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Estimating the historic size and current status of the Kemp's ridley sea turtle (Lepidochelys kempii) population

E. Bevan,[1,†] T. Wibbels,[1] B. M. Z. Najera,[2] L. Sarti,[2] F. I. Martinez,[3] J. M. Cuevas,[4] B. J. Gallaway,[5] L. J. Pena,[4] and P. M. Burchfield[4]

[1]*Department of Biology, University of Alabama at Birmingham, Birmingham, Alabama 35294 USA*
[2]*CONANP, Nicolas Bravo 335, Ciudad Victoria, Tamaulipas CP 87000 Mexico*
[3]*CDEN, Calle Simon Castro #619 Col. J. Luna, Ciudad Madero, Tamaulipas C.P. 89514 Mexico*
[4]*Gladys Porter Zoo, 500 Ringgold Street, Brownsville, Texas 78520 USA*
[5]*LGL Ecological Research Associates Inc., 4103 S. Texas Avenue, Bryan, Texas 77802 USA*

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Abstract. This study is a quantitative evaluation of historic nesting levels of the Kemp's ridley sea turtle (Lepidochelys kempii) in 1947 based on (1) the Herrera film of a 1947 arribada, (2) Hildebrand's 1963 report regarding the 1947 arribada shown in the Herrera film, (3) historic documentation regarding the Herrera film, and (4) current nesting characteristics related to arribada size relative to total nests for a season. Using this information in a quantitative approach, we estimate a total of approximately 26 916 nests during the 1947 arribada recorded by Herrera. Based on current nesting trends, we also predict that this would equate to approximately 121 517 total nests for the 1947 season (range of 82 514–209 953), which would represent approximately 48 607 nesting females (range of 33 006–83 981). This suggests that during and prior to the 1947 nesting season a relatively robust population of Kemp's ridleys existed, which could support arribadas consisting of at least 26 916 females. The results of the current study indicate that from 1947 through 1985 (the lowest point in the decline of Kemp's ridley nesting) the Kemp's ridley population underwent a 99.4% decline (range of 99.2–99.7%) from an estimated 121 517 nests per season in 1947 to 702 nests per season in 1985. Although the Kemp's ridley population has been recovering since the 1985 season, it has deviated from its exponential recovery rate and has declined in recent years. The current levels of nesting (12 053 nests in 2014) are still relatively low at 9.9% (range of 5.7–14.6%) of the total estimated nests that occurred in 1947. It is currently not clear whether this population will recover to historic levels considering recent nesting trends and due to a variety of threats that may hinder its recovery.

Key words: Andres Herrera; arribada; conservation; Gulf of Mexico; Henry Hildebrand; Kemp's ridley; Lepidochelys kempii; population status; Rancho Nuevo.

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† **E-mail:** libby84@uab.edu

Introduction

A common problem encountered when trying to assess the survival status of an endangered sea turtle population is the estimation of historic numbers of nests that occurred prior to a population's decline. Benchmarks estimating historic population sizes are usually not available. Nesting beach surveys often do not occur until after a population's survival becomes tenuous. A classic example of this is the Kemp's ridley, in which the first organized beach surveys were conducted in 1966 by the Mexican federal fisheries amid concern that the population had significantly declined and its future survival was in jeopardy (Chavez et al. 1968). The 1966 survey of the nesting beach at Rancho Nuevo, Mexico, recorded nesting between 3 May and 25 June, with four arribadas of approximately 200 turtles or more, the largest of which occurred on 31 May with 1317 nests. It was subsequently reported that during the 1970 and 1971 nesting seasons, the largest arribadas were composed of approximately 2000–2500 turtles (Pritchard and Marquez-M. 1973). Marquez (1994) provides a summary of data from 1966 through the early 1990s indicating a maximum number of approximately 5000 recorded nests during the 1966 nesting season, with the number of nests continually decreasing to approximately 900 per nesting season by the late 1970s. Several factors contributed to the precipitous decline of the Kemp's ridley between 1966 and the early 1990s. Local exploitation of eggs at Rancho Nuevo had grown exponentially during the 1950s and early 1960s due to commercialized harvesting (Hildebrand 1963, Adams 1966, Chavez et al. 1968, Marquez 1994). This was occurring at the same time that the shrimping industry was expanding in the Gulf of Mexico (Nance 1992), resulting in the increased incidental capture of juvenile and adult Kemp's ridleys (Magnuson et al. 1990). Combined with natural sources of mortality, such as predation of eggs and hatchlings, these factors led to the near extinction of this species. Although more than a decade of initial surveys documented that the Kemp's ridley population was declining, the historic levels of nesting prior to 1966 were unknown, and the magnitude of decline could have remained a mystery. Fortunately, a nesting event at Rancho Nuevo was filmed by Andres Herrera in 1947. In the classic publication from 1963, Hildebrand described the massive arribada that Herrera recorded on 18 June 1947 and estimated that it consisted of approximately 40 000 turtles (Hildebrand 1963). Subsequently, Carr (1963) supported Hildebrand's estimation of 40 000 turtles in the arribada after reviewing the Herrera film.

The Herrera film is clearly informative in regard to documenting a historic arribada, but it can also be used for estimating the historic population size during the 1947 nesting season at Rancho Nuevo prior to the near collapse of the species. In contrast to the situation for most endangered species, the Herrera film provides a benchmark for estimating the size of the historic Kemp's ridley population. However, using the Herrera film for such an estimate requires an accurate estimation of the number of nests in that historic 1947 arribada and how that arribada size relates to the total number of nests for that season. To address the first aspect of this prediction requires an accurate assessment of the number of turtles in that 1947 arribada. Hildebrand (1963) indicates that based on the numbers of turtles in the film and discussions with Herrera, he estimated that at least 10 000 turtles were on the beach at a given time, and that approximately 40 000 turtles nested on that day in 1947. However, Hildebrand did not include the methodology by which he derived his estimate for the size of that arribada. Therefore, part of the current study is to provide an independent evaluation of the number of turtles in the 1947 arribada based on the Herrera film and historic documentation regarding that event.

