

ESTIMATING THE SEX RATIO OF ADULT OLIVE RIDLEY TURTLES IN THE MEXICAN PACIFIC: A BIOMETRIC STUDY

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Abstract.—Information on male sea turtles is important, yet scarce, due to the difficulty in accessing them. For sea turtles, tail length is an important secondary sexual characteristic in adults and can be helpful for demographic research. Here, we measured curved carapace length (CCL), curved carapace width (CCW), plastron to tip total tail length (TTL), and cloaca to tip tail length (CTTL) of presumed male and female Olive Ridley Sea Turtles (*Lepidochelys olivacea*) to determine maturity stages. We studied 106 nesting females on a solitary nesting beach and 94 turtles captured offshore. Based on CCL (58.5–78 cm) and TTL (6.5–20 cm) data from nesting females, we inferred the maturity stage and the individual sex of the turtles captured offshore. Of all individuals captured offshore, 31.9% were presumed males (minimum CCL of 58.5 cm and average TTL of 27.8 cm), 36.2% presumed females, and 31.9% immature. This corresponds to a 1.1F:1.0M adult sex ratio. This finding is consistent with the previously reported sex ratio of Olive Ridley adults from the Costa Rican offshore population; however, it contrasts with earlier studies on hatchlings from Mexico reporting a strong female bias (1.4F:1.0M) likely induced by increasing incubation temperatures due to climate change. Our results highlight the ecological importance of investigating Olive Ridley adult sex ratio and its relationship with hatchling sex ratio, as it may affect the fitness of Olive Ridley turtles and their resilience to climate change.

Key Words.—breeding males; curved carapace length; *Lepidochelys olivacea*; sea turtles; secondary sexual characteristics; sexual maturity; temperature-dependent sex determination; total tail length

INTRODUCTION

Olive Ridley Turtles (*Lepidochelys olivacea*) are the most abundant sea turtle species in the world and are highly migratory, moving between the neritic and pelagic zone in tropical regions (except the Gulf of Mexico; Morreale et al. 2007). The genus *Lepidochelys* manifests a unique behavior known as *arribada* nesting. Thousands of turtles congregate over a few days to oviposit their eggs. Additionally, they may nest solitarily or employ a mixed strategy (Bernardo and Plotkin 2007). Three decades of records from *arribada* nesting sites showed that the population of Olive Ridley Turtles in the Mexican

Pacific is the largest in the world and has a stable trend (Shanker et al. 2021).

Olive Ridley Turtles reach sexual maturity when they are about 13 y old (range of values, 10–18 y; Zug et al. 2006), and according to Márquez (Márquez, M.R. 1990. FAO species catalog. Volume 11. Sea turtles of the world. An annotated and illustrated catalog of sea turtle species known to date. FAO Fisheries Synopsis, no. 125, Rome, Italy. Available from <https://www.fao.org/3/t0244e/t0244e00.htm> [Accessed 7 July 2023], adult females from the Mexican Pacific present an average curved carapace length (CCL) of 64 cm. Although some studies have found that males and females have a similar

average of CCL (Frazier 1984; Figgenger et al. 2022), some Olive Ridley populations present sexual size dimorphism, with males being larger than females (Girard et al. 2021). For example, during the second half of the 20th Century, commercial catch data in the Mexican Pacific reported sizes between 51 and 75 cm, with males being approximately 3 cm longer than females (Márquez, *op. cit.*).

In sea turtles, sexual dimorphism only becomes evident once they reach sexual maturity. Mature males differ from females by their longer tail with a terminal nail (Wibbels 1999; Fig. 1), enclosed penis, and enlarged claws on the front flippers (Owens 1997), together with a decornified region in the middle of the plastron (Owens 1997; Rostal 2007). The tail of females is shorter and extends only slightly beyond the marginal shields (Wibbels 1999; Fig. 1). For immature turtles, several methods exist to ascertain the sex of hatchlings, juveniles, and subadults (Mrosovsky and Provanca 1992; Gross et al. 1995; Owens 1997; Wibbels 2007; Wyneken et al. 2007). Detecting the serum antimullerian hormone in neonates requires blood samples to be analyzed, using the still expensive Western blot technique as a sex-specific marker in Loggerhead Turtle neonates, and has not yet been successfully tested for other sea turtle species (Tezak et al. 2020). Alternatively, sex ratios for clutches are often estimated indirectly from nest temperatures or nest incubation duration (e.g., Godley et al. 2001; Sandoval-Espinoza 2012), which can be inaccurate. Therefore, determining the sex of immature turtles is difficult and leads to a lack of data on sea turtle sex ratios.

