Baseline data reveal importance of Río Oro National Wildlife Refuge to the East Pacific Olive Ridley (*Lepidochelys olivacea*) sea turtle stock.

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Abstract

Previous studies had identified the Río Oro National Wildlife Refuge (RONWR), Osa Peninsula, Costa Rica, as a site of major solitary Olive Ridley nesting[1][2][3][4][5][6]. Ease of access via a public road meant that these nests were especially vulnerable to being poached, and yet the refuge was left abandoned without routine protection for many years. A new program established by the Corcovado Foundation in 2015 aims to provide long-term monitoring and protection of the site. From 01 August through 31 December 2015, 2,951 Olive Ridley nests were registered on Río Oro beach (density = 61.5/100m), corresponding to 49.5% of all nests registered for this species on the five major nesting beaches in the Osa Peninsula. Nesting peaked at the beginning of October, and nesting frequency was observed to increase markedly during the third quarter phase of three consecutive lunar cycles. Analysis of a sample of 524 nests revealed a hatching rate of 81.0%, comparable to that of neighboring beaches, and much higher than that reported for beaches on which arribadas take place[7][8]. These data demonstrate that the RONWR makes a greater contribution to the Olive Ridley sea turtle stock than any other site in the South Pacific of Costa Rica.

Figure 1. Map of Costa Rica showing the five major sea turtle nesting beaches located outside the Corcovado National Park in the Osa Peninsula (inset).

Methods

Río Oro beach was cleaned and marked with reference posts at 100m intervals, delimiting 48 distinct sectors, from Laguna Pejeperrito (adjacent to Carate beach) to Laguna Pejeperro (adjacent to Pejeperro beach). Río Oro beach was monitored continuously from 20 July 2015 through 25 January 2016 by means of daily night patrols and/or morning censuses of nests and tracks, during which temporal, spatial and biometric data pertaining to turtles and nests were recorded as described previously[9]. A total of 1,202 Olive Ridley sea turtles were marked with tags (#681 INCONEL) displaying the prefix OP, OSA or JG. Nests were left to incubate *in situ* unless found below the high tide line (zone 1), in which case they were relocated to a nearby alternative site above this line (zone 2). A sample of 314 nests was marked using labeled plastic bottles tethered to pieces of wood buried alongside the nests. A sample of 524 nests was excavated and analyzed, as described previously[9], of which 200 were previously marked, of which 144 qualified for reliable thermal profiling. Cycling incubation temperatures from dataloggers (HOBO Pendant Temperature UA-001-08/64 [accuracy ±0.47 °C]) buried at control locations on the beach (sectors 21 and 34) were converted to a constant temperature equivalent (CTE) for each day. These data were used to predict offspring sex ratio, based on the CTE one third of the way through the incubation period, using published pivotal temperatures for this species in Costa Rica[10]. The number of days since the previous full moon (0-28) was calculated for each *solitary* (non-arribada) nesting event on the beaches of Río Oro (2015), Corozalito (2009-2015), and San Miguel (2010-2012). The proportion of nests laid on each day of the lunar cycle was calculated as the percentage of the total number of nests in the sample. Alignments were made of datasets from multiple seasons, from which mean data were generated.

Results

Turtle Crawls			Initial Status of Nests			Final Status of Nests					Reproduction Rate		Estimated Sex Ratio	
Total Crawls	Total Nests	False Crawls	Marked (M)	Left *In Situ*	Relocated *Ex Situ*	M Recovered	M Not Recovered	Lost to Poaching	Lost to Predation	Total Excavated	Mean Hatching Rate	Mean Emergence Rate	Female	Male
4,187	2,951	1,236	314	2,759	173	200	114	44	4	524				
%	70.5	29.5	10.6	93.5	5.9	63.7	36.3	1.5	0.1	17.8	81.0	76.1	72.5	27.5

Figure 2. Summary of Olive Ridley turtle crawls and nests registered on Río Oro beach from 01 August through 31 December 2015, showing initial and final status of nests, the reproduction rate based on a sample of 524 excavated nests, and the estimated sex ratio based on a sample of 144 excavated nests.