The second part of this study is to provide a prediction of the total number of nests for the 1947 nesting season based on that arribada to provide insight on the historic population size. In 1963 it was not possible to address this question because little was known about the Kemp's ridley or its nesting biology. Fortunately, the Kemp's ridley has recovered to some extent, and its current nesting biology provides clues to the historic level of nesting back in 1947.

The ability to estimate the historic population size of an endangered species has significant implications for evaluating its current status. For example, one of the listing criteria used by the International Union for the Conservation of Nature (IUCN) in their Red List Assessment takes into account the percent decline of a species over multiple generations. In the case of the Kemp's ridley, the species came close to extinction in the mid 1980s. Due to intense, binational (Mexico and Unites States) conservation efforts, the species began to rebound in the 1990s and acquired an exponential recovery rate. This recovery rate was anticipated to continue, but since 2009, the annual number of nests has declined, with a low of approximately 13 000 nests in 2014, but the causal basis for the decline is unclear (Burchfield 2014, Caillouet 2014; Wibbels and Bevan 2016). Therefore, understanding the historic population size is critical for evaluating the current conservation status and recent decline of the Kemp's ridley.

Methods

Herrera film and quantification of turtle density

Three digitized copies of the Herrera film were obtained for analysis. During June 2014, the original Herrera film, as well as a DVD copy of the original film, were obtained from the Herrera family. A second digitized copy was then commercially produced from the original Herrera film. Additionally, a third digital copy was made from a U-matic copy that was dubbed from the original Herrera film by KUHT public television during the 1981 production of the Heartbreak Turtle (Heartbreak Turtle Documentary, 1981, KUHT Public Television, Houston, TX, USA). All three copies of the Herrera film were initially evaluated and the film with the greatest clarity (i.e., the DVD copy obtained from the Herrera family) was used for quantitative analysis of turtle density.

The film was viewed in its entirety, and all aspects of the film were initially evaluated based on their relevance for quantification. Of the entire film, two panoramic views of the beach were the most informative. Each panoramic view was digitally stitched together into a single composite image for quantification. The first image was a wide pan of the beach starting at the northernmost extent of the field of view and extending to the southernmost field of view which included Herrera's plane (Fig. 1). This figure was used to evaluate variability in nesting density over a wide section of beach. This was the same view that was previously evaluated by Dickerson and Dickerson (2006).The second image was a scene in which Herrera was standing approximately midway between the surf and the dune, and panned the camera from the surf to the dune with his airplane positioned at the southern boundary of the arribada (Fig. 2). This composite photo was used to quantify the total number of turtles on the beach, including those on the dune where the majority of nesting is known to occur.

Since turtles were abundant throughout each of the composite photos, the relative lengths of the turtles were used as a metric for estimating the distance of beach analyzed in each of the photos. Adult female Kemp's ridleys have a relatively

Fig. 1. A composite image from a wide panoramic view of the June 18, 1947 arribada at Rancho Nuevo, Mexico filmed by Andres Herrera. This represents the widest panoramic view of the arribada shown in the film. The analysis of nesting density is shown in Table 1.

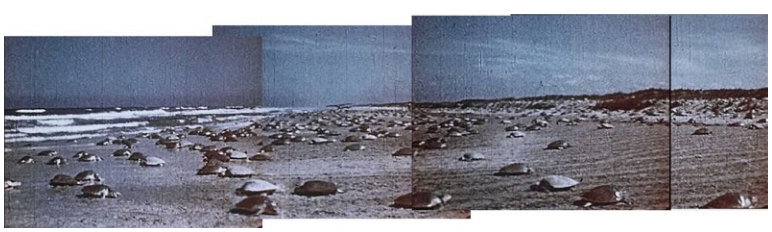

Fig. 2. A composite image from the June 18, 1947 arribada at Rancho Nuevo, Mexico filmed by Andres Herrera. This image represents the best panoramic view from the film that includes all sections of the beach, ranging from the surf up through the dune. The analysis of nesting density is shown in Table 1.

narrow range of carapace lengths, and a carapace length to width ratio of nearly 1:1, thus the carapace is nearly as wide as it is long in comparison to most other sea turtles (Pritchard and Marquez-M. 1973, Marquez 1994, Epperly and Teas 1999). These two factors enhanced the accuracy of using the turtles in the photos as a metric for estimating distances in the photos.

We adopted two novel methods for estimating relative distances on the beach using carapace sizes of the turtles. In the first approach the relative carapace lengths of the turtles in the photos were directly used to estimate distances. This method was optimal for Figure 1 since it included relatively large numbers of turtles spread over a wide expanse of beach that included various camera angles. The panoramic view was divided into eight equal segments and turtle lengths were analyzed throughout each segment on the beach flat adjacent to the tidal interface. The segment length was then divided by the average turtle carapace length for each segment, which converted the lengths of each segment into a specific number of "turtle carapace equivalents" (TCEs). Considering the turtles were oriented in a variety of directions in Figure 1, we used a general estimate of 65 cm for a single TCE, based on the average carapace lengths and widths reported for nesting females (Pritchard and Marquez-M. 1973, Marquez 1994).

In the second method, turtle carapace lengths were used to generate relative carapace length ratios (CLRs) at various distances from an observation point (i.e., camera). Sixty-five-centimeter pieces of one-half-inch PVC pipe were used to represent the straight carapace length of nesting ridleys. Segments were placed at 10-m intervals from 5 to 360 m and photographs were taken. Relative lengths of the pipes at various distances in the photographs were measured using ImageJ software. A series of ratios were generated by comparing those lengths at various distances. In similar fashion, ImageJ software was used to determine the relative lengths of the turtle carapaces at various distances from the camera in the composite images. Those lengths were then used to generate ratios that were then compared to the experimental ratios to estimate distances. The second method was optimal for estimating distances in Figure 2 due to the camera perspective from the middle of the beach pointed directly south towards Herrera's airplane and with most turtles oriented perpendicular to the camera. In the case of Figure 2, the carapace lengths of the three closest turtles were compared to the carapace lengths of six turtles near the southern border of the arribada immediately in front of Herrera's airplane. The ratio of those carapace lengths were then compared to those in the experiment to estimate the distance from the camera to the airplane. As an independent validation, the TCE method was also applied to Figure 2 with similar results. Further, the CLR method described above was also applied to Figure 1 with similar estimates to those produced by the TCE method.