Like the other species of sea turtles, Olive Ridleys have temperature-dependent sex determination (TSD). The pivotal temperature, i.e., the temperature range for which hatchling sex ratio is 1:1, ranges between 29°–31° C for Olive Ridleys worldwide (Wibbels, 2007) and the thermo-sensitive period, defined as the time during development when sex is determined, occurs in the second third of the incubation period (Merchant-Larios et al. 1997). In this process, lower temperatures (< 29° C) of the embryo's environment leads to a higher proportion of males, while higher temperatures (> 31° C) lead to a higher proportion of females (Merchant-Larios and Díaz-Hernández 2013). The increase in environmental temperatures due to climate change can feminize sea turtle populations, affecting their sex ratio (Wibbels 2003; Wibbels 2007), and ultimately lead to reduced genetic diversity if the number of mating male individuals is too low (Jensen et al. 2018).

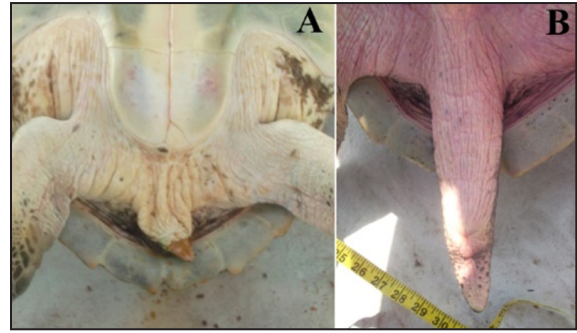


FIGURE 1. Tales of presumed female and male adult Olive Ridley Turtles (*Lepidochelys olivacea*) from the Central Mexican Pacific. (A) The tail of a female (11 cm total tail length) turtle and (B) a male (27 cm total tail length) turtle that we captured. Both specimens had curved carapace length > 58.5 cm. We determined turtles to be males if total tail length was > 20 cm. (Photographed by Rodolfo Martín-del-Campo).

The sex ratio of Olive Ridley hatchlings hatched at the *arribada* beach Escobilla (Mexico, Oaxaca) is biased by 55% towards females (Hernández-Echeagaray et al. 2012), while for solitary nesting beaches is biased by more than 67% (Sandoval-Espinoza 2012). Sex ratio data for immature and adult Olive Ridley Turtles are scarce (Wibbels 2007; Peavey et al. 2017). A bycatch study in the Costa Rican longline fishery estimated a 1:1 sex ratio for Olive Ridley Turtles ($n = 2,864$), of which 25.8% were adults, and of those adult turtles, 13.2% were females, which measured more than 65 cm CCL (Dapp et al. 2013). Conversely, the minimum CCL for nesting females sampled on a solitary nesting beach in Costa Rica was 58.5 cm (James and Melero 2015). In contrast, a study in the Eastern Pacific (from the Gulf of California to Peru) reported a strong bias towards males (1.0 F:1.5 M; Peavey et al. 2017), in which individuals with straight carapace length ≥ 56 cm (59 cm of CCL using the conversion of Peavey et al. 2017) and long tails (> 20 cm in length) were considered adult males. Our study captured Olive Ridley Turtles in the Central Mexican Pacific offshore and at a nesting site to estimate sex ratio for individuals that were presumed to be adults because of their morphometrics (body size and tail length). More specifically, our goal was to provide biometric information about Olive Ridley secondary sexual characteristics, i.e., total tail length and curved carapace length, and to estimate the sex ratio for presumably adult Olive Ridley Turtles in a foraging area of the Central Mexican Pacific.

MATERIALS AND METHODS

Sample of females at the nesting beach.—Playa Ceuta, Sinaloa, Mexico, is a beach with legally defined protection activities and is a sanctuary for Olive Ridley nesting (Diario Oficial de la Federación 2002). This 37-km-long beach is located between the Cospita River (23°05'40"N, 107°11'42"W) and the Elota River (23°52'43"N, 106°55'51"W) in the central region of the state of Sinaloa (Fig. 2). We obtained biometric data from 106 nesting females at Playa Ceuta, Sinaloa, during the 2016–2018 seasons (Fig. 2), including curved carapace length (CCL), curved carapace width (CCW), plastron to tip total tail length (TTL), and cloaca-to-tip tail length (CTTL) according to Bolten (1999) and Wyneken (2001). We compiled the data following the current plan for the Management and Conservation of sea turtles of the Universidad Autónoma de Sinaloa (PROTORMAR-UAS) and the National Commission of Natural Protected Areas (CONANP).

