Estimation of Gray Whale (*Eschrichtius robustus*) Birth Interval based on Photo-ID in Laguna San Ignacio, BCS, México (2005-2017).

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Abstract

Birth interval (the interval between the births of sequential calves) were calculated from photographic records of known individual females gray whales (*Eschrichtius robustus*) obtained during the winter breeding/calving season from January to April between the years 2005 and 2017 in Laguna San Ignacio, Baja California Sur, México. Photographically documented birth histories indicated 1394 female gray whales produced 1930 calves during the 13year study period: 1038 females were photographed only once with a calf and birth intervals could not be calculated; 356 females were photographed with 2 to 5 calves during the study. The birth histories for these 356 females included 536 birth intervals ranging from 2-11years; no annual births (two births in sequential years) were documented; some birth intervals were incomplete with no photographs obtained for periods from 2-10 years, and due to the uncertainty of the presence or absence of calves in the missing years, these were not used to calculate average birth interval. An average birth interval of 2.39 years (S.D. ± 0.556) was calculated from 375 unambiguous birth intervals ranging from 2-4 years: 2 yr intervals n= 240 (64%); 3 yr intervals n= 122 (32.5%); and 4 yr intervals n= 13 (3.5%). Low counts of females with calves in Laguna San Ignacio between 2005 and 2010 were investigated by comparing the total number of female-calf pairs photographed (n = 1930) and the number of calves produced by the 356 females observed with 2 to 5 calves (n = 892) for two periods, from 2005 to 2010, and from 2011 to 2017. This comparison indicated 23.2% (n= 448) of all calves observed and 18.2% (n= 65) of the calves from females observed with 2-5 calves born during the period from 2005 to 2010, compared to 76.8% (n= 1482) and 81.8% (n= 291), respectively, were born during the period from 2011-2017, suggesting that overall calf production increased during the most recent period. We suggest that environmental factors reducing the prey availability on the summer feeding areas, and the loss of breeding females during the range-wide mortality event in the late 1990's may have contributed to the reproductive decline during the period from 2005-2010, and that the increasing number of calves observed in recent years is the result of new cohorts of females reaching sexual maturity and beginning to reproduce, and the changes in ice cover areas and duration of ice cover in the Artic in recent years.

Key words: birth history; birth interval; Eschrichtius robustus; *gray whale; photographic identification; population growth;*

Introduction

The birth interval or calving interval is the period of time (given in years) between the birth of successive calves (Barlow, 1990), and it is a fundamental parameter for understanding the dynamics of cetacean populations. Estimation of birth interval is particularly important for modeling exercises designed to project the potential growth of a given population and, in the case of endangered populations, their ability to recover from a depleted state (Cooke *et al*., 2008). Estimation of birth interval requires continuous monitoring of known individuals of a species for a long periods of time, which is rare for free ranging large cetaceans. Photographic identification (Photo-ID) methods allow positive identification of individual whales over prolonged periods of time, and these data facilitate the documentation and estimation of important behavioral and population statistics including: local movements and oceanic migrations, site fidelity and duration of residence, minimum age estimation, reproductive rates including birth intervals, etc. (Hammond *et al*., 1990).

Gray whales attain sexual maturity at ages from 6 to12 years (average is 8 years for both sexes), and generally have a two year reproductive cycle allowing the production of one calf every two years, although longer intervals of three or more years between calves may occur (Rice and Wolman, 1971; Jones, 1990). Females usually conceive following their first ovulation but may undergo another estrous cycle about 40 days later if they fail to conceive (Rice and Wolman, 1971). Mating and calving are strongly seasonal and synchronized with the migratory cycle when females come into estrus in late autumn or in early winter. Thus, mating occurs mainly during the middle of the fall southward migration along the Western coast of North American, although courtship and mating activity continues during January and February on the winter aggregation and breeding areas of Baja California, Mexico (Swartz, 1986; Jones and Swartz, 2009). Following mating and conception, from late-January to April female gray whales begin their northward migration to the summer feeding grounds in the North Pacific and Arctic seas. They arrive as the winter ice cover is receding and this allows them to maximize feeding time in the North Pacific and Arctic (Perryman *et al*., 2002).