Beach topography

The nesting beach at Rancho Nuevo is a relatively broad sand beach, bordered by a well-defined and vegetated dune area, as described by Pritchard and Marquez-M. (1973), which often includes two berms separated by a trough (Marquez 1994). Marquez (1994) further partitions the beach into zones defined as, (1) beach flat, (2) the front (base) of the primary dune, (3) the seaward face of the primary dune, and (4) the top of the primary dune.

Quantification and location of nesting

Figure 2 was optimal for quantifying the total number of turtles on a portion of the beach since it included all areas that were occupied by turtles ranging from the water up through the top of the primary dune. The number of turtles in the image was independently estimated by 26 individuals using photo editing software (e.g., Paint, etc.) that allowed for enlarging the image and marking the turtles. We partitioned these estimates into the number of turtles on the beach flat (zone one, as indicated by Marquez (1994)) vs. the number of turtles located in the area at the base of the dune and up through the top of the primary dune. In contrast to Figure 2, the camera perspective in Figure 1 does not facilitate the accurate quantification of turtles at the base of the dune and on the dune. Therefore, the percentage of turtles at the base of the dune and on the dune in Figure 2, was used to estimate the number of turtles at the base of the dune and on the dune in Figure 1 based on the number of turtles quantified on the beach flat in Figure 1. For the purposes of the current study, we defined the base of the dune as the area within approximately 3 m directly in front of the primary dune, up to the seaward facing slope of the primary dune, which corresponds to zone two as described in Marquez (1994). Marquez (1994) reported that 47.64% of Kemp's ridley nesting occurred in zone three (i.e., the seaward facing slope of the primary dune), followed by 24.11% of nesting in zone two, and 17.77% of nesting in zone four. The value we obtained for zones 2 and 3 from Figure 2 (35.8%) may be conservative, since we also calculated this value hypothetically based on previously reported data on the timing of nesting events on the beach (e.g., emerging from the surf, crawling up the beach, nesting, and return to the water). Previously reported data indicate that Kemp's ridleys spend approximately 15 min moving onto the beach and selecting a nesting area, approximately 30 min for the nesting process, and approximately 5 min or less to return (Pritchard 1969, Pritchard and Marquez-M. 1973, Marquez 1994). Although the dynamics of arribada nesting have not been well quantified, if the main portion of an arribada represents a steady state in which the same number of turtles are moving onto as well as off of the beach, then we could predict that during this portion of the arribada, approximately 60% would be engaged in the nesting process and 30% would be in transit moving up the beach preparing to nest or returning to the sea. Based on current nesting trends, the majority of nesting at Rancho Nuevo occurs in the area at the base of the dune or on the dune, with 10% or less of nesting occurring on the beach flat (J. Pena, personal communication). The turtle density in Figure 2 was calculated for the entire portion of beach shown by dividing the total number of turtles quantified by the length of beach estimated using the CLR method. For comparison, we performed a similar analysis on an image from a recent arribada from a similar camera perspective in June of 2011 (Fig. 3).

The camera perspective (i.e., from the top of the dune) used in Figure 1 did not provide a full view of all sections that were occupied by turtles and therefore a complete count of turtles was not possible. Specifically, due to the camera perspective, the seaward portion of the dune along with any turtles nesting in that region were not visible towards the northern and southern portions of the image. Additionally, due to the relatively large distance shown in the image, it becomes increasingly difficult to quantify turtles near the northern and southern extremes of the composite image. Therefore, we focused on quantifying turtles on the beach flat, which were more accurately distinguishable throughout this image, and used those data to evaluate variation in turtle density. The number of turtles in Figure 1 was independently estimated by eight individuals using photo editing software (e.g., Paint, etc.) that allowed for enlarging the image and marking the turtles.

Fig. 3. An example of a recent, relatively large Kemp's ridley arribada on June 5, 2011 at Rancho Nuevo, Mexico. In this image of the arribada, an estimated 313 turtles were quantified on approximately 50 m of beach for a turtle density of 6.3 turtles/meter. It is estimated that a total of 7000 turtles nested over approximately 200 m of beach or less from approximately 3 pm until 9 pm. (Photo Credit: Toni Torres, Gladys Porter Zoo).

Figure 1 was arbitrarily divided into eight equal segments to calculate turtle density. As indicated above, only turtles on the beach flat area were counted (i.e., turtles on the dune were excluded). The turtle density for each segment was calculated by dividing the total number of turtles on the beach flat in each segment by the estimated length of each segment (length calculations are described above). In Figure 2, all turtles were counted and the density was calculated by dividing the total number of turtles by the estimated distance from the camera to the turtles directly in front of Herrera's plane.

Historic information and documentation regarding the Herrera film

In addition to reviewing Hildebrand's 1963 publication, research was conducted to compile pertinent information regarding the 1947 arribada recorded by Herrera. This included (1) information and personal correspondence from Andres Herrera that was obtained from the Herrera family, (2) correspondence and information compiled by Henry Hildebrand that was obtained from USFWS/NPS, (3) video interviews from the Heartbreak Turtle recorded by KUHT public television (Heartbreak Turtle Documentary, 1981, KUHT Public Television, Houston, TX, USA), (4) video discussions with the family of Andres Herrera including his wife, Evelina Herrera and long-time residents of Rancho Nuevo, and (5) relevant information from other publications that address the 1947 arribada (e.g., Carr 1963, 1967, Phillips 1989, etc.). This information was reviewed with the intention of refining the 1947 arribada, including (1) the duration of the arribada, (2) the length of beach over which the arribada occurred, and (3) the density of nesting. Each of these parameters is discussed in more detail below.