Offshore turtle sampling.—We captured 94 immature and mature Olive Ridley Turtles between November 2011 and July 2012 during three research surveys on feeding grounds in the coastal and oceanic region of the Central Mexican Pacific (Fig. 2), an area of 70,134.4 km², delimited by Maruata, Michoacan (16°50'38"N, 104°13'21"W) and Cabo Corrientes, Jalisco (19°17'16"N, 107°18'34"W). We employed the turtle rodeo technique (Limpus 1985; Ehrhart and Ogren 1999) from a small boat with an outboard motor to capture individuals floating on the surface during sunbasking. Similar to nesting females, we recorded CCL, CCW, TTL, and CTTL.

Maturity stage and sex of individuals sampled offshore.—We calculated descriptive statistics for CCL, CCW, TTL, and CTTL to determine the maturity stage and sex of individual turtles sampled offshore. We used the minimum CCL of the sampled nesting females to establish our own baseline for maturity. We classified individuals captured offshore as mature (referred to as presumed adults hereafter) if their CCL was equal to or exceeded the minimum CCL (> 58.5 cm) of the nesting individuals sampled on the beach; otherwise, they were classified as immature. We classified offshore presumed adult individuals as males (referred to as presumed adult males hereafter) when their TTL exceeded the maximum TTL (> 20 cm) measured in the females sampled on the beach; Peavey et al. (2017) used the same tail length

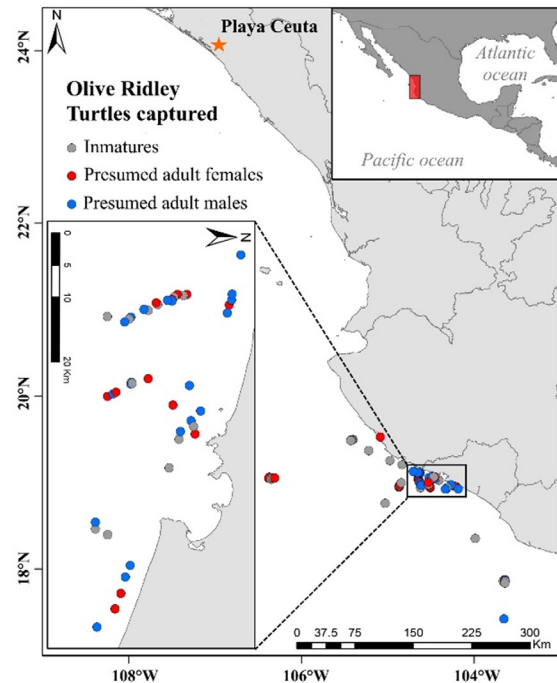


FIGURE 2. Study areas in the Mexican Pacific Ocean. Circles indicate the offshore sampling locations. The star indicates the sampling location for nesting female Olive Ridley Turtles (*Lepidochelys olivacea*). The closer view shows the catches where there was a higher density of turtles.

threshold for mature male status. We considered individuals with CCL \leq 58.5 cm as immature, thus we did not determine their sex as their tail does not present any sexual dimorphism; therefore, this group was excluded from any further statistical analysis.

Comparison of biometric data.—We performed all statistical tests using the statistical program R 4.0.2. (R Development Core Team 2020). We analyzed the biometric data collected to assess the statistical significance of differences between sexes and between life stages. With this aim, we compared, separately, CCL, CCW, TTL, and CTTL between presumed adult females and presumed adult males captured offshore and between presumed adult females captured offshore and nesting females.

Groups had unequal sample sizes and were not normally distributed. Thus, we used the wilcox.test function to evaluate whether CCL, CCW, TTL, and CTTL were significantly different between groups. We selected these comparison groups as the most biologically meaningful for this study, and the other possible group combinations were not considered. In the results, we present the test statistic W (i.e., the sum of the ranks of one of the two groups) and the

TABLE 1. Mean (\pm standard deviation, SD), minimum and maximum values (below mean) for curved carapace length (CCL), curved carapace width (CCW), total tail length (TTL), and cloaca-to-tip length (CTTL) measurements (cm) of Olive Ridley (*Lepidochelys olivacea*) nesting females at Playa Ceuta, Mexico, during the 2016–2018 nesting seasons, and immature, presumed adult female, and presumed adult males captured offshore at the Central Mexican Pacific during 2011 and 2012.

