IN SITU NEST AND HATCHLING SURVIVAL AT RANCHO NUEVO, THE PRIMARY NESTING BEACH OF THE KEMP'S RIDLEY SEA TURTLE, LEPIDOCHELYS KEMPII

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Abstract.-The Kemp's Ridley (Lepidochelys kempii) was historically the world's most endangered sea turtle and it neared extinction by the mid-1980s. Due to a gradual recovery of this species, a varying number of nests have been left in situ in recent years. The current study evaluated the impact of predators on in situ nests and hatchling survival using arribada nests during the 2009-2012 nesting seasons at Rancho Nuevo, Tamaulipas, Mexico. The results reveal a low predator impact, yielding relatively high in situ nest survival, with most hatchlings successfully reaching the sea. The results suggest a limited number of mammalian predators frequent the beach. This finding contrasts with historical anecdotes suggesting a great abundance of predators, in particular large numbers of Coyotes (Canis latrans) congregating at Rancho Nuevo for the nesting season. The decline in mammalian predators on the nesting beach could relate to: (1) the historic decline of Kemp's Ridley nests at Rancho Nuevo; (2) relocation of almost all nests to protected egg hatcheries for almost five decades; and (3) loss of natural habitat for predators inland from the beach. The results suggest that low predator impact may be due to low numbers of predators. Considering the relatively low predator impact on in situ nests and hatchlings, leaving nests in situ from arribadas may represent an efficient and natural means for producing hatchlings at Rancho Nuevo. However, it is unknown if predator abundance will rebound if increasing numbers of nests are left in situ in future years.

Key Words.—arribada nesting; conservation; covote; egg hatcheries; predation

INTRODUCTION

The Kemp's Ridley sea turtle was historically an abundant species inhabiting the Gulf of Mexico and the Atlantic coast of the U.S. (Pritchard and Marquez 1973). Based on the "Herrera film" of 1947 it has been estimated that approximately 40,000 turtles nested during a single arribada (mass nesting event) on 18 June Considering the normal nesting (Hildebrand 1963). biology of the Kemp's Ridley, (TEWG 2007; Rostal 2007) that arribada was probably one of several arribadas that season. Following the discovery of this film in the early 1960s, initial nesting surveys by Mexican fisheries biologists in 1966 revealed approximately 2,060 females for the entire nesting season (Marquez 1994). Compared to the 40,000 nesting females estimated for a single day in 1947, the 2,060 females reported for the entire season in 1966 conservatively represented at least a 95% decline for the species. The Mexican government began protecting nests and nesting females at Rancho Nuevo in 1966 and that program was expanded to a bi-national U.S./Mexico conservation program in 1978. Despite those efforts, the

number of nesting females continued to decline through the mid-1980s with fewer than 300 nesting females annually and remained near this critically low level during the late 1980s and early 1990s (Marquez 1994). Following the implementation of turtle excluder devices (TEDs) in 1989 (Donnelly 1989), the number of nesting females began to slowly increase (Heppell et al. 2007). The continued protection of nesting females, nests, and hatchlings at the nesting beach, in combination with the implementation of TEDs resulted in a steady recovery of the species for approximately two decades starting in the early 1990s through 2009. The gradual increase ceased in 2010 with a distinct decrease in nesting, the population has not regained the steady increase it was experiencing prior to the 2010 nesting season (Patrick Burchfield, pers. comm.). The reasons for decline and lack of recovery in the past five seasons are unknown.

When the Kemp's Ridley conservation program began in 1966, almost all nests were moved to egg hatcheries for protection and this has been the primary method of protection for nearly five decades. However, in recent vears, the conservation program at Rancho Nuevo has begun leaving a variable number of nests in situ, since the total number of nests can exceed the capacity of the

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egg hatcheries, or in the case of large arribadas, it can exceed the logistic capacity of the biologists working on the beach. The number of nests left *in situ* is dependent upon factors such as total number of nests during the nesting season, and the size, location, timing, and number of arribadas per season. It is therefore of conservation interest to determine the predation rate on nests and hatchlings on the natural nesting beach.

The purpose of the current study was to evaluate the fate of these *in situ* nests and compare it to the fate of nests moved to the egg hatcheries. This study also evaluated the abundance and distribution of predators on the nesting beach. These data are a prerequisite for the development of effective management strategies for selecting the locations, timing, and number of nests that are left on the natural nesting beach. Nesting en masse could provide certain advantages over scattered nesting such as reduced predation rate through predator satiation (Eckrich and Owens 1995).

MATERIALS AND METHODS

Study site.—We collected data for this study during each nesting season (i.e., between approximately the end of March through July) from 2009-2012. The study was conducted along a 30-km stretch of beach at Rancho Nuevo, Tamaulipas, Mexico (23°11'N, 97°46'W) which is the primary nesting location for the Kemp's Ridley sea turtle (Fig. 1). This nesting beach is located in the western Gulf of Mexico in an area where the local people subsist primarily through ranching and agriculture. The Rancho Nuevo area is characterized by multiple natural estuaries and rivers adjacent to the beach, providing a diverse habitat for the fauna of Rancho Nuevo. Thus, the land inland from the nesting beach is used for ranching and agriculture, but the nesting beach and the area directly bordering it remains undeveloped. This area represents habitat for a variety of natural predators of sea turtle eggs and hatchlings, including Coyote (Canis latrans), Raccoon (Procyon lotor), Skunk (Mephitis mephitis), Wild Pig (Sus scrofa), Ghost Crab (Ocypode quadrata), and a variety of predatory birds including Crested Caracara (Caracara cheriway), Osprey (Pandion haliaetus), Black Vulture (Coragyps atratus), and Turkey Vulture (Cathartes aura), among other species.