Beach	Length (km)	Nests (n)	Nests (%)	Density (n/100m)	Poaching (%)	Hatching (%)	Emergence (%)	Organization
Carate	2.8	593	9.9	21.2	4.0	61.0	60.0	COTORCO
Río Oro	**4.8**	**2,951**	**49.5**	**61.5**	**1.5**	**81.0**	**76.1**	Corcovado Foundation
Pejeperro	5.5	1,382	23.2	25.1	21.1	-	-	Osa Conservation
Piro	4.5	927	15.6	20.6	36.1	-	-	Osa Conservation
Drake	3.6	107	1.8	3.0	6.5	73.9	70.0	Corcovado Foundation

Figure 3. Comparison of the number, proportion and density of Olive Ridley nests registered on the five major nesting beaches in the Osa Peninsula, from 01 August through 31 December 2015, showing poaching and reproduction rates.

Data from Carate beach, and from Pejeperro and Piro beaches, used with kind permission from COTORCO (Barquero-Edge PS) and Osa Conservation (Sánchez M), respectively.

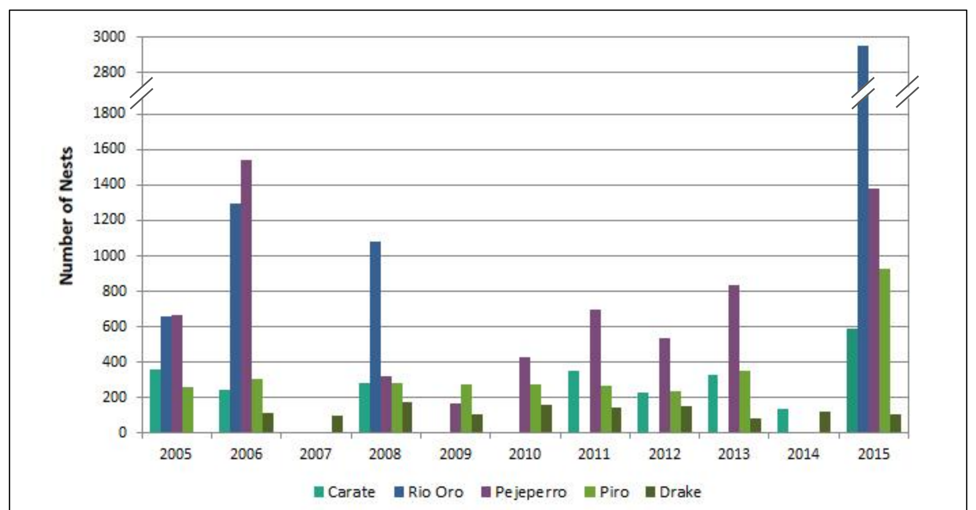

Figure 4. Comparison of number of Olive Ridley nests registered on the five major nesting beaches in the Osa Peninsula each season, from 2005 to 2015. Río Oro beach was not routinely monitored from 2009 through 2014. All other gaps correspond to data that are currently irretrievable.

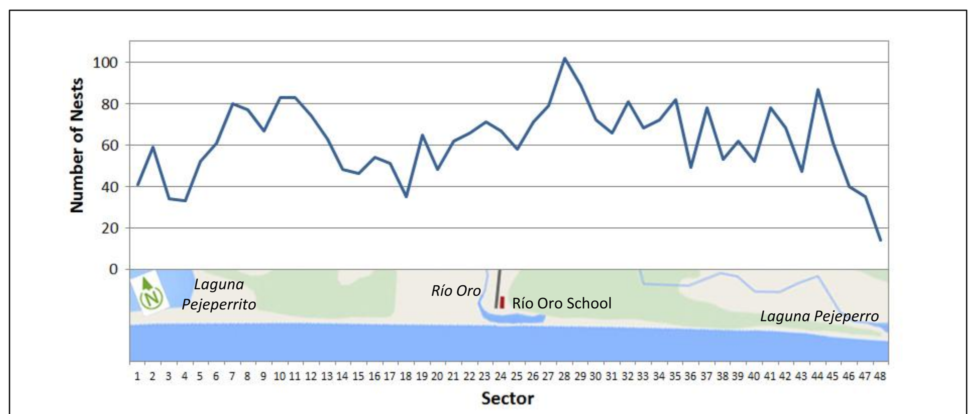

Figure 5. Spatial distribution showing number of Olive Ridley nests registered on Río Oro beach from 01 August through 31 December 2015, showing locations of the Río Oro river, Laguna Pejeperrito and Laguna Pejeperro, all of which remained isolated from the sea during this period.