Following summer feeding, late pregnant females begin their southward migration in November and December to return to their winter aggregation and calving areas off Baja California. Estimates of the gestation period vary from 11 to 13 months (Jones and Swartz 1984; Sumich 2014). Birth season for the eastern North Pacific population lasts from late December to early March, when near-term females are in or near the Mexican calving grounds, although some are born during migration off California. Mothers and calves remain in the breeding area until April or May, allowing calves to strengthen and rapidly increase in size before the north migration. Weaning occurs at 7–9 months usually around August. Females then have a 3–4 month resting period until their next estrus begins anew around November–December, thus completing the 2-yr reproductive cycle (Swartz, 1986; Jones and Swartz, 2009).

Here we present updated estimates of the average and range of birth intervals for known individual females of the Eastern North Pacific gray whale population that resided in Laguna San Ignacio, Baja California Sur, Mexico during the winter months from 2005 to 2017. Our estimated average birth interval is compared with previous estimates by Jones (1990) and Díaz (2004 unpublished), and we discuss environmental factors that may have influenced gray whale reproduction during the study period, particularly low calf counts during the period from 2005 to 2010, and that will likely continue to affect the whales' behavior and biology. The Photo-ID data obtained during this 13-year period represents the longest such time series for any gray whale population, and demonstrates the value of dedicated sampling efforts and long-term field studies of known individuals.

Methods.

Study Site:

San Ignacio lagoon is located in the western coast of Baja California Peninsula, among the 26˚ 43' and the 27˚00' of latitude N and 113˚16' and the 113˚08' of longitude W (Figure 1). This lagoon is part of the Vizcaino Biosphere Reserve, with a maximum length (from north to south) of 30 km and a maximum width of 6 km. The lagoon is protected from the ocean by the barrier islands however it's entrance is open to the ocean allowing tidal waters to flow into and out of the lagoon through a network of deep channels. Interior channels range in depth from 25 meters near the entrance, to only 2 meters in the northernmost interior. The dominant winter winds are from the northwest and southwest (Winant & Gutiérrez, 1999).

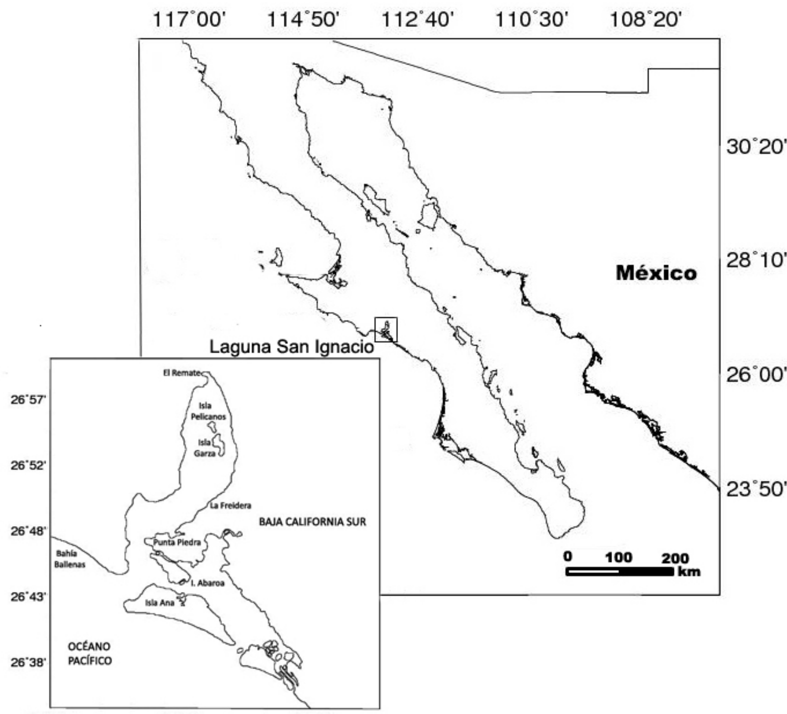

Figure 1. Laguna San Ignacio, Baja California Sur, México.

Photo-ID Procedure:

Photo-ID surveys were conducted in Laguna San Ignacio Baja California Sur, México, during the winter months (January to April) from 2005 to 2017 by teams of researchers from the

Universidad Autónoma de Baja California Sur and the Laguna San Ignacio Ecosystem Science Program (UABCS/LSIESP). Surveys were conducted from a 7 m. long open boat (panga) powered by a 75 hp outboard motor. The entire lagoon interior was searched for whales during each survey, and all gray whales encountered were photographed, particularly females with calves. A suite of information was recorded for each gray whale sighting, including: date; time of sighting; sighting number; group type (e.g., single individual, female-calf pair); group size; and environmental conditions (e.g., visibility, wind direction, water temperature, depth at sighting location).