Nest predation.—We left approximately 300 to 500 nests from one arribada each year to incubate *in situ* to evaluate nesting and hatchling survival during the 2009–2012 nesting seasons. These nests represented approximately 30% or less of each arribada. If possible, we established a relatively high density nesting area (approximately 300 to 500 nests per 300 meters of beach) and a relatively low density nesting area (approximately 30 to 50 nests or less per 300 m of

beach) of nests from an arribada to compare the survival rates of nests and hatchlings relative to nest density. The high and low density nesting areas used as study locations on the Rancho Nuevo beach varied depending on the location and spatial distribution of the arribada. Arribadas can occur in various locations along approximately 30 km of beach at Rancho Nuevo, and the spatial distribution of each arribada can vary from a few hundred meters to several kilometers depending on the specific arribada. The location of the study areas were documented as the distance from the main camp in kilometers, with negative numbers indicating the study area was south of the main camp, while positive numbers indicated the study area was to the north. We recorded the location of each nest by GPS and marked the nests with either a labeled stake (2009–2011) or with a labeled rock (2012). We monitored all of these in situ nests daily for signs of predation. We attempted to determine the predators that had impacted each nest via their tracks, but this proved unreliable due to a variety of factors such as the masking of tracks by wind, rain, or tide, as well as the overlapping tracks from multiple predators in the area. We marked a nest as "semidepredated" if a portion of the eggs in a clutch were destroyed by predators, leaving some eggs untouched and intact. Likewise, we marked a nest as "completely depredated" if all the eggs in a nest were destroyed, leaving no viable eggs intact for that nest. Fisher's exact tests were used to compare the percentage of nests that were depredated in the high density nesting area versus the low density nesting area for each nesting season.

In situ hatching success.—Following hatchling emergence, we removed and inventoried the contents of each *in situ* nest during the 2009–2012 nesting seasons to determine average hatching success (Miller 1999). Every in situ nest was inventoried, unless it was lost due to high tides associated with tropical storms. We used eggshells, unhatched eggs, and dead hatchlings to calculate the average hatching success for each in situ Hatching success calculations included nest. undisturbed nests, partially depredated nests, and totally depredated nests. Hatching success was calculated using two different methods. The first method only included the impact of predators on nests, while the second method included both the impact of predators and the impact of nest loss due to erosion. We used Chi-square tests ($\alpha = 0.05$) to compare hatching success between high density and low density nesting areas for each year of the study.

Hatchling survival from nest to sea.—We evaluated hatchling survival during their movement from the nest to the sea for all *in situ* nests in the high and low density nesting areas during only the 2009 and 2012 nesting



FIGURE 1. The project locations on the primary nesting beach of the Kemp's Ridley Sea Turtle (Lepidochelys kempii) at Rancho Nuevo, Tamaulipas, Mexico. The project areas were used throughout the study period (2009-2012) and are shown relative to the location of the arribadas that were used in the current study. All symbols are color-coded by year with red, yellow, green, and blue representing 2009, 2010, 2011, and 2012, respectively. Triangles illustrate the location of the predator plots for each nesting season during the study period, while each star indicates the location of nests left in situ from a major arribada that occurred during each year of the study period. Thus the stars also mark where the arribada occurred for each year of the study period.

seasons. We calculated hatchling nest to sea survival high tide line. We assessed nest to sea survival by based on examining all hatchling tracks originating from a nest (i.e., hatchlings were not directly observed crawling from the nest to the sea). Following emergence, we evaluated hatchling tracks and estimated the percentage of tracks that successfully reached the 25%), or none (binned as 0%) of the hatchling tracks

classifying each nest into one of four general success categories based on the hatchling tracks: all (binned as 100%), greater than half but less than all (binned as 75%), less than half but greater than none (binned as TABLE 1. The fate of Kemp's Ridley Sea Turtle (Lepidochelys kempii) nests left in situ on the natural nesting beach from 2009-2012 at Rancho Nuevo, Tamaulipas, Mexico. In 2010, Hurricane Alex hit approximately 5 d prior to emergence. These were the only nests that were located after Hurricane Alex.

Year (Nesting Density)	Location of Study Area	Date of Arribada	Total Nests Monitored for Predation	Nests Lost Due to Erosion	Number of Nests Used for Hatching Success
2009 (High)	-10.2	17 May	178	16.7% (n = 30)	148
2009 (Low)	-2.1	17 May	55	20% (n = 11)	44
2010 (High)	-9.9	5 June	288	44.4% (n = 128)	160
2010 (Low)	-9.0	5 June	66	74.2% (n = 49)	17
2011 (High)	-8.3	28 April	398	21.4% (n = 85)	313
2012 (High)	-12.2	16 May	269	24.5% (n = 66)	203
2012 (Low)	-1.1	16 May	81	3.7% (n = 3)	78
Total (High)			1133	27.3% (n = 309)	824
Total (Low)			202	31.2% (n = 63)	139

made it to the water. The goal was to generate a general nesting seasons from 2009–2012. For each year, we estimate of the level of predation on hatchlings during their movements from the nest to the sea. Nest to sea survival estimates were compared between high and low density nesting areas for the 2009 and 2012 nesting seasons using the Z-test for the difference between two proportions.