Percentage of total seasonal nesting represented by large arribadas

Considering the only historic data we have from 1947 is the Herrera film, we propose a novel method for estimating the total number of nests for the 1947 nesting season based on recent nesting trends and the relative size of arribadas. For more than two decades, the Binational Kemp's Ridley Recovery Program has conducted multiple surveys daily of the beach at Rancho Nuevo over the nesting season. Multiple personnel are mobilized to monitor and translocate the nests to the egg corrals during an arribada, and the beach is monitored after an arribada to evaluate predation and emergence of any nests that were not moved to the egg corrals. This has provided a robust database for evaluating total nests per season as well as relative arribada size. It is plausible that during an arribada some nests may be undetected, and as such, the arribada nest counts should be considered a minimum. Specifically, we have evaluated the percentage of the total nests per season that are represented in the largest arribada for each year during eight recent nesting seasons (2006–2013). These years were chosen since each nesting season included a relatively large arribada of approximately 1000–7000 nests. We then used this information to predict the total the number of nests during the 1947 nesting season based on the arribada recorded in the Herrera film.

Table 1. Quantification of turtles on the beach in Fig. 2 from the June 18, 1947 arribada filmed by Andres Herrera at Rancho Nuevo, Mexico.

Individual	Turtles on the Beach Flat	Turtles Counted on the Dune†	Total Number of Turtles Counted in Fig. 2	Percent of Turtles in Dune†
1	189	121	310	39.0
2	203	82	285	28.8
3	212	137	349	39.3
4	181	104	285	36.5
5	271	161	432	37.3
6	174	101	275	36.7
7	180	95	275	34.5
8	175	89	264	33.7
9	177	108	285	37.9
10	176	133	309	43.0
11	149	76	225	33.8
12	186	91	277	32.9
13	228	93	321	29.0
14	169	72	241	29.9
15	215	93	308	30.2
16	159	92	251	36.7
17	183	117	300	39.0
18	160	104	264	39.4
19	156	132	288	45.8
20	152	84	236	35.6
21	185	80	265	30.2
22	127	107	234	45.7
23	246	90	336	26.8
24	163	95	258	36.8
25	155	97	252	38.5
26	202	109	311	35.0
Average	184	102	286	35.8
Standard Deviation	31	21	44	4.9

† Dune represents beach zones two (i.e., the base of the primary dune), three (i.e., the seaward facing slope of the dune), and four (i.e., on top of the primary dune), as described in Marquez (1994).

Results

Nesting density estimates

A total of 26 individuals counted the number of turtles in Figure 2 from the 1947 Herrera film to yield an average of 286.0 and 43.5 SD turtles (Table 1). Results indicated that approximately 35.8% and 4.9% SD of turtles occurred

Table 2. Evaluation of nesting density in Figs. 1 and 2 from the June 18, 1947 arribada filmed by Andres Herrera at Rancho Nuevo, Mexico.

Beach Section Analyzed	Estimated Length of Beach Section (meters)	Turtles Counted on Beach Flat	Turtle Density on Beach Flat†	Turtles in Dune	Total Number of Turtles	Total Turtle Density†	Predicted Number of Turtles for 2 km of Beach	Predicted Number of Turtles Over 4 h‡
Fig. 1-Section 1	72.0	74.0	1.0	41.3§	115.3	1.6	3204.9	15383.7
Fig. 1-Section 2	36.0	99.0	2.7	55.2§	154.2	4.3	8512.9	40861.9
Fig. 1-Section 3	31.0	80.0	2.5	44.6§	124.6	4.0	7928.1	38054.7
Fig. 1-Section 4	22.0	58.0	2.6	32.3§	90.3	4.1	8152.9	39134.0
Fig. 1-Section 5	22.0	44.0	2.0	24.5§	68.5	3.1	6153.0	29534.4
Fig. 1-Section 6	29.0	54.0	1.9	30.1§	84.1	2.9	5889.8	28271.2
Fig. 1-Section 7	36.0	89.0	2.5	49.6§	138.6	3.9	7742.5	37164.1
Fig. 1-Section 8	73.0	79.0	1.1	44.1§	123.1	1.7	3385.4	16249.7
Entire Fig. 1	321.0	578.0	1.8	322.3§	900.3	2.8	5607.6	26916.7
Entire Fig. 2	60.0	183.6	3.1	102.4¶	286.0	4.8	9533.3	45760.0

† Represents one meter of beach length extending from the surf through the dune.
‡ Based on 4 h of high-density nesting over 2 km of beach with an average time spent on the beach of 50 min per turtle.
§ Hypothetical based on 35.8% of total turtles located in the dune, as per analysis of Fig. 2.
¶ Actual number counted in dune.

in the dunes. Based on the CLR method using the relative carapace lengths of the closest vs. the farthest turtles in Figure 2, it was estimated that the turtles in the composite image were on approximately 60 m of beach, yielding a density of 4.8 turtles per meter of beach (Table 2).

The lengths for each of the eight segments in Figure 1 were calculated using the TCE method and the results are shown in Table 2. The number of turtles on the beach flat and the resulting turtle density for the beach flat is shown for each segment in Table 2. Additionally, the hypothetical number of turtles in the dune is also shown in Table 2 for each segment based on intrinsic data from Figure 2, as described in Methods. The data from Figure 2 indicated that 35.8% and 4.9% SD of the total turtles on the beach were located on the dune, and 64.2% were located on the beach flat. The total length of the beach in Figure 1, calculated by the TCE method, was estimated to be 321 m with a total of 578 turtles counted on the beach flat and an estimated 322 turtles in the dune, for a total of 900 turtles and a density of 2.8 turtles per meter.

Duration of the arribada

Hildebrand (1963) estimated that, based on reports provided by Herrera, the duration of the 1947 arribada was approximately 4 h lasting from nine am until about one pm. Hildebrand therefore used a duration of 4 h in his calculations for the total number of turtles in the 1947 arribada. This was supported in a letter from Andres Herrera to Hildebrand in which Herrera states that arribadas occur from 9 in the morning to 12 or 1 in the afternoon. In addition to discussions with Herrera, Hildebrand also interviewed local residents of Rancho Nuevo, who corroborated that 4 h is a reasonable estimate for the duration of an arribada. Using this information, our initial estimates are based on a 4-h duration for the arribada. However, there are several lines of evidence that suggest the arribada could have been longer than 4 h and these points are addressed below in the discussion.