Whales were approached to within 10 to 20 meters to ensure adequate photograph image size and resolution. Whenever possible, digital photographs were obtained for both the left and right dorsal flanks of each whale, however to insure positive identification of individuals, only images of the right sides of the whales were used in the analysis of birth interval. Photographs were made using Canon and Nikon Digital SLR (Single Lens Reflex) cameras fitted with 70 mm to 300 mm zoom telephoto lenses, at exposures of 1/1000 second and an ISO light sensitivity setting = 200. All digital images were assigned a unique alphanumeric reference number that indicated: the year (05-17); an individual reference number (from 1 to n for each year); whether the image was of the left or right side of the whale; the lagoon (LSI = Laguna San Ignacio); and the sex/reproductive class of the whale (single or female-calf pair).

All of the digital images obtained during a winter season were assembled into a Photo-ID catalog for that year (one catalog for each year), and these catalogs were compared to identify "recaptures" (re-sightings) of the same individuals within a winter season, and across all years. For known females, birth histories were compiled from the images during years when the whale was photographed with a calf and years when it was photographed as a single whale. Birth intervals (the number of years between photographs of a female with a calf) were identified from the birth histories of each female whale. Because each female was not photographed every year, and due to the uncertainty of a calf's presence in years without photographs, birth intervals with sequences of two or more years without the photographic documentation of a calf were not used in the analysis of average birth interval; thus, "average birth interval" for known females was estimated from unambiguous birth intervals of $\leq$ 4-yrs and documentation of two calves (one the year before an interval begins, and a second calf at the end of the interval). Birth intervals from all known females were also compared for two time periods (from 2005 to 2010 compared to 2011 to 2017), to determine if there have been changes in the birth rates during the study period that corresponded to observations of calf abundance for the same years in San Ignacio Lagoon.

Results:

Photo-ID Effort:

From 2005 to 2017, 641 Photo-ID surveys were conducted yielding 6116 digital photoidentifications (right sides). From these photographs a total of 1930 female-calf pairs were identified (Table 1). Of these, 536 females were re-photographed in different years, yielding the identification of 1394 unique individual females, each with a unique birth history.

Of the 1930 individual females, 1038 were photographed only once with a calf, and their birth histories could not be used to calculate birth intervals. The remaining 356 females were re-photographed with two to five calves in different years during the 13-year study period: 222 with two calves; 95 with three calves; 32 with four calves; and 7 with five calves. The birth histories for these females included 536 birth intervals that ranged from two-years to 11-years (Table 2). All calves were young-of-the-year, and no annual birth intervals were identified, which is consistent with the gray whale's 2-year reproductive cycle.

Table 1. Photographic Identification effort for gray whales carried out between 2005 and 2017 in the Laguna San Ignacio, BCS. (N/A- not available).

Year	Survey Effort (days)	Effort (hours)	No. of Sightings	Total No. of right side Photo-ids	No. of Female-calf pairs Photo ids
2005	33	N/A	N/A	402	116
2006	15	66.3	107	248	54
2007	25	155.1	261	353	75
2008	31	135.7	249	244	90
2009	58	300.7	540	524	75
2010	58	366.8	630	561	37
2011	55	319.2	686	510	188
2012	64	359.3	863	546	213
2013	57	290	607	478	185
2014	66	336.5	906	653	199
2015	67	348.3	1145	512	279
2016	56	320.3	830	577	221
2017	56	264.9	489	508	198
Totals:	641	3263.1	7313	6116	1930

Average Birth Interval:

Some birth intervals were incomplete, missing photographs for periods up to 10-yrs, and because of the uncertainty of the presence or absence of a calf in years without photographs, these could not be used to calculate average birth interval. An average birth interval of 2.39 years (S.D. ± 0.556) was calculated from 375 birth intervals that ranged from two years to four years with unambiguous documentation of the presence or absence of a calf. These included: 240 two year intervals (64%); 122 three year intervals (32.5%); and 13 four year intervals (3.5%) (Table 2 shaded entries).

Table 2. Birth intervals (536) from 356 known females that ranged from 2-years to 11-years. The shaded area corresponds to the 375 birth intervals of ≤ 4 years with sufficient information to confirm the presence or absence of a calf in a given year that were used to estimate the average birth interval of 2.39 years (+ 0.55 years).

● = Female-calf pair, ○ = Single whale, --- = No record.