established four different study areas from Barra Carrizo (16.5 km north of the main turtle camp) to Barra del Tordo (13.5 km south of the main turtle camp). In each location, we designated 10 one-meter squares of open beach, or "predator plots" that were evenly-spaced and alternated approximately every three meters on each side of a line parallel to the dune in an area where the majority of nesting occurred. We evaluated the predator plots one to three days per week throughout the nesting

Predators.-We evaluated the type and presence of predators on the beach at Rancho Nuevo for all four

TABLE 2. The extent of predation on Kemp's Ridley Sea Turtle (Lepidochelys kempii) nests left in situ on the natural nesting beach from 2009-2012 at Rancho Nuevo, Tamaulipas, Mexico. The P-values for Fisher's exact tests comparing the percentage of undisturbed nests from high and low density nesting areas for each nesting season and for the entire study (2009-2012) are shown adjacent to the low density value for each year and for the entire study period. Significant P-values are indicated by an asterisk.

Year (Nesting Density) ^a	Number of Nests	Un-disturbed ^b	Fisher's Exact	Semi-depredated ^c	Totally Depredated ^d
2009 (High)	148	92.6% (n = 137)		4.7% (n = 7)	2.7% (n = 4)
2009 (Low)	44	75.0% (n = 33)	0.005*	6.8% (n = 3)	18.2% (n = 8)
2010 (High)	288 ^e	95.1% (n = 274)		3.5% (n = 10)	1.4% (n = 4)
2010 (Low)	66 ^e	98.5% (n = 65)	0.321	0.0%	1.5% (n = 1)
2011 (High)	313	71.6% (n = 224)		25.6% (n = 80)	2.9% (n = 9)
2012 (High)	203	88.2% (n = 179)		9.4% (n = 19)	2.5% (n = 5)
2012 (Low)	78	88.5% (n = 69)	0.335	10.3% (n = 8)	1.3% (n = 1)
Total (High)	952	85.5% (n = 814)		12.2% (n = 116)	2.3% (n=22)
Total (Low)	188	88.8% (n = 167)	0.771	5.9% (n = 11)	5.3% (n=10)

^a High density areas had 300-500 nests per 300 m of beach. Low density areas had 30-50 nests per 300 m of beach.

^b Nests that were not impacted by predators throughout the entire incubation period.

^c Nests that were partially impacted by predators with some viable eggs remaining.

^d Nests in which all eggs were impacted by predators.

"Nests from this arribada were monitored for only the first 45 d of incubation due to Hurricane Alex. Typically nests would hatch in approximately 50 d.

season (late March through July). During an evaluation day, we checked the plots twice daily, once in the morning to document nocturnal predators that had walked through the area during the previous night, and once later in the afternoon to document diurnal predators that walked through each plot during the day. We smoothed the plots after each observation to ensure only new tracks were recorded during the next observation. We identified predator tracks using a standard field guide to animal tracks (Aranda 2000). We identified the mammalian predator tracks as coyote, raccoon, skunk, or wild pig. Additionally, we classified tracks from birds into three categories, large (e.g., Crested Caracara, Osprey, vultures, and herons), medium (e.g., various gulls, terns, and Willets), or small (e.g., Sanderlings) bird tracks. Periodically, we positioned motiontriggered wildlife cameras among the predator plots in each study area to record predators that visited the plots. The pictures provided visual verification of the identity of predators that visited specific locations of the beach.

The locations of the predator plots (Fig. 1) were chosen to span the central portion (approximately 16 km) of the Rancho Nuevo nesting beach where the majority of nesting typically occurs. The locations were areas in which arribadas have historically been known to occur, and were on wider sections of beach in which the predator plots and typical nesting areas were not prone to tidal inundation. In 2009, 2010, and 2011, we established two predator plot study sites to the north of the main camp at Rancho Nuevo, one at 8.1 km and the other at 5.7 km north. We also established predator plots in two locations to the south of the main camp, one at 0.6 km and one at 5.4 km south. In 2012, we established two predator plot study sites to the north of the main camp, one at 5.7 km and one at 4.2 km north, and we also established two predator plot study sites at 1.2 km and 5.7 km to the south of the main camp at Rancho Nuevo.

The predator plot data provide an accurate method of indicating the presence of a predator type in a given study location. Further, the use of ten plots in each study location enhanced the resolution of detecting predators. However, there is the possibility that a single predator

could walk through multiple plots in a study location on a given day. Thus, to be conservative, we have not used these data to predict the total number of individuals of a particular predator type in a study location, rather the data indicate the presence of a particular predator type on a given day. Fisher's exact probability tests using the Freeman-Halton extension were used to examine if each predator type was detected uniformly across all study locations, and uniformly across the entire nesting season (α =0.05). For the analyses, the nesting season (late March through July) was divided evenly into thirds, and the number of days in which a predator type was detected in a study location was summed for each period.

RESULTS

In situ nest survival.—We found 27.3% of nests in the high density and 31.2% of nests in the low density nesting areas for all nesting seasons combined were lost due to erosion (Table 1). The percentage of undisturbed nests in the high density nesting areas was 85.5% and was 88.8% for all low density nesting areas, combined over the 2009–2012 study period (Table 2).

In situ hatching success.—The average hatching success for all of the *in situ* nests from all four years of the study (2009–2012) was 70.9% when the impact of predation was considered alone and 51.1% when the impacts of both predation and nest loss due to erosion were taken into account (Table 3).