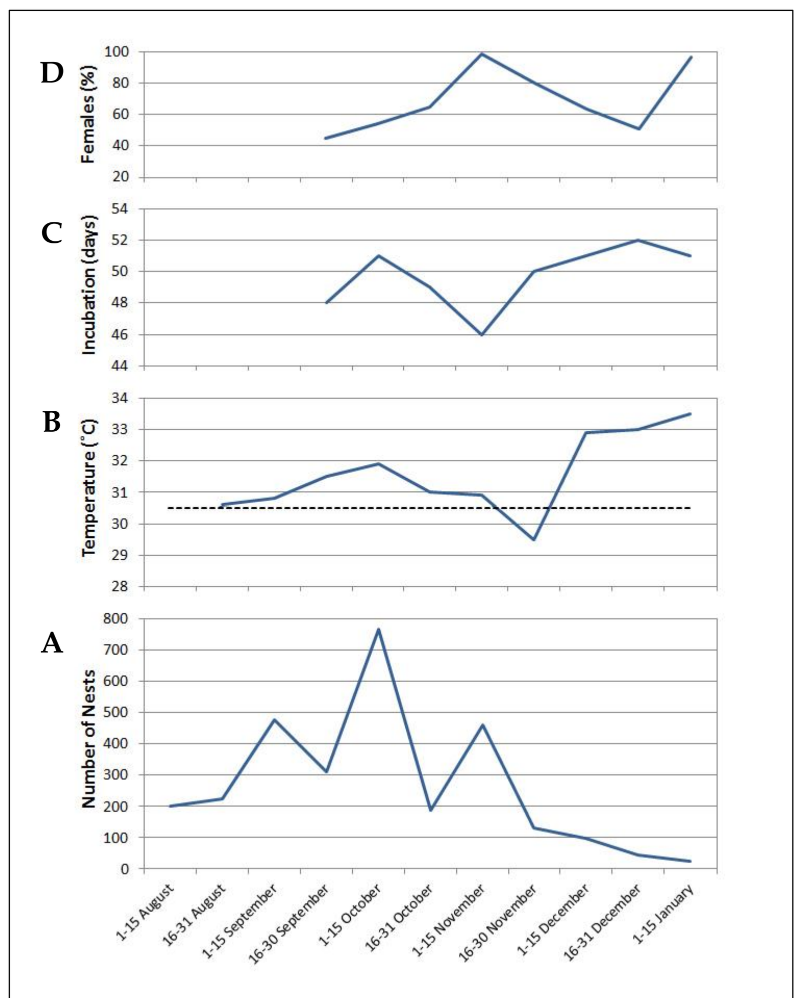

Figure 6. Temporal distributions showing **A**. number of Olive Ridley nests registered on Río Oro beach, and **B**. mean CTEs (°C) showing pivotal temperature (dotted)[10], and **C**. mean incubation period (days) and **D**. mean estimated sex ratio (%♀) for a sample of 144 nests (plotted according to hatch date), during 15/16-day periods from 01 August 2015 through 15 January 2016.