No. of Intervals	breeding interval (years)	Years =>	1	2	3	4	5	6	7	8	9	10	11
215	2	●	---	●									
25	2	●	○	●									
101	3	●	---	---	●								
4	3	●	○	---	●								
17	3	●	---	○	●								
1	4	●	○	○	○	●							
3	4	●	○	○	---	●							
2	4	●	---	○	○	●							
7	4	●	---	○	---	●							
2	4	●	○	---	---	●							
7	4	●	---	---	○	●							
51	4	●	---	---	---	●							
22	5	●	---	---	---	---	●						
1	5	●	○	---	---	○	●						
1	5	●	○	---	---	---	●						
6	5	●	---	○	---	---	●						
1	5	●	---	○	---	○	●						
1	5	●	---	---	○	---	●						
7	5	●	---	---	---	○	●						
17	6	●	---	---	---	---	---	●					
1	6	●	---	○	---	---	---	●					
1	6	●	---	---	○	---	○	●					
1	6	●	---	---	---	○	---	●					
2	6	●	---	---	---	---	○	●					
8	7	●	---	---	---	---	---	---	●				

1	7	●	○	---	---	---	---	---	●				
1	7	●	○	○	---	○	---	○	●				
1	7	●	○	---	---	---	---	○	●				
2	7	●	---	○	---	---	---	---	●				
1	7	●	---	---	○	---	---	---	●				
1	7	●	---	---	---	○	○	---	●				
3	7	●	---	---	---	---	---	○	●				
9	8	●	---	---	---	---	---	---	---	●			
1	8	●	---	---	○	---	---	---	---	●			
1	8	●	---	---	---	○	○	---	○	●			
1	8	●	---	---	---	---	---	○	---	●			
4	9	●	---	---	---	---	---	---	---	---	●		
1	9	●	---	---	○	---	---	---	---	---	●		
4	10	●	---	---	---	---	---	---	---	---	---	●	
1	11	●	---	---	---	---	---	---	---	---	---	---	●

Comparison of Average Birth Intervals:

Two previous estimates of gray whale birth interval from different time periods were compared with the average birth interval reported in this study. Jones (1990) calculated an average birth interval of 2.11 years (SD = 0.40) from 64 birth intervals from 55 known female gray whales photographed in Laguna San Ignacio between 1977 and 1982. These birth intervals ranged from one year (1.6%), two years (87.5%), to three years (9.4%), and four years (1.6%).

Díaz (unpublished) calculated an average birth interval of 2.41 years (SD = 0.50) from 17 birth intervals from female gray whales photographed in Laguna San Ignacio and Laguna Ojo de Liebre (LOL) between 1996 and 2002. These intervals ranged from two years (47.1%), to three years (29.4%), and four years (23.5%).

The average birth interval reported in this study is 2.39 years (SD = 0.55 years) calculated from 375 birth intervals from 356 identified female whales: 64% were two year intervals; 32.5% were three year intervals; and 3.5% were four year intervals (Table 3).

Table 3. Effort data, average and frequencies of birth interval for the three sampling periods. LSI = Laguna San Ignacio, LOL = Laguna Ojo de Liebre.

Author	Jones	Díaz	UABCS/LSIESP
Photo/ID Sampling periods	1977-1982	1996-2002	2005-2017
Survey area	LSI	LSI & LOL	LSI
No. of photographs	6074	9966	101354
Whales photo identified	562	2471	4751
Females photo identified	55	1137	1394
No. of birth intervals analyzed	64	17	375
Average birth interval	2.11	2.41	2.39
SD (Standard deviation)	0.403	0.50	0.556

Birth interval (1 year)	1.6%	---	---
Birth interval (2 years)	87.5 %	58.8 %	64 %
Birth interval (3 years)	9.3 %	41.2 %	32.5 %
Birth interval (4 years)	1.6 %	---	13.5 %

The estimated average birth intervals calculated for three different time periods were statistically compared with a non-parametric Kruskal-Wallis test (Math Lab version X), which revealed a Chi-square value of 22.35, and probability value of $p = 1.4x10^{-5}$ (< 0.05), suggesting there are significant differences between the three average birth interval values (Table 4).

Table 4. Kruskal-Wallis analysis to compare the average birth interval average among different periods: Jones (1977-1982), Díaz (1996-2002) and UABCS/LSIESP (2005-2017).