Hatchling survival from nest to sea.—We evaluated hatchling survival from nest to the sea for all nests that produced hatchlings for only two nesting seasons of this study, 2009 and 2012 (Table 4). This included a total of 144 *in situ* nests in 2009 and 137 nests in 2012 from high density nesting areas and a total of 37 nests in 2009 and 48 nests in 2012 from low density nesting areas. We did not evaluate hatchling survival from the nest to sea in 2010 or 2011. The comparison of nest to sea survival between high and low density nesting areas from 2009 and 2012 suggested higher survival from the low density

TABLE 3. Hatching success for all Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) nests left *in situ* on the natural nesting beach from the high and low density nesting areas during the 2009–2012 nesting seasons at Rancho Nuevo, Tamaulipas, Mexico. The calculations for hatching success included the impact of predators on each nest. Nests that were washed out by high tides were not included in this analysis. Data from the low density nesting area in 2011 was not available due to beach erosion resulting from Hurricane Arlene.

Year	Number of Nests	Hatching Success High Density	Hatching Success Low Density	T-test (t-stat, df, P-value)	Average
2009	192	81.2%	79.4%	(2.95, 190, 0.002)	77.9%
2010	177	61.5%	54.0%	(0.89, 175, 0.187)	60.8%
2011	313	76.1%			76.1%
2012	281	64.3%	72.5%	(-1.64, 279, 0.051)	66.6%
Average		71.3%	68.4%	(0.975, 962, 0.165)	70.9%

TABLE 4. Evaluation of nest to sea survival for subsets of Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) nests left *in situ* on the natural nesting beach from high and low density nesting areas in the 2009 and 2012 nesting seasons at Rancho Nuevo, Tamaulipas, Mexico. Calculations for the high and low density nesting areas in each year are based on the total number of nests that produced emerging hatchlings in each area respectively. Nests were placed into one of four general categories of success based on the evaluation of hatchling tracks leading from the nest to the sea: (1) all; (2) most - greater than half; (3) few - less than half; or (4) none of the hatchlings made it to the surf. To estimate the total number of hatchlings surviving from emergence to the sea the following survival percentages were used for the four categories: all (100%), greater than half (75%), less than half (25%), none (0%). To calculate average nest to sea survival, we used an estimate of 100 hatchlings as the maximum number of hatchlings possible from each nest. Asterisks indicate significant Chi-Square P-values (P<0.0001) for a comparison between average nest to sea survival in high versus low density nesting areas during a given nesting season.

		% Total Nests (Number of Nests)	Maximum Hatchlings	Predicted Number of	
Year	Success Category	in Each Category	Possible	Hatchlings Surviving	Overall Survival
2009	All	82.6% (n = 119)	11,900	11,900	
(High Density)	Most	16.7% (n = 24)	2,400	1,800	
(n = 144)	Few	0.7% (n = 1)	100	25	
	None	0%	0	0	
	Total		14,400	13,725	95.3%
2000	A 11	75.70% (n - 28)	2 800	2 800	
2009	All	73.770 (II – 28)	2,800	2,800	
(Low Density)	Most	21.6% (n = 8)	800	600	
(n = 37)	Few	2.7% (n = 1)	100	25	
	None	0%	0	0	
	Total		3,700	3,425	92.6%*
2012	All	20.4% (n = 28)	2,800	2,800	
(High Density)	Most	72.3% (n = 99)	9,900	7,425	
(n = 137)	Few	7.3% (n = 10)	1,000	250	
	None	0%	0	0	
	Total		13,700	10,475	76.5%
2012	A 11	60.4% (n = 20)	2 900	2 900	
		00.470 (II - 25)	2,500	2,900	
(Low Density)	Most	33.3% (n = 16)	1,600	1,200	
(n = 48)	Few	6.3% (n = 3)	300	75	
	None	0%	0	0	
	Total		4,800	4,175	87.0%*

nesting area ($Z_{2009} = 6.68$, df = 1, P < 0.001; $Z_{2012} = 15.45$, df = 1, P < 0.001).

Predators.—Predator presence is presented as the percentage of observation days in which tracks from each type of predator were detected in a study location. The primary nocturnal mammalian predators were Coyote, Raccoon, and Skunk. Ghost Crabs were the most prevalent predator at all times (both nocturnal and diurnal periods) for all locations in the 2009–2012 nesting seasons (Fig. 2). In addition to Ghost Crabs,

several species of birds were the main diurnal predators on the beach. The photos from the wildlife cameras validated the use of the tracks as a method for accurately identifying specific predators. There were significant annual and seasonal variations in the presence of predators between all four study areas (Tables 5 and 6).

DISCUSSION

In situ nest predation.—The *in situ* nests in the current study represented typical nests from arribadas



FIGURE 2. The percentage of days for which diurnal and nocturnal predator tracks were recorded in predator plots at each study area during the 2009 (A), 2010 (B), 2011 (C), and 2012 (D) nesting seasons at the nesting beach for the Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) at Rancho Nuevo, Tamaulipas, Mexico. Each bar corresponds to the percent of days that each type of predator was recorded at a specific study area. Study area is indicated on the z-axis.

that occurred at various times during the nesting season over the four-year study. Some of the nests were lost to storm-induced erosion (discussed below under In situ hatching success), and the remaining nests were evaluated for predation. Nest predation was low for in situ nests, with a relatively small percentage of nests being completely destroyed by predators (approximately 1.3-18.2%), and with most of the nests being undisturbed by predators (approximately 71.6-98.5%). Consistent with the predator satiation hypothesis (Carr 1967; Pritchard 1969; Cornelius 1986; Eckrich and Owens 1995; Bernardo and Plotkin 2007), during the 2009 nesting season, the percentage of undisturbed nests in the high density nesting area (92.6%) was significantly greater than that in the low density nesting area (75.0%). However, no significant differences were detected between high and low density nesting areas during 2010 and 2012 nesting seasons, and in both of those years there was a greater percentage of undisturbed nests in low density nesting areas in comparison to the high density nesting areas. Thus, predation levels were relatively low in all nesting areas, and no consistent differences were detected in the predation levels between low and high density nesting areas.