Temporal and spatial dynamics in arribada nesting density

The temporal dynamics of nesting density for arribadas is not well documented in any study of arribada nesting in ridleys. The time required to reach high-density nesting and subsequently the time required for nesting to decrease at the end of the arribada has also not been quantified. Data from studies from olive ridleys as well as recent data from Kemp's ridleys indicate that high nesting density during arribadas can last for multiple hours. There is anecdotal evidence that heavy nesting density can be reached relatively quickly. As an example, Cornelius (1986) indicates that the transition from low level nesting to high density nesting in olive ridleys can occur rapidly "in less than an hour", followed by many hours of high-density nesting. In the case of the 1947 Herrera arribada, Hildebrand (1963) indicates that high-density nesting occurred over at least a 4-h period, based on discussions with Herrera and local residents of Rancho Nuevo. Further, Herrera indicated that high density nesting was occurring at the time when he left the beach after recording the film. Therefore, as a conservative estimate, we are only using the 4-h value that represents the period of high-density nesting as indicated by Hildebrand and Herrera and does not reflect the time periods prior to and after the high-density nesting levels.

During the period of high-density nesting in the arribada, there appears to be both spatial and temporal variation in nesting density, as evident in Figures 1 and 2, and listed in Table 2. The highest density of turtles recorded is shown in Figure 2 with five turtles per meter. Interestingly, this same area appears to show a lower density of turtles in Figure 2, which suggests temporal diversity in turtle density during the arribada and Table 2 exemplifies the spatial diversity in turtle density during the arribada. These factors are taken into consideration in the estimates below in the calculations for predicting the total number of turtles in the arribada.

Length of beach over which nesting occurred

The Herrera film does not appear to document the entire length of beach occupied by the arribada. The widest pan of the camera in the Herrera film shows several hundred meters of beach with relatively high-density nesting. The high-density nesting extends to, and potentially beyond, the northernmost field of view that was recorded in the pan of the beach and to the south, the high-density nesting extends to Herrera's airplane. However, the southern border of the arribada may have expanded while Herrera was on the beach, since he noted that he had to push his airplane to the south to take off because turtles were moving under it ("to the degree that when I came back to my plane I could not take off because they were passing below it", stated in Hildebrand (1963), and stated in a letter from Herrera to Hildebrand dated 20 May 1961). Although the entire length of beach was not documented in the film, Herrera is quoted on the subject. Hildebrand (1963) quotes Herrera who indicated that more than 1 mile of beach was totally covered with turtles ("tenia una extension de mas de una milla totalmente llena de tortugas"). The observation of "more than a mile of beach" was also specifically stated in two of Herrera's letters to Hildebrand (letters dated February 10, 1961 and May 20, 1961). In a video interview of Herrera in the 1981 documentary "The Heartbreak Turtle", Herrera states "possiblemente dos milos", possibly 2 miles of beach covered with turtles (Heartbreak Turtle Documentary, 1981, KUHT Public Television, Houston, Texas, USA). Hildebrand (1963) reports that he verified these observations with Juan Gonzales Galvan, a local resident of Rancho Nuevo who had been observing arribadas for 25 years, and who had learned details of previous arribadas by word of mouth from local residents and indicated that the observations reported by Herrera are certainly not exaggerated. Hildebrand also states that based on his discussions with Herrera and local residents, arribadas usually cover approximately 2 km or less of beach. Based on this information, we chose 2 km as the length of beach used in the calculations below. Two kilometers was also the estimate used by Dickerson and Dickerson (2006) in their evaluation of the 18 June arribada.

Average time spent on the beach by a nesting turtle

No comprehensive studies have directly addressed the average time required by a Kemp's ridley to complete the nesting process, yet a variety of anecdotal information does exist and suggests approximately 45 min to 1 h. Pritchard (1969) meticulously documented the entire nesting process from emergence to return to the water and reported approximately 50 min. Marquez (1994) reported that the nesting process takes approximately 50–60 min. Based on direct observations, Pritchard and Marquez-M. (1973) reports that the total time from emergence to return to the sea was approximately 50 min, which was confirmed in discussions with local residents of Rancho Nuevo. Biologists currently conducting the conservation project at Rancho Nuevo indicate that 50 min appears to be a reasonable estimate for the time spent by a Kemp's ridley on the nesting beach. Based on these anecdotes, we used 50 min as the value for the average time spent on the entire nesting process.

Predicting total number of turtles in the 18 June 1947 arribada

Based on the material reviewed above, we chose the following values for our initial estimate of the total number of nests in the 1947 arribada: (1) Duration of high density nesting was 4 h, (2) Average time spent on the beach by a nesting turtle was 50 min, (3) Length of the beach occupied by the arribada was 2 km. Considering the spatial and temporal diversity in turtle density observed in the Herrera film, we used two methods of estimating the total number of turtles in the arribada. Based on Figure 1, an estimate of 578 turtles were counted on the beach flat, which represents 64.2% of the estimated total number of turtles on the beach. Combining this number with the predicted 35.8% of turtles on the dune would result in an estimate of 900 turtles on the beach over the 321 m. Using this density in the equation below results in an estimate of 26 916 turtles for the 4 h of high density nesting during the 1947 arribada.

Estimated total number of nests in Figure 1 = [density (900 turtles per 321 m of beach) X length of beach (2000 m/321 m)] × [duration of the arribada (4 h)/amount of time needed for nesting (50 min)] = 26 916 turtles.

Based on Figure 2, which represented the highest nesting density zone evaluated, a total of 286 turtles were estimated over 60 m of beach, including both the beach flat and dune area. Using this nesting density in the equation above results in a total of 45 760 turtles during 4 h of high-density nesting in the 1947 arribada.

We provide a detailed discussion below of underlying assumptions and potential sources of error that could confound this prediction.