Group	CCL	CCW	TTL	CTTL
Nesting females (n = 106)	65.2 (\pm 2.9) 58.5–78.0	70.2 (\pm 2.9) 65.0–83.0	13.3 (\pm 2.7) 6.5–20.0	4.3 (\pm 1.1) 1.0–7.0
Immature (n = 30)	53.8 (\pm 7.9) 25.0–58.5	57.5 (\pm 10.3) 23.0–66.5	11.1 (\pm 3.9) 3.0–20.0	3.4 (\pm 1.2) 1.5–6.0
Presumed adult females (n = 34)	63.0 (\pm 3.1) 59.0–69.0	65.4 (\pm 5.7) 53.5–76.0	11.9 (\pm 3.7) 5.5–19.0	3.6 (\pm 0.8) 1.8–5.5
Presumed adult males (n = 30)	64.7 (\pm 2.6) 59.5–70.0	68.7 (\pm 3.2) 62.5–76.0	27.8 (\pm 2.9) 23.0–33.0	6.3 (\pm 1.1) 5.0–9.5

P-value (i.e., the probability under the assumption of no difference, of obtaining a result equal to or more extreme than what was actually observed). We compared TTL/CTTL ratios between sexes of individuals captured offshore, specifically between presumed adult females and males. Because ratios were normally distributed in all groups, but sample sizes were unequal, using the *t*-test function, we ran a Welch two-sample *t*-test to compare TTL/CTTL ratios.

Correlation of biometric data.—We performed a correlation test to assess a statistical correlation between CCL and CCW and between TTL and CTTL within each group. When the data were normally distributed, we used the *cor.test* function with the option method = Pearson to perform a Pearson's Product-moment Correlation Test. When data appeared abnormally distributed, we used the *cor.test* function with the option method = Kendall to perform Kendall's Rank Correlation Test. We presented results as $\tau(n)$, where τ represents the correlation coefficient tau and *n* the number of samples.

Sex ratio of sea turtles sampled offshore.—After determining the number of presumed adult males and females sampled offshore, we ran a binomial test to assess whether the deviance from an equal sex ratio (i.e., a sex ratio of 50%) was significant (Wilson and Hardy 2002; Costa and Salvidio 2020). We used the *binom.test* function, setting the theoretical probability of catching a female as 0.50, corresponding to a sex ratio of 1.0 (Fisher 1958). We also calculated the power of the binomial test using the formula power = 1- β , where β is the type II error (i.e., failing to reject the null hypothesis when it is actually false).

RESULTS

We measured 106 nesting Olive Ridley females at Playa Ceuta (Table 1). We captured 94 presumed adults and immature Olive Ridley Turtles offshore. Using the minimum CCL of nesting females at Playa Ceuta (58.5 cm) we estimated that, of all individuals measured offshore, 31.9% were immature individuals and 68.1% were presumed adults. Based on TTL of Playa Ceuta nesting females (maximum tail length 20.0 cm), of the 64 presumed adults sampled offshore, we identified 30 as presumed adult males (TTL > 20.0 cm), and 34 were presumed adult females (TTL < 20.0 cm; Peavey et al. 2022).

The CCL, CCW and CTTL significantly differed between nesting females sampled on the beach and presumed adult females sampled offshore ($W = 1093.0, P < 0.001$; $W = 835.0, P < 0.001$; $W = 1006.5, P < 0.001$, respectively). The CCL, CCW and CTTL also significantly differed between presumed adult males and females sampled offshore ($W = 349.5, P = 0.031$; $W = 338.5, P = 0.021$; $W = 13.0, P < 0.001$, respectively). Total tail length significantly differed between presumed adult males and nesting and presumed adult females ($W = 0, P < 0.001$).