To control for lay date in this study, the low density nesting areas were selected on the same day as the high density areas during the occurrence of an arribada. These nesting areas had a lower density of nests than the main arribada areas, however, the nests may still have

TABLE 5. Temporal comparison of predator presence showing P-values (* = significant) from Fisher's exact tests using the Freeman-Halton extension for comparing the presence of each predator over the entire nesting season at four different study areas on the nesting beach for the Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) at Rancho Nuevo, Tamaulipas, Mexico during the 2009–2012 nesting seasons. Each study area was evaluated separately. Predator presence was recorded by evaluating predator tracks in designated plots of sand at each location approximately three days per week for the study period (late March through July). The study period was evenly divided into three time periods which were compared to evaluate temporal changes in predator presence.

Year	Location	Skunks	Raccoons	Coyotes
2009	8.1 N	0.698	0.310	0.100
	5.7 N	0.110	0.0887	1.000
	5.4 S	1.000	0.027	1.000
	0.68	0.088	0.002*	1.000
2010	8.1 N	0.416	0.212	0.092
	5.7 N	0.014*	0.842	0.292
	5.4 S	0.501	0.581	0.024*
	0.68	0.076	0.498	0.070
2011	8.1 N	< 0.001*	< 0.001*	0.055
	5.7 N	< 0.001*	0.002*	0.329
	5.4 S	1.000	0.017*	0.174
	0.68	0.009*	0.021*	0.488
2012	5.7 N	0.027*	0.014*	0.201
	4.2 N	1.000	0.003*	< 0.001*
	5.7 S	0.317	0.031*	0.118
	1.2 S	0.317	< 0.001*	0.020*

been more densely grouped (44–66 nests laid on the same day over 300 m of beach) in comparison to nests from solitary females (Bernardo and Plotkin 2007). Therefore, these nesting areas may still have had a density great enough to quickly satiate predators and may not have been a true representation of scattered nesting (Eckrich and Owens 1995; Bernardo and Plotkin 2007). It is quite possible that predator satiation was rapidly achieved in both high and low density nesting areas due to low predator abundance. A previous study using direct observations of predators with night vision equipment and wildlife cameras concluded that there were a limited number of predators in a variety of study areas examined on the Rancho Nuevo nesting beach (Eich 2009).

We found that the nest predation levels that we recorded in the current study are relatively low in comparison to those reported in many previous studies of sea turtles. As initially indicated in a review by Stancyk (1982), nest survival can vary widely depending on the sea turtle species, nesting beach location, predator types, predator abundance, nesting behavior, as well as other factors. In some studies, Raccoons destroyed up to 90% of Loggerhead (Caretta caretta) nests along the Atlantic coast of Florida (Bryant 1985; McMurtray 1986), and between 55.1 and 93.8% of Loggerhead nests on beaches in South Carolina (Hopkins et al. 1978; Stancyk et al. 1980). Monitor Lizards were found to destroy nearly all Hawksbill Sea Turtle (Eretmochelys imbricata) nests on Lacey Island along the Great Barrier Reef (Limpus 1980) and Flatback Sea Turtle

TABLE 6. Predator presence by species between all study locations showing P-values (* = significant) from the Fisher's exact tests using the Freeman-Halton extension comparing each time period among four study areas on the nesting beach for the Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) during the 2009–2012 nesting seasons at Rancho Nuevo, Tamaulipas, Mexico. Predator presence was recorded by evaluating predator tracks in designated plots of sand at each location approximately three days per week for the nesting season (late March through July). The P-values are for Fisher's exact tests using the Freeman-Halton extension for comparing presence of each predator between all four study areas during each third of the nesting season. The study period (late March–July) was evenly divided into three time periods.

Year	Time Period	Skunks	Raccoons	Coyotes
2009	1	< 0.001*	< 0.001*	1.000
	2	< 0.001*	0.047*	0.357
	3	0.002*	< 0.001*	1.000
2010	1	0.018*	0.157	0.444
	2	0.015*	0.960	0.732
	3	0.133	0.491	0.423
2011	1	< 0.001*	< 0.001*	0.054
	2	< 0.001*	0.044*	0.078
	3	0.356	0.715	0.935
2012	1	0.233	0.042*	0.897
	2	1.000	0.006*	0.387
	3	1.000	< 0.001*	0.012*

southeastern Queensland (Limpus 1971).