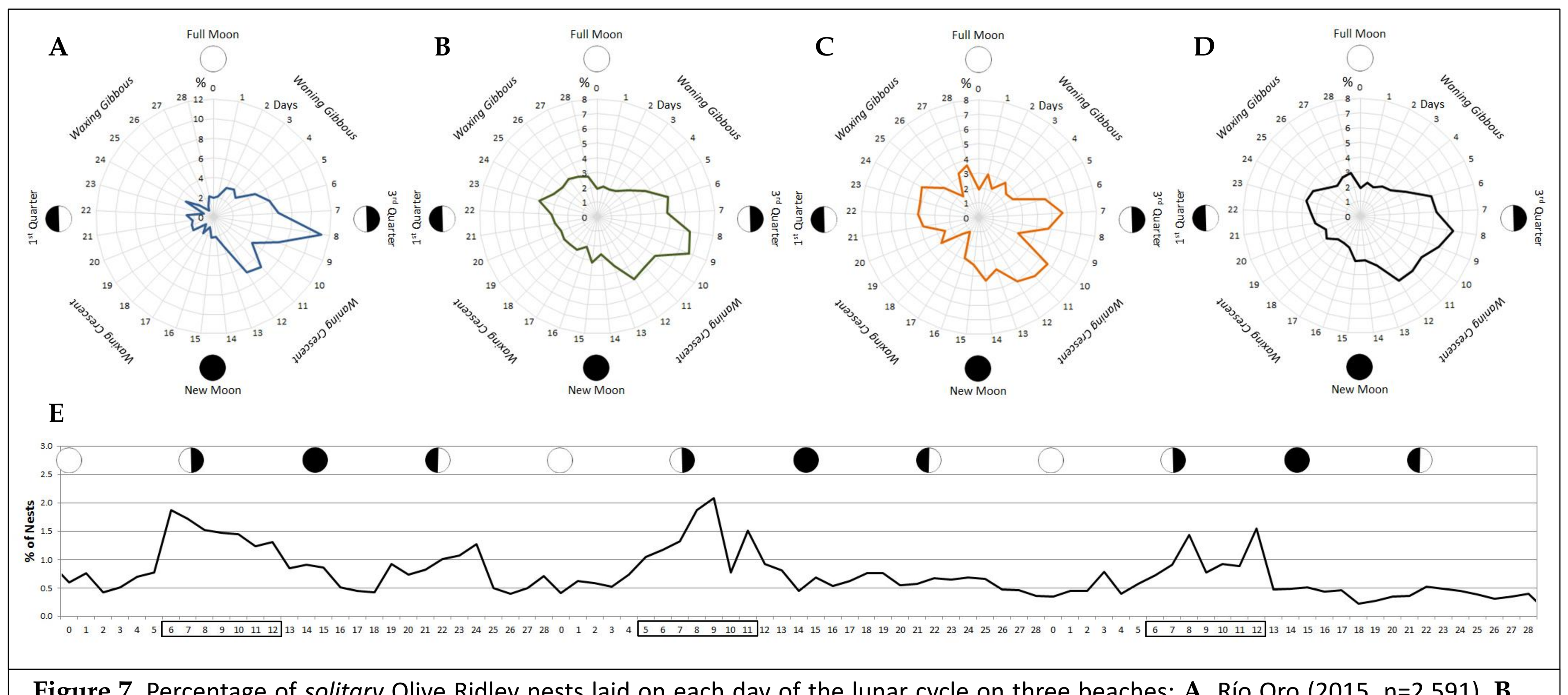

Figure 7. Percentage of *solitary* Olive Ridley nests laid on each day of the lunar cycle on three beaches: **A**. Río Oro (2015, n=2,591), **B**. Corozalito, Nicoya Peninsula (mean: 2009-2015, n=10,223), **C**. San Miguel, Nicoya Peninsula (mean: 2010-2012, n=1,004), and **D**. mean of all datasets. **E**. Mean dataset plotted linearly over three lunar cycles (3rd, 4th and 5th of nesting season) showing three conserved peaks. Data from Corozalito and San Miguel beaches used with kind permission from PRETOMA (Arauz Vargas R).