CCL and CCW were significantly correlated for nesting females ($r = 0.69, t = 9.70, df = 104, P < 0.010$), presumed adult males ($\tau = 0.42, P < 0.010$) and presumed adult females ($\tau = 0.49, P < 0.010$) sampled offshore, and immature individuals ($\tau = 0.58, P < 0.010$; Fig. 3). TTL and CTTL also were significantly correlated for nesting females ($r = 0.35, t = 3.85, df = 103, P < 0.010$), presumed adult males ($\tau = 0.48, P < 0.01$) and presumed adult females ($r = 0.54, t = 3.67, df = 32, P < 0.010$) sampled offshore, and immature individuals sampled offshore ($r = 0.71, t = 5.07, df = 26, P < 0.010$; Fig. 4). The mean TTL/CTTL ratio was 3.32 (\pm 1.44), 3.32 (\pm 0.87), 4.51 (\pm

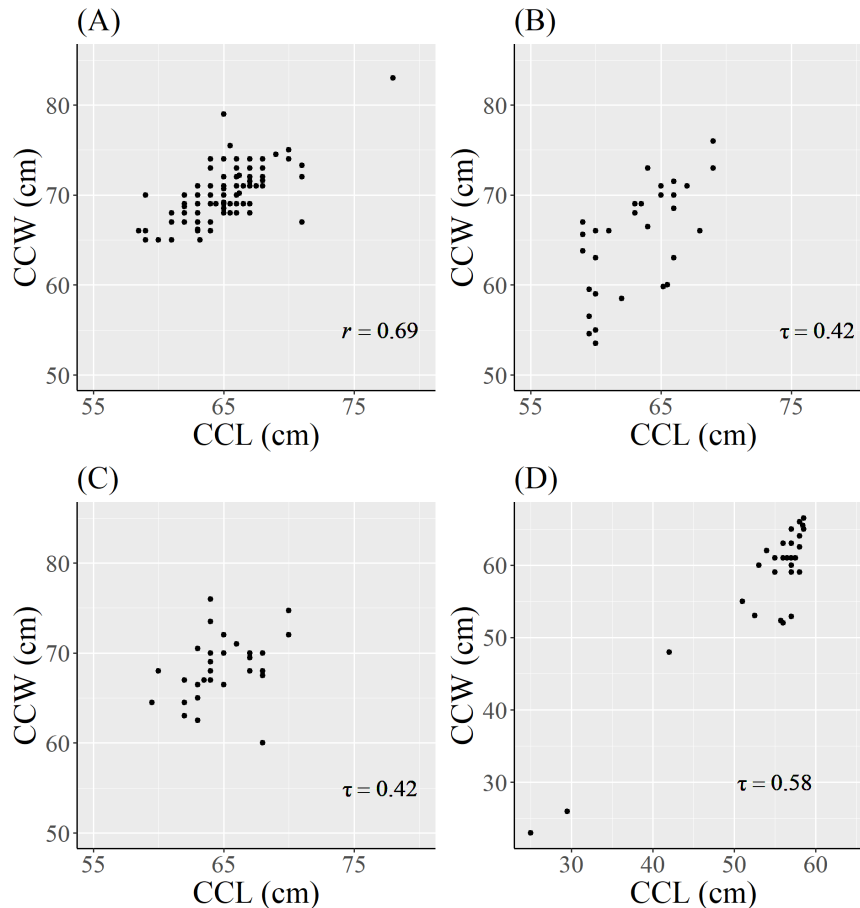


FIGURE 3. Correlation of curved carapace length (CCL) and curved carapace width (CCW) (cm) of Olive Ridley Turtles (*Lepidochelys olivacea*): (A) nesting females (measured at nesting site), (B) presumed adult females captured offshore, (C) presumed adult males captured offshore, and (D) immature individuals sampled offshore. The r and τ are the correlation coefficients of the Pearson's Product-moment Correlation Test and Kendall's Rank Correlation Test, respectively.

0.54) and $3.33 (\pm 1.06)$ for nesting females, presumed adult females and males, and immature, respectively. TTL/CTTL ratio differed significantly only between presumed adult males and presumed adult females sampled offshore ($t = -6.60$, $P < 0.010$). The experimental probability of catching an adult female was 0.53 (95% Confidence Interval = 0.40–0.66) and that the deviance of the experimental probability from the theoretical probability of 0.50 was not significant ($P = 0.710$). The power of the binomial test was 0.39.

DISCUSSION

Our study gathered size and biometric data to estimate maturity state and sex ratio data for presumed adult Olive Ridley Turtles in feeding grounds of the Central Mexican Pacific, directly addressing the lack of knowledge about the species in this area. The oceanic Central Mexican Pacific is a potential

foraging area for Olive Ridley Turtles, which are epipelagic feeders (Morreale et al. 2007; Zepeda-Borja et al. 2017; Carpena-Catoira et al. 2022). Because they spend most of their life offshore, it is difficult to gather data on non-nesting individuals.