Kruskal-Wallis ANOVA Table

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	194241.6	2	97120.8	22.35	1.40501e-05
Error	3117618.9	379	8225.9		
Total	3311860.5	381			

To determine the significance of the differences in the average values of the three birth interval estimates, a multiple comparative analysis was calculated using a Scheffe statistic (Zar 1984) with the Confidence Interval of 95%. These comparisons indicated that there was no significant differences between the Díaz (Unpublished) estimate versus the other studies, yet these was a significant difference between the birth interval estimate by Jones (1990) versus the average birth interval estimate presented in this study (Fig. 2 & 3).

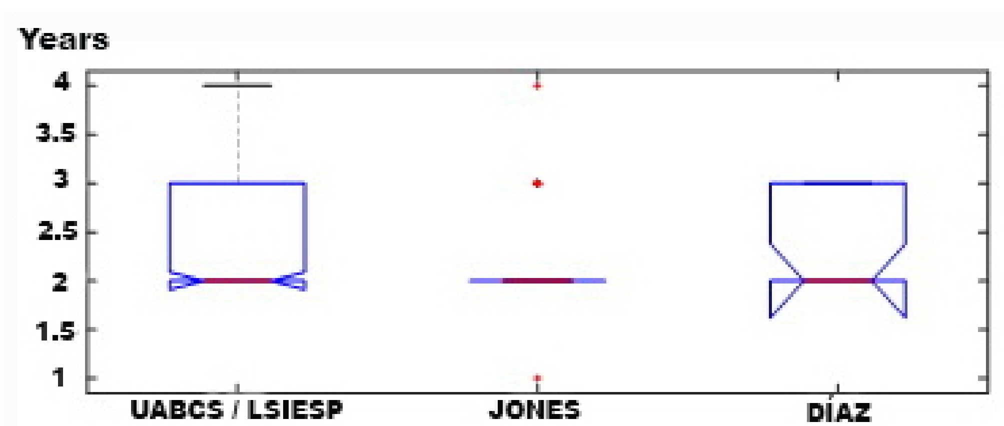

Figure 2. Comparison of the estimated average birth intervals obtained from this study (2005-2017), Jones (1977-1982), and Díaz (1996-2002).

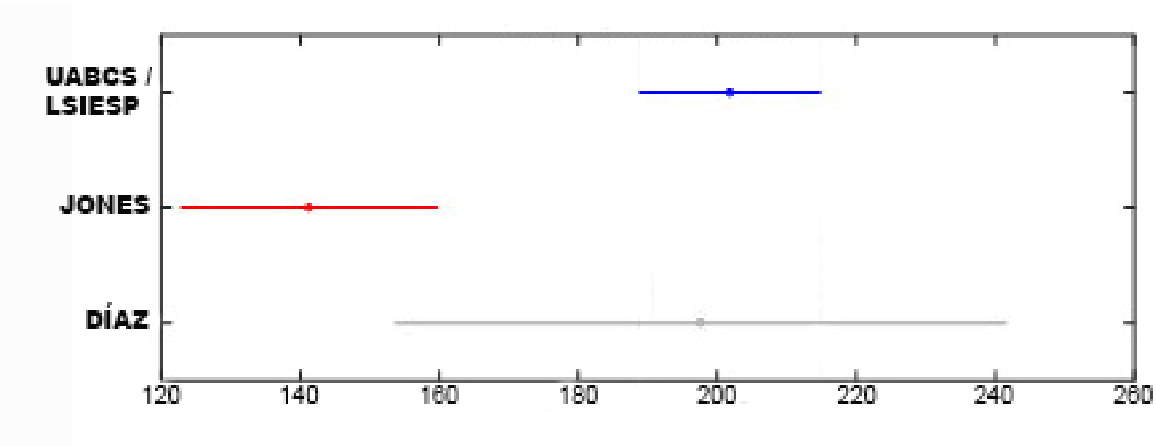

Figure 3. Graph of the Scheffe statistics to compare the average values and birth interval variances, data obtained from UABCS/LSIESP (2005-2017), Jones (1977-1982), and Díaz (1996-2002).

Temporal Distribution of Calf Births from 2005 to 2017:

The temporal distribution of calf births across the entire study period (2005 to 2017) was examined by comparing the number of calves observed in two time periods: 2005 to 2010 and 2011 to 2017. These time periods were selected because they corresponded to consecutive years of low calf counts observed in Laguna San Ignacio (2005 to 2010), and consecutive years with increasing numbers of calves counted in the lagoon (2011-2017). This comparison was done for two groups: (1) the total number of females observed with at least one calf (n = 1930); and (2) the females that produced two or more calves during the study period (n = 356).