In addition to relatively high predation rates, there have also been many reports of relatively moderate to low nest predation levels on some sea turtle nesting beaches. Low to moderate predation rates have been reported across multiple species and beaches, such as 32.8% predation of Green Sea Turtle nests at Tortuguero, Costa Rica (Fowler 1979), 27.0% of Hawksbill nests in the Barbados, West Indies, (Leighton et al. 2008), and little to no predation reported of Flatback, Olive Ridley, and Hawksbill nests on Crab Island in the northeaster Gulf of Carpentaria, Australia (Limpus et al. 1983). In an extreme example of low nest predation, there were no signs of nest predation at rookeries for Hawksbill Turtles on three small islands in Western Samoa on which rats were the only mammalian predator (Witzell and Banner 1980). Highly variable predation rates by Monitor Lizards have also been reported within the same species, for example 52% of Flatback Sea Turtle nests were destroyed at Fog Bay in Australia's Northern Territory (Blamires and Guinea 2003; Blamires et al. 2003), but rarely any nests were destroyed by Monitor Lizards at Mundabullangana in Western Australia (Prince and James 1994). For the western Pacific Leatherback, pigs were reported to destroy 29.3% of nests on Warmamedi Beach (Tapilatu and Tiwari 2007) and a variety of predators were reported to destroy between 8.8 and 21.2% of nests on Wermon Beach (Wurlianty and Hitipeuw 2006; Hitipeuw et al. 2007).

Thus, nest predation rates vary widely, and are most certainly influenced by the reproductive ecology of the specific sea turtle species and the ecology of the specific nesting beach habitat. Ideally, meaningful comparison of predation rates should consider contributing factors (e.g., nesting behavior, nesting beach location and topography, predator types, predator abundance, etc.), but comprehensive data of this sort are often lacking. Further, a variety of studies have indicated that poaching of nests by humans represents another confounding factor when attempting to evaluate and compare the impact of predators (Hendrickson 1958; Fowler 1979; Limpus et al. 1983; Whiting et al. 2007). Regardless, the nest predation recorded in the current study at Rancho Nuevo represents relatively low levels of predation in comparison to those reported in most previous studies.

Implications of predator abundance.--It has been suggested that the evolution and maintenance of the arribada nesting behavior would require strong selection pressure (Hildebrand 1963; Carr 1967; Pritchard 1969; Ims 1990a, b). Since the initial report of arribada nesting in the Kemp's Ridley (Hildebrand 1963), it has frequently been hypothesized that this mass nesting

(Natator depressus) nests on Facing Island in behavior could enhance the survival of eggs and hatchlings through predator satiation (Carr 1967; Pritchard 1969; Cornelius 1986; Eckrich and Owens 1995; Bernardo and Plotkin 2007). However, the results from the current study indicate the level of predation was relatively low in all study areas, which suggests low numbers of predators. With low numbers of predators, predator satiation could be achieved in arribada, low density, and even solitary nesting areas which makes it difficult to test the predator satiation hypothesis. Although it has been commonly hypothesized that the combination of high predation both on the beach and in nearshore waters would greatly enhance the selection pressure for arribada nesting (Hildebrand 1963; Carr 1967; Pritchard 1969), we are unable to discern whether the predators are satiated or simply leave Rancho Nuevo to forage in more profitable areas.

> While the predator satiation hypothesis is generally accepted as the most likely selection pressure for the evolution of arribada nesting behavior (Bernardo and Plotkin 2007), only two studies have attempted to test this hypothesis (Eckrich and Owens 1995; Eich 2009). Eckrich and Owens (1995) compared the predation of solitary versus arribada nests at an Olive Ridley arribada nesting beach in Costa Rica and the results supported the predator satiation hypothesis. Eich (2009) examined predator abundance and nest predation at Rancho Nuevo in high and low density nesting areas. The results indicated low predator abundance with no consistent differences between high and low density nesting areas. That study also found a relatively high level of nest predation for a small number of scattered nests (5 or 6 nests) at 4 widely-separated low density nesting areas, but a high density nesting area was not available for comparison during that year of the study. Bernardo and Plotkin (2007) suggest that optimal testing of the predator satiation hypothesis would require the comparison of predation on arribada beaches versus non arribada beaches with only solitary nesting. This type of comparison is possible in the Olive Ridley, but may not be possible with the Kemp's Ridley since it is unknown if any Kemp's Ridley nesting areas would represent true solitary nesting beaches analogous to those described for the Olive Ridley (Bernardo and Plotkin 2007).

> An alternative hypothesis is that predator abundance on the Rancho Nuevo beach in recent years is far less than it was at least a half century ago. Based on the 1947 Herrera film, turtles laying millions of eggs along with the later emergence of potentially millions of hatchlings provided an abundant food source for the beach ecosystem at Rancho Nuevo for approximately five months of the year. This most likely attracted a seasonal, large-scale migration of predators to the nesting beach to feed on an abundant and predictable food source. A similar scenario has been reported for the Olive Ridley at Nancite, Costa Rica, in which "the

densest turtle nesting in the world supports an extremely dense predator assemblage" and "the predators are experienced hunters of turtle nests" (Bernardo and Plotkin 2007:59-87p). The historic decline in the Kemp's Ridley coupled with the relocation of almost all nests to protected egg hatcheries for nearly five decades have effectively removed sea turtle eggs and hatchlings as a major food source for predators on the nesting beach. This could have a profound effect by decreasing predator abundance and/or alter the behavior and location of predators in the vicinity of the nesting beach. Additionally, there has been a large reduction in natural habitat for predators over this same time period in which much of the wilderness inland from the beach has been converted for agricultural uses. Thus, the lack of eggs and hatchlings as a food source on the beach together with loss of habitat adjacent to the beach may have significantly reduce predator abundance.