The measured minimum CCL of 58.5 cm for nesting females sampled on Playa Ceuta corresponds to the minimum CCL (58.5 cm) of Olive Ridley Turtles sampled on a solitary nesting beach in Costa Rica by James and Melero (2015). The results from our study, however, are valid for the Olive Ridley population of the Mexican Pacific, and we encourage the replication of this analysis on other populations because CCL size can vary among nesting beaches, especially for such a widely distributed species (Wibbels 1999). For example, in Rushikulya (one of the main *arribada* beaches in India), nesting female mean CCL was 67.1 cm (range of values, 60.8–73.6 cm; Tripathy 2008). For comparison, if we use

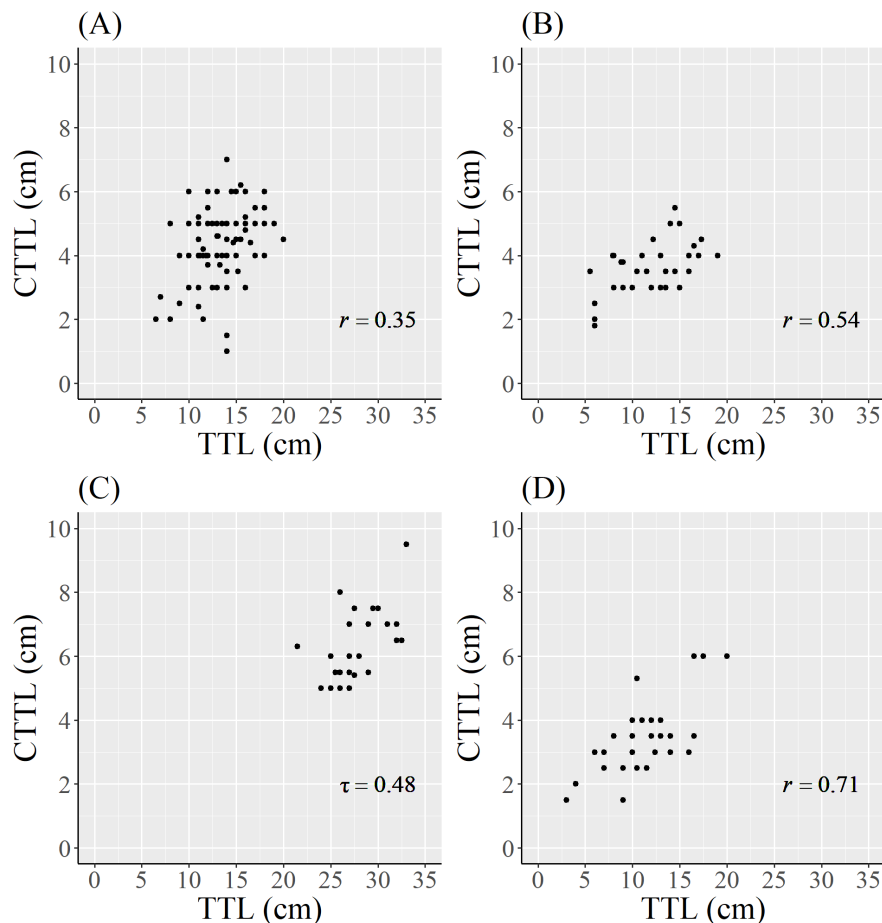


FIGURE 4. Correlation of total tail length (TTL) and cloaca-to-tip length (CTTL) of Olive Ridley Turtles (*Lepidochelys olivacea*): (A) nesting females (measured at nesting site), (B) presumed adult females captured offshore, (C) presumed adult males captured offshore, and (D) immature individuals measured offshore. The r and τ are the correlation coefficients of the Pearson's Product-moment Correlation Test and Kendall's Rank Correlation Test, respectively.

the minimum CCL of 60.8 cm CCL suggested by Tripathy (2008), the proportion of adults in our study would be reduced by 15.5%.

Curved carapace length and CCW of presumed adult males (64.7 ± 2.6 cm and 68.7 ± 3.2 , respectively) were significantly larger than those of presumed adult females sampled offshore (63.0 ± 3.1 cm and 65.4 ± 5.7 , respectively), which is in line with results for an Olive Ridley population in the Congo showing a strong sexual size dimorphism, with males being larger than females (mean CCL = 73.85 ± 2.00 cm and mean CCL = 69.64 ± 2.05 cm, respectively; Girard et al., 2021). These results suggest that sexual size dimorphism could be a global pattern for Olive Ridley Turtles, with mean CCL varying between populations. In other sea turtle species, however, sexual size dimorphism is less commonly observed (Frazier 1984; Figgner et al. 2022).