This comparison revealed that 23.2% (n= 447) of all females observed with at least one calf and 18.2% (n= 162) of the calves from females observed with two or more calves were born during the first period from 2005 to 2010, compared to 76.8% (n= 1483) and 81.8% (n= 730), respectively, that were born during the most recent period from 2011-2017 (Fig. 4).

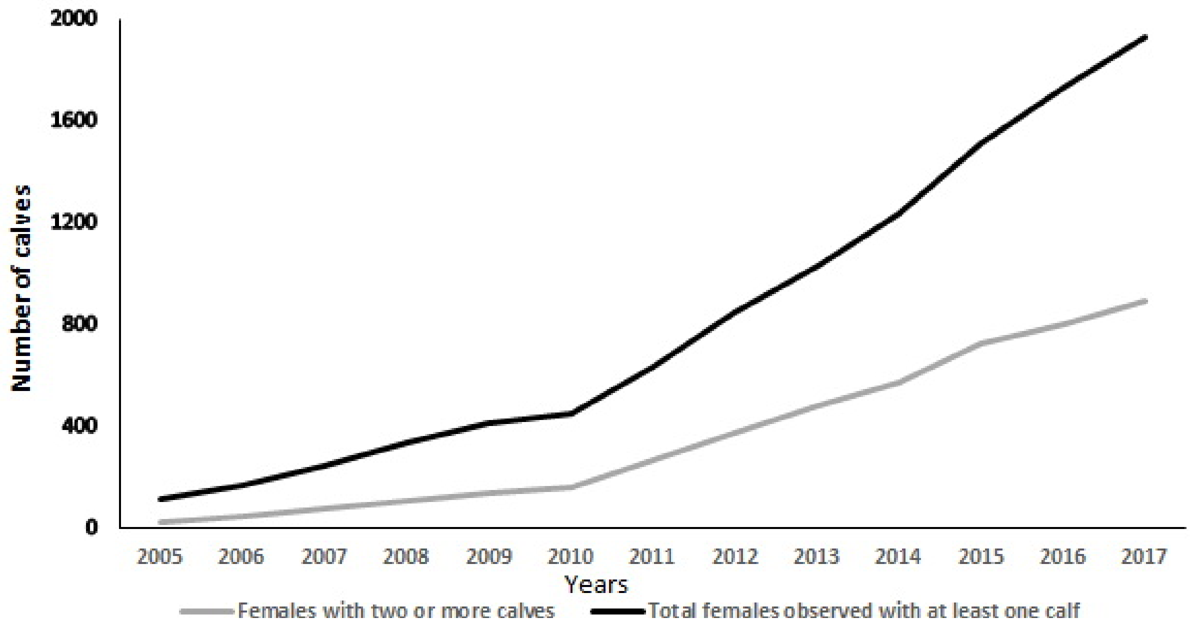

Figure 4. The increase in the number of calves born between 2005 to 2010 and 2011 to 2017 segregated by groups (total females, and females with at least two calves).

Discussion:

Apparent changes in gray whale birth interval:

The most frequently reported gray whale birth interval is two years for the North Eastern and Western Pacific populations (Rice and Wolman, 1971; Jones, 1990; Sumich, 2014; Weller *et al*., 2009). Nonetheless, longer birth intervals are not rare and likely result from calf mortality, failure of conception, or nutritional and health related stress that prevents a female whale from bringing her calf to term. Jones (1990) reported two year birth intervals comprised 87.5% of her sample obtained during the period from 1977 to 1982, while Díaz (unpublished) reported a reduction of two year birth intervals to 58.8% during the period from 1996 to 2002, and this study reported 64% of two year intervals during the 2005 to 2017 period. In contrast, these studies also suggest that the frequency of longer birth intervals have increased. Three year intervals increased from 9.3% in the 1977 to 1982 period, and 41.2% and 32.5% during the 1996 to 2002 and 2005 to 2017 periods, respectively. Similarly, the frequency of four year intervals also increased from 1.6% in the 1977 to 1982 period (Jones 1990), to 13.5% during the 2005 to 2017 period. Weller *et al*. (2009) reported frequencies of birth intervals from western gray whales sampled between 1997 and 2007 that are similar to those reported by Díaz (unpublished) and this study: the frequency of two year intervals was 51.3% (n = 20); three year intervals was 33.3% (n = 13); and four year intervals was 10.3% (n = 4).