The hypothesis of historically high predator abundance at Rancho Nuevo is also supported by anecdotal evidence reported in the 1960s when scientists first began visiting the nesting beach. Hildebrand (1963) notes that Coyotes are the main predator of Ridley nests and hatchlings, and he proposes that the arribada behavior may have resulted from strong selective pressure from intense Coyote predation of nests. Carr (1967) indicated that Coyotes were very abundant and were the primary mammalian predator at Rancho Nuevo, and Pritchard and Marquez (1973) noted that Coyotes normally destroy any nest that is left on the beach for more than 24 hours. Some of the more intriguing anecdotes have come from interviews with locals during the 1960s who were familiar with the Kemp's Ridley arribadas, indicating that Coyotes "congregate" at Rancho Nuevo before an arribada (Carr 1963) "in numbers seen nowhere else" and that "the coyotes come in arribadas of their own, in packs the people who have seen them say are bigger than anyone ever saw before" (Carr 1967:130–131p). Thus, it is guite possible that the low predator abundance suggested in the current study has resulted over the past half century and is contrary to extremely high predator levels that may have existed prior to that time.

In situ hatching success.—Considering the yearly variability in tropical weather systems affecting the Gulf of Mexico, we felt it was informative to examine hatching success both with and without nest loss due to erosion, thus providing a range of scenarios that might occur in future years. The average *in situ* hatching success of 70.9% (without the impact of erosion) is within the estimated range of approximately 62 to 75% for hatching success in egg hatcheries at Rancho Nuevo (Chávez et al. 1968; Márquez et al. 2001). Further, it is comparable or in many cases higher than the average hatching success reported in studies of other sea turtle

species, for example the Loggerhead Sea Turtle (Davis and Whiting 1977; Stancyk et al. 1980; Peters and Verhoeven 1994; Peters et al. 1994); the Green Sea Turtle (Fowler 1979; Stancyk 1982; Niethammer et al. 1997); and the Leatherback Sea Turtle (Tapilatu and Tiwari 2007). This suggests that even with predation as a factor, the hatching success for *in situ* nests in the current study was relatively high.

Consistent with the predation data discussed above, the hatching success (including the impact of predation) for 2009 was greater for nests in the high density nesting area in comparison to the low density area, but no significant differences were detected between the high and low density nesting areas for the 2010 and 2012. As discussed above, this variability could be due to a variety of factors, including the low predation level.

Loss of *in situ* nests due to beach erosion must be considered when making decisions regarding beach management strategies for endangered sea turtles. This represents a loss of hatchlings that would have been produced had nests been relocated to egg hatcheries (Whitmore and Dutton 1985). The average *in situ* hatching success rate of 70.9% reported above does not include the 372 *in situ* nests (27.9% of the total number of *in situ* nests) that were lost to beach erosion over the four year study. If we include those nests in the calculations, the average hatching success for the four year study decreases to approximately 51.1%. Thus, in the current study, nest erosion resulted in a 19.8% decrease in hatching success for the *in situ* nests.

However, nest loss due to erosion also represents a natural cause of mortality that has previously been a sustainable part of the Kemp's Ridley's life history. If nest-site selection is a heritable trait, then natural loss of nests would therefore be a selection pressure that could lead to the evolution of optimal nest-site selection in the Kemp's Ridley (Mrosovsky 1983; Kamel and Mrosovsky 2004, 2005; Ernst and Lovich 2009). That is, *in situ* nests that are laid closer to the high tide are more vulnerable to tidal inundation and would thus reduce the fitness of individual female sea turtles (Kamel and Mrosovsky 2004, 2005). Further, relocating vulnerable in situ nests to the protection of egg hatcheries could artificially eliminate this selection pressure, resulting in poor nest-site selection in this species (Vogt 1994; Kamel and Mrosovsky 2004, 2005; Mrosovsky 2008; Ernst and Lovich 2009). Thus, there could be an evolutionary-based advantage to leaving nests in situ. However, when working with an endangered sea turtle population, the maximal production of hatchlings may be the priority, so moving nests to hatcheries may take precedence. Nevertheless, as the population recovers, the long-term fitness of the species should be considered and could potentially be enhanced by allowing nature to select for maximum fitness of nesting females and hatchling. The topic of nest site selection has not been previously addressed in the Kemp's Ridley hatchlings and would require the monitoring of specific females throughout a given nesting season as well as during successive nesting seasons.

Hatchling survival from nest to sea.—The hatchling tracks from the nest to the sea indicated that an estimated 86.9% of the hatchlings emerging on the beaches of Rancho Nuevo successfully made it to the high tide line. Although significantly more hatchlings were predicted to make it to the sea in the low density nesting areas, in general, survival was high in both high and low density areas. These findings suggest a relatively high natural survival rate for hatchlings during their movement to the sea at Rancho Nuevo, and may reflect a limited number of predators (as suggested above). A previous study at Rancho Nuevo estimated the survival of hatchlings from in situ nests to the sea to be 66.4% (Eich 2009). Although these survival rates are relatively high, from a conservation viewpoint, they should be considered relative to those from the egg hatcheries in which all viable hatchlings are released in or near the surf. However, from an ecological and evolutionary viewpoint, it is possible that predation of hatchlings during their crawl to the sea may be a selection pressure for ensuring that the most robust hatchlings survive, thus optimizing the fitness of individuals in the population. Leaving nests in situ in contrast to moving them to egg hatcheries could be advantageous for enhancing fitness, even though moving nests to hatcheries would maximize hatchling production in the short term. As indicated above, in an endangered sea turtle population, optimizing hatchling production through the use of hatcheries may take precedence.