Estimating total seasonal nesting represented by large arribadas

The largest Kemp's ridley arribada each year for the 2006–2013 nesting seasons at Rancho Nuevo is shown in Table 3. The 2006–2013 nesting seasons included two to four relatively large arribadas (greater than approximately 750 nests or more per arribada). The number of nests in the largest arribada of each nesting season ranged from a minimum of 1797 nests out of 14 018 total recorded nests in 2010, to a maximum of 7000 nests of 21 462 total recorded nests in 2011. The largest arribada of each nesting season accounted for a minimum of 12.82% in 2010, to a maximum of 32.62% in 2011 (mean 22.15%) of the total number of nests recorded during each respective nesting season. We have attempted to be conservative in our approach to prevent overestimating the total number of nests in the 1947 nesting season by (1) only using the largest arribada each year and (2) by providing a range of predictions that reflect the variability seen in arribadas from recent nesting seasons. Further, we provide a detailed discussion below

Table 3. Largest Kemp's ridley arribada each year from 2006 to 2014. The total number of seasonal nests reflects those reported from the entire state of Tamaulipas, including Rancho Nuevo, Texas, and Tecolutla, Veracruz.

Year	Total Number of Recorded Nests For Nesting Season	Largest Arribada of the Nesting Season (Date)	Largest Arribada of the Nesting Season Approximate Number of Nests	Percent of Total Seasonal Nests Represented by Largest Arribada
2014	12053	4/30/2014	2000	16.6
2013	17359	6/6/2013	3100	17.9
2012	22818	5/16/2012	6600	28.9
2011	21462	6/5/2011	7000	32.6
2010	14018	6/3/2010	1797	12.8
2009	22012	5/17/2009	5023	22.8
2008	18867	4/12/2008	2558	13.6
2007	15567	5/20–24/2007	5000	32.1
2006	12629	5/11/2006	2085	16.5

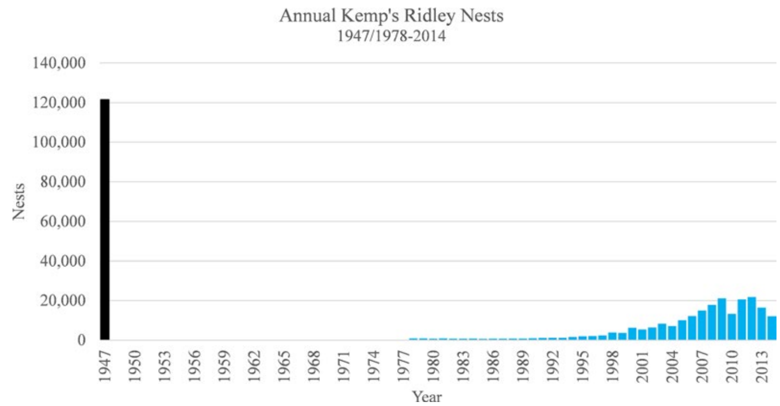

Fig. 4. Estimated annual number of nests from the Bi-National Recovery Program for the Kemp's ridley sea turtle starting in 1978 shown together with the estimate from the current manuscript for the 1947 nesting season. Blue bars indicate total annual nests reported by the Bi-National Program. The solid black bar is the total number of nests estimated for the 1947 nesting season in the current manuscript based on our independent quantification of the arribada filmed in 1947 by Andres Herrera.

of underlying assumptions and potential sources of error that could confound these predictions.

If these percentages are applied to our estimates of 26 916 total nests in the 1947 Herrera arribada (as described above), it results in a predicted range of total nests for the season of approximately 82 514–209 953 total nests (using recently observed large arribadas that range from 12.82% to 32.62% of total nesting for the season). If the June 18, 1947 arribada represented the mean percentage of total nesting for the season (22.15%), then the estimate for the total number of nests in the 1947 nesting season becomes approximately 121 517 nests.

Based on a value of 2.5 clutches per nesting female per season (TEWG 2000), our predictions suggest a range of 33 006–83 981 (mean 48 607) females nested during the 1947 nesting season.

It is important to note that our analysis of Figures 1 and 2 indicates that nesting density was higher on the same approximate portion of the beach during the time when Figure 2 was taken. This suggests that the overall nesting density could have been greater over the area of beach shown in Figure 1 during some portions of the arribada.

Estimating total nesting in 1947 using Hildebrand's estimate for the 18 June arribada and current nesting trends

We can also apply the percentage of total nesting represented by the largest arribadas in recent years to the Hildebrand (1963) estimate of 40 000 turtles for the 18 June arribada to estimate total nesting for 1947 as a comparison to our estimate for total nesting derived from the analysis of Figures 1 and 2. Assuming that Hildebrand's estimate (1963) of 40 000 turtles represented an average of 22.15% (range of 12.82 and 32.62%) of total nesting in 1947, then the predicted total nests for the season would be an average of 180 587 (range of 122 624–312 013) (Fig. 4).

Discussion

This study is an independent evaluation of historic nesting levels of the Kemp's ridley sea turtle (Lepidochelys kempii) in 1947 based on (1) the Herrera film of a 1947 arribada, (2) Hildebrand's 1963 report regarding the 1947 arribada shown in the Herrera film, (3) historic documentation regarding the Herrera film, and (4) current nesting characteristics related to arribada size relative to total nests for a season. Using this information, we estimate a total of approximately 26 916 nests during the 1947 arribada recorded by Herrera. Based on current nesting trends, we also predict that this would equate to approximately 121 517 total nests during the 1947 season (range of 82 514–209 953), which would represent approximately 48 607 nesting females (range of 33 006–83 981).

