	1,014.4	1,008.0	93.5	859.5	1,215.0
2006	1,131.9	1,123.0	109.2	947.0	1,369.0	1,137.6	1,132.0	106.8	958.5	1,373.5
2007	460.8	458.0	52.9	369.0	572.0	453.9	451.0	50.7	364.0	568.0
2008	616.0	610.0	64.0	509.0	759.0	612.1	608.0	62.2	501.5	750.5
2009	353.3	350.0	45.1	274.5	448.5	360.1	356.0	43.4	286.0	455.5
2010	281.9	278.0	37.3	218.0	362.0	295.3	293.0	37.4	228.5	375.0
2011	961.0	952.0	97.0	802.0	1,177.6	931.7	924.0	88.5	784.5	1,123.5
2012	1,249.6	1,240.5	114.3	1,056.0	1,505.1	1,266.9	1,259.0	113.4	1,067.0	1,505.5
2013	1,223.7	1,214.0	112.5	1,027.0	1,470.0	1,229.3	1,220.5	114.6	1,036.5	1,481.0
2014	1,616.7	1,608.0	143.8	1,364.0	1,940.0	1,606.7	1,589.0	142.8	1,367.0	1,912.0
2015	1,558.3	1,544.0	141.3	1,312.5	1,856.0	1,558.0	1,542.5	141.6	1,318.9	1,889.6
2016	1,453.0	1,445.0	132.3	1,230.0	1,734.1	1,458.3	1,446.5	132.4	1,236.5	1,753.5
2017	1,079.7	1,073.0	99.6	909.0	1,295.1	1,143.3	1,133.0	105.2	965.5	1,371.0

	Updated Method					Previous Method				
Year	Mean.v3	Median.v3	SE.v3	LCL.v3	UCL.v3	Mean.v1	Median.v1	SE.v1	LCL.v1	UCL.v1
2018	948.0	938.0	90.8	796.0	1,152.5	950.2	944.0	89.6	800.5	1,152.5
2019	342.4	340.0	43.4	266.0	440.0	356.5	353.0	43.2	282.0	452.0
2021	380.5	377.0	48.2	300.0	486.0	382.3	380.0	48.1	295.0	488.0
2022	214.3	212.0	33.9	156.0	290.0	216.7	214.0	33.4	159.0	290.0
2023	414.3	410.0	51.9	322.0	522.0	412.4	411.0	51.6	321.0	524.0
2024	220.7	218.0	34.1	161.0	295.0					