Bias in estimated birth intervals:

The birth intervals presented by Diaz (Unpublished) are based on a small sample size (n = 17 intervals) compared to Jones (1990) 64 intervals, and this study's 375 intervals, and may not be representative of gray whales during the 1996 to 2002 time period. Jones (1990) used different assumptions with regard to missing data in the birth intervals she analyzed; she assumed that four of five females with four year birth intervals that included some years with missing data, may have had multiple two year birth intervals, and this may have inflated the representation of two year birth intervals in her sample. This adjustment from four year to two year intervals reduced her estimated average birth interval from 2.25 years (SD = 0.628) to the 2.11 years (SD = 0.403) reported (Jones 1990).

The 2.39 year (SD = 0.556) average birth interval presented in this study was based on 375 un-ambiguous birth intervals; the only assumption being that female gray whales do not produce calves in consecutive years (Table 2). This large sample size of birth intervals collected over a relatively long period of time (13-years) facilitated the calculation of average birth interval for gray whales with greater precision than previous studies with smaller sample sizes collected over shorter time periods. While a total of 536 birth intervals were obtained from the birth histories, including 161 incomplete or ambiguous birth intervals with data gaps (missing photographs), would have introduced excessive uncertainty in the estimation of average birth interval. These results point out the value of research over long-time periods for long-lived species that develop long-time series of observations of individual whales, and the importance of obtaining sufficient sampling to minimize data gaps in birth histories to maximize precision of such estimates.

Environmental and Behavioral Factors Influencing Birth Interval Estimations:

Various factors can influence the probability of observing and photo-documenting an individual female gray whale and its offspring. The specie's inherent behavioral characteristics (e.g., fidelity to the study site, water temperature preferences, residence time in that location, amount of time spent at the surface of the water, and even calf mortality) can affect the availability of that individual for photo-documentation, along with differences in the photographic-survey effort across years.

Previous research indicates that that during years with El Niño (ENSO) conditions (water temperatures warmer than average), the gray whales' winter distribution is shifted to more northern areas within their winter range, presumably where water temperature is adequate for the mating and calving activities. While during La Niña years (water temperatures cooler than average) more gray whales are present in their southern aggregation areas, and even entering the Gulf of California where warmer water temperatures persist during the winter months (Urbán *et al*., 2003; Salvadeo *et al*., 2015). These differences in the whales' distribution would also affect their availability to be photographed.

Baker *et al*. (1987) reasoned that if some animals were not seen every year of an investigation, then the average birth interval may be overestimated; this may occur if some females exhibit low fidelity of a particular breeding area, and while they may have given birth to a calf, they were not observed in the study area. Long-term Photo-ID research has demonstrated that gray whales circulate among the three primary winter aggregation areas in Baja California (Jones and Swartz, 1984, 2009), and may or may not be observed in each area during each winter. Comparison of photo-ID images of the gray whales identified in the present study confirm that some females and their calves visited multiple aggregation areas along the Baja California peninsula, which can influence the interpretation of birth intervals: of the females observed in Laguna San Ignacio that had birth intervals between two and four years, 32were also photographed with calves in Bahia Magdalena; eight were also photographed in Laguna Ojo de Liebre; and only two females were photographed in all three primary aggregation areas. Thus, inconsistent fidelity to aggregation areas could influence the opportunity to photographically document a specific female each year that she produced a calf and further bias estimates of birth interval.

Influence of Health and Nutritive Condition:

Other factors that can influence the length of the birth interval include health and nutritive condition of the female, which are linked to habitat and environmental variables (Perryman *et al*., 2002), and human disturbance (Richardson *et al*., 1995). Ultimately, prey availability, nutrition, and health will determine whether a female can conceive, gestate, and successfully bring a pregnancy to term and give birth to a healthy calf. Once born, the physical condition of the female will determine whether her calf receives sufficient nutrition from her milk to continue to develop and grow until it is weaned seven to nine months following its birth. For a female gray whale all of these reproductive activities occur while she is migrating from the winter breeding areas to the high-latitude summer feeding areas, and then returning to the southern breeding aggregation areas, a minimum round-trip migration of up to 20,000 km (Rice and Wolman, 1971; Jones and Swartz, 2009). Successful reproduction in gray whales is therefore influneced by the amount and quality of food available to breeding females, and the amount of time a female is able to feed while pregnant and lactating (Perryman *et al.* 2002). Clearly, breeding females are the most energetically stressed of all gray whale age and sex classes, and resource availability is a determinant of calf production and survival until weaning (Sumich, 2014), and as such, health, nutritive condition, and food availability can also influence the birth interval.