Several potential sources of error should be noted in regards to the evaluation of hatchling survival from nest to sea. First, categorizing nests based on hatchling tracks leading away from the nest should be considered an estimation and could be subject to potential bias in methodology depending on the individual who is assigning values. Other complications in determining hatchling survival from nest to sea are high tides, seaweed and debris, and many overlapping tracks leading away from the nest can make it difficult or impossible to estimate a reasonably accurate number of hatchlings. However, in many cases the tracks are obvious and unobscured, thus providing a logistically feasible method of estimating hatchling survival to the sea from relatively large numbers of nests (Fowler 1979).

Predators.—The predator plot study during the 2009– hatcheries. Further, the overall goal of this conservation 2012 nesting seasons revealed a distinct difference in program is to restore the Kemp's Ridley to an nocturnal and diurnal predator composition. While Ghost Crabs are one of the most commonly reported nest

predators, after burrowing into nests, they often vacate the nest after consuming a variable number of eggs. Thus the scale of their direct impact on nest survival tends to be smaller than that of mammalian predators at Rancho Nuevo (Stancyk et al. 1980; Stancyk 1982). In regards to sea turtle nest predation, birds are not known for excavating nests (Stancyk 1982) and their impact is typically limited to scavenging previously depredated nests and predation of hatchlings (Honegger 1967; Pritchard 1971; Fowler 1979; Stancyk 1982). Since the current predator plot data support previous studies that have reported the relatively heavier impact of mammalian predators on nest survival at Rancho Nuevo, we focused our analysis in the current study on only the nocturnal mammalian predators (Stancyk 1982; Eckrich and Owens 1995; Eich 2009).

Statistical analysis of the predator plot data indicates that the prevalence of predators in each specific study area was variable, including variability during a specific nesting season. Additionally the results suggest that predator prevalence often varied between the four study locations during a particular time period of the study. The variability in predator prevalence could represent a response to environmental or biotic factors specific to each year and study location (e.g. rainfall, humidity, temperature, other predators, food availability, etc.). For example, limited food availability on the beach could necessitate the movements of predators during their searches for appropriate prey.

Conservation implications.—The relatively low predation rates of the in situ nests in the current study suggest low numbers of predators on the beach at Rancho Nuevo. The primary predators impacting nests at Rancho Nuevo are a few nocturnal mammalian species (i.e., Covotes, Raccoons, and Skunks) and their numbers are limited on any one area of beach. Additionally, Ghost Crabs represent a primary diurnal predator, but their impact is typically limited to a few eggs per nest, and some birds may represent secondary predators in regards to nests. However, the collective impact of all these predators appeared to be relatively low in the current study with approximately 86.1% of the *in situ* nests remaining undisturbed throughout their incubation period. Historically, most nests have been moved to egg hatcheries for almost five decades at Rancho Nuevo, which protects nests from predation and ensures that virtually all hatchlings reach the sea. This effort has been a priority conservation measure and has been instrumental in initiating the recovery of this species. However, if the Kemp's Ridley continues to recover it will exceed the capacity of the current egg hatcheries. Further, the overall goal of this conservation program is to restore the Kemp's Ridley to an ecologically stable and natural state in which the

necessary (USFWS and NMFS 1992). Considering the relatively low predation rates recorded in the current study, leaving a proportion of the nests from an arribada *in situ* could represent a relatively efficient, practical, less labor-intensive, and natural means for producing hatchlings at Rancho Nuevo. Further, the eventual shift back to natural nesting could potentially facilitate enhanced fitness in nesting females as well as hatchlings (Kamel and Mrosovsky 2004, 2005).

It is important to note that predator abundance could change if relatively large numbers of nests are consistently left *in situ*, potentially sustaining a greater predator population, and higher predation levels. Therefore, it would be of interest to monitor changes in predator abundance and nest predation if increasing numbers of nests are consistently left *in situ* during future nesting seasons. In particular, if the Kemp's Ridley recovers to the point of having arribadas with tens of thousands of nesting females, it will be interesting to see if there is a corresponding rebound in the seasonal predator population on the beach, such as the return of "coyote arribadas" suggested in anecdotes from five decades ago (Carr 1963, 1967).

Acknowledgments.—The information reported in this manuscript represents one of the research components of the Kemp's Ridley Sea Turtle Bi-national Restoration Program. This program is directed in Mexico by the General Directorate for Wildlife of the Secretariat of Environment and Natural Resources (SEMARNAT) in coordination with the National Commission of Natural Protected Areas (CONANP). This bi-national restoration includes collaborations from a variety of Mexican and U.S. agencies, including the U.S. Fish and Wildlife Service, the NOAA Fisheries, Secretaría de Desarrollo Urbano v Medio Ambiente in the State of Tamaulipas (SEDUMA), and Texas Parks and Wildlife. This program is conducted under permits from Direccion General de Vida Silvestre: SGPA/DGVS 03497/06. SGPA/DGVS/05469/10, SGPA/DGVS/03990/11, and SGPA/DGVS/04476/12. This research would not have been possible without the efforts of a wide variety of dedicated biologists who coordinate and conduct the conservation program at the Kemp's Ridley nesting beach at Rancho Nuevo. The research presented in this manuscript was funded in part by grants from NOAA's National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and from the Marine Turtle Conservation Fund. We would like to acknowledge the University of Alabama at Birmingham Department of Biology for providing a graduate fellowship to Elizabeth Bevan.

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