We also found that nesting females were larger (65.2 ± 2.9 cm and 70.2 ± 2.9 , CCL and CCW respectively) than presumed adult females offshore (63 ± 3.1 cm and 65.4 ± 5.7 , CCL and CCW respectively). This could be because older females (assumed to be larger) may lay more clutches per season than younger females who have only recently begun to nest, so it could increase the probability of finding longer females on nesting beaches. Furthermore, and as mentioned above, the size reported for adult females is known to vary among nesting beaches and studies; for example, according to Márquez (*op. cit.*) and Pritchard (2007), mean female CCL was 63.5 cm in Escobilla (Mexico), 68.8 cm in Nancite (Costa Rica), and 72 cm in Guyana (SCL converted to CCL as in Peavey et al. 2017). In our study, we identified nesting females from Playa Ceuta with CCL up to 78 cm. Longer CCL have been

found in Olive Ridley Turtles in the eastern Atlantic were female CCL ranged between 62–80 cm (mean CCL = 70.1 cm) and for males 64–86 cm (mean CCL = 70.6 cm; Fretey 2001). In our study, it is possible that sampling of offshore males could be limited and potentially size-biased, therefore it may be harder to capture the larger males because they could present more avoidance behavior.

Olive Ridleys have previously been described as having a steep-sided and flat-topped carapace, and its width 90% of its length (when SCL is measured; Pritchard 2007; Márquez, *op. cit.*). In our study, the Olive Ridley carapace is wider than long when measuring CCL and CCW, and this is consistent with previous studies from the Eastern Pacific (Hart et al. 2014; Dornfeld et al. 2015; James and Melero 2015; Martínez-Vargas et al. 2022). We found a positive correlation (CCL and CCW in all the groups we analyzed, something previously reported in Olive Ridleys (Pritchard 1969). Furthermore, we identified a positive correlation between TTL and CTTL among all the groups analyzed (Fig. 4), which shows that biometric measures increase as the turtle grows, regardless of maturity stage or sex. Finally, the TTL/CTTL ratio of mature males was significantly greater than the other groups. All the correlations mentioned above have been shown in sexually mature Loggerhead Turtles in the Mediterranean (Casale et al. 2005).

Our analysis infers the sex ratio of adult Olive Ridley Turtles in the feeding ground of the Central Mexican Pacific. The current results suggest a 1:1 ratio of presumed adult males and presumed adult females. These results concur with the ratio identified in Costa Rican waters (Dapp et al. 2013), but caution should be taken when interpreting these results, as the power of the binomial test was 0.39, representing a medium power (Cohen 1988). It is necessary to increase the sample size to increase the strength and identify small but significant effects (Cohen 1992). Additionally, the genetic origin of our offshore Olive Ridleys is unknown. Yet a subsample ($n = 85$) of these turtles showed that 50% of them corresponds to the haplotype Lo46 (Martín-del-Campo et al., 2023); and this haplotype is dominant for all the Eastern Pacific, including *arribada* and solitary nesting rookeries from Mexico and Costa Rica (Campista-León et al., 2019; Silver-Gorges et al., 2020; Vilaça et al., 2022). Therefore, we cannot yet fully define the genetic relationship between the turtles sampled offshore and on Playa Ceuta (Martín-del-Campo et al. 2023).

Most studies of solitary nesting Olive Ridley sex ratios use data from hatcheries (Wibbels 2007) where nests are relocated to protect them from predation and poaching. García et al. (2003) found that the bias towards females was similar in relocated and *in situ* Olive Ridley nests (1.35 F:1.00 M and 1.41 F:1.00 M, respectively). This biased female sex ratio also has been reported among other sea turtle species such as Green (*Chelonia mydas*), Kemp's Ridley and Loggerhead turtles (Casale et al. 2005; Wibbels 2007; Limpus et al. 2009; Booth et al. 2020). It is worth noting that the sex ratio bias towards females reported for hatchlings in the early 1990s (García et al. 2003) was confirmed in more recent years (Sandoval-Espinoza 2012); however, our study shows a stable sex ratio in presumed adult turtles. Regarding studies of sex ratio on immature Olive Ridleys based on hormone analysis, most of these studies reported a sex ratio bias towards females, and only a few reported a male-biased sex ratio (Shaver 1991; Wibbels 2007).