Citations

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Discussion

From 01 August through 31 December 2015, a total of 4,187 crawls by Olive Ridley sea turtles were registered on Río Oro beach, of which 2,951 were nesting events and 1,236 were false crawls (**Figure 2**). A comparison of data from the five major nesting beaches in the Osa Peninsula (**Figure 3**) shows that 49.5% of the total nests registered during this period were laid on Río Oro beach, giving rise to a nesting density (61.5/100m) several times higher than on any other beach. Historical data suggest that Río Oro beach has always been a site of major Olive Ridley nesting in the region[1], but analysis of more recent data suggest that its relative superiority may have increased dramatically since 2006 (**Figure 4**).

The mean hatching (81.0%) and emergence (76.1%) rates reported here for Río Oro beach are typical for this species and comparable to that of neighboring beaches (**Figure 3**). The poaching (1.5%) and predation (0.1%) rates appear to be exceptionally low; however, assuming that the 144 marked nests that were not recovered were also poached, the former rate may be closer to 6.4%. The poaching rate prior to 2015 is not known; however, data from neighboring beaches (**Figure 3**) and personal communications from local residents would suggest that it may have been over 30.0% of nests.

The spatial distribution of nests on Río Oro beach during this period (**Figure 5**) reveals more or less uniform density across the 48 sectors, although nesting was slightly more intense in the southern half (sectors 25-48, density = 64.5/100m) compared to the northern (sectors 1-24, density = 58.5/100m). The highest nesting density was registered in sectors 28 and 29, immediately to the South of the zone where the Río Oro river typically forms a mouth.

The temporal distribution of nests (**Figure 6A**) reveals that nesting peaked during the period 1-15 October 2015 on Río Oro beach, with 276 nests registered between 5-6 October alone. The mean CTE for each 15/16-day period (**Figure 6B**) remained above the published pivotal temperature (30.5°C) for this species[10], except during the period 16-30 November which experienced the greatest rainfall of the season. These high temperatures gave rise to relatively short nest incubation periods (**Figure 6C**) and a putative female bias in the majority (77.8%) of the 144 nests profiled (**Figure 6D**). An estimated 72.5% of the hatchlings liberated from this sample of nests were likely to have been female (**Figure 2**). The strong El Niño effect during 2015 resulted in an extraordinarily hot and dry rainy season on the Pacific coast, and previous reports suggest that this female bias is probably season-specific[4].

The temporal distribution of nests on Río Oro beach (**Figure 6A**) is characterized by three notable peaks in nesting frequency, which were found to clearly coincide with the 3rd quarter lunar phase. Increased nesting frequency during this phase was reported previously on Drake beach[12], however, the sample size was small (n=958). The data presented here (**Figure 7**) correspond to a larger sample of nests (n=13,818) and suggest that this trend is not only conserved in the Osa Peninsula (**Figure 7A**. Río Oro), but also on beaches in the Nicoya Peninsula (**Figure 7B**. Corozalito, and **Figure 7C**. San Miguel) located over 250km to the North.

Conclusions

The data presented here demonstrate that the RONWR is the most important site for Olive Ridley nesting in the South Pacific of Costa Rica, and represents a high-priority site for the conservation of this species. The high reproduction rates reported here, compared to those reported for arribada beaches[7][8], highlight the importance of the contribution of high-intensity *solitary* nesting beaches, such as Río Oro, to the overall Olive Ridley sea turtle stock. The marked reduction in poaching activity at Río Oro beach during 2015 is a major achievement for the program and indicates that the conservation methodology used was effective.

The Olive and Kemp's Ridley – uniquely among sea turtle species – are apparently able to delay nesting until conditions are favorable, and their predisposition toward synchronized nesting behavior is dramatically demonstrated during Olive Ridley arribada events. Arribadas in the eastern Pacific generally coincide with the 3rd quarter lunar phase, and there is substantial evidence to suggest that environmental – rather than social – cues may be responsible for inducing these simultaneous nesting events[11]. Evidence for reproductive synchrony in *solitary* Olive Ridley populations, however, is largely absent from the literature. The data presented here support the hypothesis that the same environmental cues are responsible for inducing synchronized nesting behavior in both *arribada* and *solitary* Olive Ridley populations, and that this periodicity is robustly coupled to the lunar cycle. The precise nature of these cues, the selective pressures at work and the evolutionary advantage of such synchrony remain elusive.