Differences in the Number of Calves Observed During 2005-2010 and 2011-2017 periods:

Limited resources and changing environmental conditions apparently contributed to a range-wide mortality event that reduced gray whale breeding stock, and resulted in low calf production for a number of years. Between 1998 and 2000 annual gray whale mortalities exceeded the previous ten year averages by up to ten-fold. Dead whales examined from Alaska to Mexico appeared emaciated, undernourished, and the majority of the dead animals were females. This mortality event was presumably triggered by a decline in biomass of the whale' principal prey, due in part to the combination of increasing sea surface temperatures resulting from a "regime shift" during the previous decade in the North Pacific, the 1997-1998 El Niño and 1998-1999 La Nina events, and increased predation on benthic invertebrates from the growing gray whale population (LeBoeuf *et al*., 2000; Urbán *et al*., 2003b; Gulland *et al*., 2005; Moore, 2008).

Assessments after the mortality event indicated that the Eastern North Pacific gray whale population had decreased 23% from 21,135 in 1997-1998 to 16,369 in 2000-2001 (Laake *et al.*, 2009), suggesting that up to one-third or more breeding females were lost from the population. Loss of breeding females would result in lower calf production following the die-off (LeBoeuf *et al.*, 2000; Urbán *et al.*, 2003b; Urbán *et al.*, 2010), as noted in Laguna San Ignacio where the lowest number of gray whale calves (registered by photo-id) were recorded during the 2005-2010 winters (only 447 new born calves), but began to increase in 2011 and continued to increase through 2017 (1483 calves). In the present study, 23.16 % of the calves observed were born between 2005 and 2010, while 76.84 % were observed in the years 2011 to 2017, further suggesting that overall calf production has increased in recent years despite the apparent increase in average birth interval from the 1970’s to the present.These observations are consistent with those of Perryman *et al*. (2017) who reported that the counts of northward migrating gray whale female-calf pairs past central California were considerably high during the period from 2012 to 2016, suggesting the production of more than 6,500 calves in this period, which is approximately 5% of the total abundance for the Eastern gray whales population of 29,690 individuals (Durban *et al*., 2017).

These higher calf counts in recent years may be the result of the combination of different factors, but the most important could be the increased in primary productivity and invertebrate prey in the gray whales' feeding grounds since 2007 (Arrigo and Dijken, 2015), and the new cohorts of female whales that have reached sexual maturity following the mortality event. Perryman *et al*. (2002) identified a relationship with the timing of seasonal ice melt in the gray whales’ Pacific Arctic feeding areas and the numbers of northbound gray whale calves counted the following spring; in heavy ice years the lack of access to the foraging areas appears to have a negative impact on calf production. They have proposed that in recent decades gray whales have been experiencing a period of favorable feeding conditions in the Arctic owing to less seasonal ice cover, increased primary production, and increasing amounts of nutrient rich water flowing through the Bering Strait (Perryman et al. 2017). It is estimated that the reduction of seasonal and permanent sea ice in the Arctic has averaged 9% each year since the late 1970’s (Comiso, 2012; Perovich *et al*., 2007; Richter-Menge, 2009; Maslanik *et al*., 2011), providing greater access to feeding areas for baleen whales. Moore (2016) commented that the Pacific Arctic marine ecosystem has experienced a dramatic transformation with a loss of 75% of its sea ice volume, resulting in the extension of seasonal open water by four to six weeks. Subarctic species of baleen whales, now join the seasonally resident gray whales and the arctic-endemic bowhead whale to utilize high latitude prey resources that resulting from an increase in the rate of primary productivity in the feeding grounds and are now accessible for longer periods (Arrigo and Dijken, 2015).

Increasing numbers of gray whale calves observed during the recent decade in the winter aggregation areas of Baja California Sur, Mexico may also be the result of new cohorts of females that have reached sexual maturity and are replacing mature breeding females that were lost during 1998-2000 mortality event (Swartz *et al*., 2012). Gray whales reach reproductive maturity on average at 8-years of age (range from 6-12years) (Rice and Wolman, 1971), and during the 17-years since the die-off of mature females, we would expect cohorts of young female gray whales to mature and begin to reproduce successfully particularly if recent changes in the Arctic ecosystems represent a "boom time" for baleen whales (Moore 2016). The continuing increase in the counts of female-calf pairs observed in Laguna San Ignacio in recent years supports this hypothesis, and illustrate the resilience of this species to persist during changing environmental conditions.

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