In the initial scientific evaluation of the Herrera film, Hildebrand (1963) estimates that the arribada filmed on June 18, 1947 had approximately 40 000 turtles on the beach. Based on the 1947 film and discussions with Herrera, Hildebrand estimated that "there were at least 10 000 turtles on the beach at a given time and that probably 40 000 individuals nested on that day". In the 1963 publication, he did not clearly indicate the methodology by which he estimated the 10 000 turtles on the beach. However, it appears that Hildebrand used a 4-h duration and 1-h time period spent by each turtle on the beach in his calculations of the arribada size, and 1.6–2 km as the length of beach occupied by the arribada, based on discussions with Herrera and information gathered from local residents from Rancho Nuevo. In evaluating Hildebrand's office documents, it appears that he counted turtles on a section of beach and extrapolated this value over the entire length of beach occupied by the arribada. However, the exact portion of the film and Hildebrand's specific method of calculation was not clearly indicated. In the current study, we used quantitative methodology and estimate 26 916 turtles for the June 18, 1947 arribada, but as discussed below, the nesting densities varied (see Table 1) and some could extrapolate to values that equate or exceed the estimate by Hildebrand (1963). During the current evaluation, we have also identified potential sources of error that could be associated with this estimate (see discussion below).

In a separate evaluation of the 1947 Herrera film, Dickerson and Dickerson (2006) estimated an average of 6000 turtles for the 4-h duration of the 18 June arribada. That study was pivotal in addressing the need for quantitative methodology to assess the size of the 1947 Herrera arribada. They adopted a logical approach of quantifying turtles in a wide pan of the beach and extrapolated that number to include a total of 2 km of beach over a 4-h arribada. They generated a composite image of the widest pan in the Herrera film, based on a VHS copy of a film that was dubbed from a U-matic dub of the original film made by KUHT Public Television (Houston, TX) for the Heartbreak Turtle documentary (1981) (VHS copy obtained by Dena Dickerson from Dave Owens, D. Dickerson, personal communication). The total number of turtles in that composite image was independently estimated by 39 individuals and the length of the beach surveyed was subjectively estimated by the volunteers to be 650 m, with an average number of 475 turtles counted on that stretch of beach. This was then extrapolated out to 2 km for the length of the beach over which the arribada occurred and was multiplied by four to account for the 4-h duration of the arribada. In keeping with Hildebrand's methodology, Dickerson and Dickerson (2006) used a 1-h duration for the average time spent on the beach by a nesting turtle.

The estimate by Dickerson and Dickerson (2006) clearly differs from those in the current study. However, there are several factors that account for these differences. Of particular interest, the current study uses recent information and resources that were not available during the previous study. First, we were able to obtain a high resolution DVD copy of the film from the Herrera family which enhanced our ability to quantify turtles on the beach. Although the composite image used by Dickerson and Dickerson (2006) and Figure 1 in the current study are from the same portion of the film, we included a wider pan of the beach in our composite image. We only counted turtles on the beach flat and obtained an average of 578 turtles, whereas volunteers in the Dickerson and Dickerson (2006) study obtained an average of 475 turtles for both beach flat and any dune areas that were visible. Additionally, we used a novel approach to estimate the length of the beach in the composite image based on turtle carapace lengths throughout the image. The results indicated an approximate 321-m stretch of beach, in contrast to the 650 m of beach from the subjective volunteer estimates in the Dickerson and Dickerson (2006) study. Further, based on information from recent arribadas at Rancho Nuevo, a large proportion of the turtles on the beach during an arribada are located at the base of the dune, or on the dune. Due to the camera perspective in the composite image used by Dickerson and Dickerson (2006) as well as Figure 1 in the current study, a large portion of the dune is not visible towards the northern and southern extremes of the image. Therefore, in the current study we objectively evaluated the percentage of turtles in the dune area vs. turtles on the beach flat using the full beach perspective in Figure 2, resulting in an estimate of 35.8% of the turtles occurring in the dune. As indicated in the results, considering the chronology of events during the nesting process, this may represent a conservative estimate. We then used this value to estimate the total number of turtles on the beach in Figure 1 based on the number that we counted on the beach flat alone, resulting in a total value of 900 turtles over the 321 m of beach. Finally, based on historic and current nesting data we estimated that a turtle spends approximately 50 min on the beach during the nesting process in contrast to the 1 h that Dickerson and Dickerson (2006) used to stay consistent with the Hildebrand methodology. Collectively, these factors account for the difference in the estimate obtained in the current study vs. the estimate from the Dickerson and Dickerson (2006) study.

As indicated above, our analysis estimates a total of 26 916 turtles in the 1947 Herrera arribada. However, there are a variety of factors that could represent sources of error in such an estimate. An obvious factor that could affect the predicted total number of nests in the arribada is the spatial and temporal variation in nesting density. This is exemplified by the nesting densities that were quantified in Figure 1 and 2 and, depending on the portion of the beach would extrapolate out to a range of 15 384–45 760 total turtles for the entire arribada (see Table 2).

Although Hildebrand (1963) suggests that the arribada occurred over approximately 2 km, our largest and most informative pan in the Herrera film (shown in Fig. 1) only represents 23% of the full length of beach occupied by the arribada (i.e., 321 m of beach). However, information from Herrera that was reported by Hildebrand in 1963, personal correspondence from Herrera to Hildebrand (letters dated 10 February and 20 May 1961), and Herrera's interviews in the Heartbreak Turtle documentary and the Great Ridley Rescue book (Phillips 1989), suggest that nesting densities observed on the area of beach in the Herrera film were consistent throughout the entire range of the arribada. It is not clear why Herrera chose the portion of the arribada shown in the film, but it is plausible the area of the arribada filmed related to the logistics of where he could land the plane (i.e., at the southern border of the arribada in an area of low-density nesting). For example, Hildebrand (1963) clearly indicated that based on discussions with Herrera and local residents, nesting density was relatively high for at least 4 h over more than a mile of beach, resulting in a beach that was inundated with turtles to the extent that turtles were crawling over one other and frequently dug up the nests that other individuals had deposited, leaving the beach completely saturated with nests. Similar comments were made by Herrera in the 1981 documentary, the Heartbreak Turtle. His comments indicated that he observed the arribada from the air and flew the length of the arribada before landing and only landed once the arribada was underway. When he landed, the arribada had already reached a high level of nesting density that extended for over a mile of beach. It is important to note that Herrera's estimate of more than a mile of high-density nesting was not simply a ground-based estimation, but was also based on his aerial surveys of the arribada.

Based on Hildebrand's discussion with Herrera and with local residents, several generalizations regarding characteristics of historic arribadas are suggested in his 1963 publication; (1) the typical duration of arribadas is approximately 4 h, and (2) covers approximately 2 km of beach or less. Additionally, Hildebrand indicated that a typical nesting season includes three large arribadas per year. It is possible that these generalizations influenced the Hildebrand (1963) estimate of 40 000 turtles in the 1947 arribada. Of particular interest is the length of the 1947 arribada, for which 4 h has been used in all of the estimates, yet it has clearly been stated that when Herrera landed, the arribada was already underway and it is assumed that he determined the time when the arribada started from the locals on the beach. When Herrera left the beach, the arribada had expanded to the south and he had to push his plane further south past the turtles to take off. This suggests that the arribada could have lasted for longer than 4 h, which would suggest that all of the previous estimates may represent conservative values.

Arribadas during recent years can also provide insight on predictions regarding the 1947 arribada in regard to nesting density, duration, and total number of turtles. As an example, an arribada during June 2011 (Fig. 3) occurred over approximately 200 m of beach or less, lasting from approximately three pm until nine pm. Based on a photo from that arribada, we quantified approximately 313 turtles on 50 m of beach, similar to the density of nesting on portions of the beach shown in the Herrera film (see Fig. 2) and the nesting density in the 2011 arribada remained high for over 4 h. Data from recent years indicate that some arribadas can include high-density nesting for longer than 4 h periods. It was estimated that there was a total of 7000 turtles over approximately 200 m of beach or less in the 2011 arribada. Extrapolating that level of high-density nesting out to the 2 km of beach estimated for the 1947 arribada would have resulted in a total number of nests consistent with the Hildebrand (1963) estimate as well as the estimate from the high-density nesting areas in the current study.

Estimating the total number of nests for the 1947 nesting season

The population estimates in this study are based on comprehensive surveys being collected by the Binational Kemp's Ridley Recovery Program. However, the accuracy of the predictions is also dependent upon a number of assumptions which could represent potential sources of error. As indicated above, the predictions are based upon the assumption that the percentage of total nests per season represented in large arribadas in recent years is similar to that from 1947. It is currently unknown if or how this value might change relative to population size and the decline and recovery of this species. However, the reappearance of relatively large arribadas in recent years attests to the instinctive nature of arribada nesting behavior in the Kemp's ridley. Further, recent nesting seasons typically include two to three large arribadas, similar to the historic, seasonal occurrence of arribadas described by Hildebrand based on conversations with locals of Rancho Nuevo and information that had been passed on through multiple generations. Although anecdotal, this suggests that recent nesting behavior is consistent with historic nesting behavior prior to the collapse of the population. To be conservative we have used a range of values reflecting the variability in the size of the largest arribadas in recent years. Furthermore, our estimates are based upon the assumption that the arribada in the Herrera film was one of the largest arribadas of the 1947 season. If not, then our predictions could represent underestimates. Hildebrand indicated that Herrera witnessed two other arribadas, one earlier that season on 26 April, and one the following year on 30 April, but there was no indication or comparison of the relative size of the arribadas. Hildebrand's interview with people from Rancho Nuevo in the early 1960s indicated that arribadas could occur from April through June or even into July. In recent years it is not uncommon to have two or three relatively large arribadas, and some large arribadas have occurred during early June. However, evaluation of nesting in recent years suggests that the largest arribadas of the season are typically observed in April and May. Therefore, it is plausible that the arribada witnessed by Herrera on June 18, 1947 may not have been the largest arribada of the season.

The results from this study predict that approximately 48 607 females nested during the 1947 nesting season with a total of 121 517 predicted nests for the season. A previous study using an independent method (back-calculation of seasonal nesting numbers using linear regression) estimated 177 478 total nests for the season (Caillouet 2006). However, as Caillouet (2006) indicates, back-calculating static rates of decline for 1947–1966 based on the rates of decline from 1966 to 1977, cannot be tested. Regardless, the estimate from Caillouet (2006) is of the same order of magnitude as in the current study. The results of this study indicate that from 1947 through 1985 (the lowest point in the decline of Kemp's ridley nesting) the Kemp's ridley population underwent a 99.4% decline (range of 99.2–99.7%) from an estimated 121 517 nests per season in 1947 to 702 nests per season in 1985. Although the Kemp's ridley population has been recovering since the 1985 season, current levels of nesting (12 053 nests in 2014) (Burchfield 2014) are still relatively low at 9.9% (range of 5.7–14.6%) of the total estimated nests that occurred in 1947 based on the current analysis of Figures. 1 and 2 (see Fig. 4). As a comparison, if we use the same methodology with the Hildebrand (1963) estimate of 40 000 turtles in the June 18, 1947 arribada, a total of 180 587 total nests would be predicted for the 1947 season. Using this estimate, the 12 053 nests in 2014 would represent 6.7% (range of 3.9–9.8%) of the total nesting in 1947. Thus, our current estimate as well as that by Hildebrand (1963) suggest that the size of the current population is a relatively small percentage of the historic population.

Collectively, the results of this study suggest that during and prior to the 1947 nesting season a relatively robust population of Kemp's ridleys existed, which could support arribadas of at least 26 916 females. The Kemp's ridley population has shown a strong recovery over the past several decades following its collapse, however, the current status of the population appears to be a small percentage (approximately 9.9%) of the historic 1947 population based on the Herrera arribada and current nesting trends. Further, in the last 5 yr, the Kemp's ridley has deviated from the previous exponential recovery rate and has declined. It is currently not clear whether this population will recover to the point of historic levels. As indicated in the most recent recovery plan, the Kemp's ridley faces a variety of threats that could hinder its recovery, such as impacts from fisheries, pollution, climate change, and predation (NMFS et al. 2011). It is plausible that these as well as other factors could be impacting the Kemp's ridley and its habitat (Gallaway et al. 2016 a, 2016 b), thus limiting the species' ability to recover to historic levels.

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Supporting Information

Additional Supporting Information may be found online at: http://onlinelibrary.wiley.com/doi/10.1002/ecs2.1244/supinfo