In the context of climate change and its effect on sea turtle populations, a 2018 study in the Great Barrier Reef (GBR) concluded that the bias towards females in northern GBR rookeries has been evident for the last 20 y, indicating that the total feminization of this population will soon occur (Jensen et al. 2018). Furthermore, Hays et al. (2003) proposed a general warming trend for Green Turtle nests between 0.36° C and 0.49° C over the last 100 y; however, Patrício et al. (2019) suggested that the Green Turtle can be resilient to climate change through the evolution of nest site selection or changes in nesting phenology. In addition, sex-specific mortality of immature and mature turtles can directly affect the sex ratio of breeding adults (Coyne and Landry 2007), and the biology of male sea turtles (e.g., multiple paternity) may help mitigate female-biased hatchling sex ratio (Hays et al. 2022).

A long-term study, as done on Green Turtles by Jensen et al. (2018), is necessary to know the effect of the rising global temperature on the sex ratios (primary, secondary, and breeding) of Olive Ridleys. This type of study, however, requires time and often use invasive methods, which presents both logistical and ethical complications (Jensen et al., 2018). In the absence of such studies for Olive Ridleys, our study provides an indicator of sex ratio derived from biometrics (TTL, CCL) that can be easily measured, and allows researchers to gather essential information on the biology of this elusive species.

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LITERATURE CITED

- Bernardo, J., and P. Plotkin. 2007. An evolutionary perspective on the Arribada phenomenon and reproductive behavioral polymorphism of Olive Ridley Sea Turtles (*Lepidochelys olivacea*). Pp. 59–87 *In* Biology and Conservation of Ridley Sea Turtles. Plotkin, P. (Ed.). Johns Hopkins University Press, Baltimore, Maryland, USA.
- Bolten, A.B. 1999. Techniques for measuring sea turtles. Pp. 110–114 *In* Research and Management Techniques for the Conservation of Sea Turtles. Publication N° 4. Eckert, K.L., K.A. Bjorndal, F.A. Abreu-Grobois, and M. Donnelly (Eds.). International Union for Conservation of Nature/Species Survival Commission Marine Turtle Specialist Group, Blanchard, Pennsylvania, USA.
- Booth, D.T., A. Dunstan, I. Bell, R. Reina, and J. Tedeschi. 2020. Low male production at the world’s largest Green Turtle rookery. *Marine Ecology Progress Series* 653:181–190.
- Campista-León, S., J.A. Beltrán-Espinoza, I. Sosa Cornejo, H. Castillo-Ureta, J.R. Martín-del-Campo, J.G. Sánchez-Zazueta and L.I. Peinado-Guevara. 2019. Haplotypic characterization of the Olive Ridley Turtle (*Lepidochelys olivacea*) in northwest Mexico: the northernmost limit of its distribution. *Animal Biodiversity and Conservation* 42: 113–126.
- Carpena-Catoira, C., C.D. Ortega-Ortiz, M.A. Liñán-Cabello, A. Olivos-Ortiz, and F.R. Elorriaga-Verplancken. 2022. Foraging ecology of the Olive Ridley Sea Turtle (*Lepidochelys olivacea*) from the Central Mexican Pacific based on stable isotopes. *Regional Studies in Marine Science* 52:102296. <https://doi.org/10.1016/j.rsma.2022.102296>.
- Casale, P., D. Freggi, R. Basso, and R. Argano. 2005. Size at male maturity, sexing methods, and adult sex ratio in Loggerhead Turtles (*Caretta caretta*) from Italian waters investigated through tail measurements. *Herpetological Journal* 15:145–148.
- Cohen, J. 1988. *Statistical Power Analysis for the Behavioral Sciences*. 2nd Edition. Lawrence Erlbaum Associates, Hillsdale, New Jersey, USA.
- Cohen, J. 1992. A power primer. *Psychological Bulletin* 112:155–159.
- Costa, A., and S. Salvidio. 2020. The need for adequate statistical analyses to estimate gender imbalance: a comment on Teixeira da Silva and Dobránszki (2019). *Archives of Sexual Behavior* 49:37–39.
- Coyne, M., and A.M. Landry, Jr. 2007. Population sex ratio and its impact on population models. Pp. 191–211 *In* Biology and Conservation of Ridley Sea Turtles. Plotkin, P. (Ed.). Johns Hopkins University Press, Baltimore, Maryland, USA.
- Dapp, D., R. Arauz, J.R. Spotila, and M.P. O’Connor. 2013. Impact of Costa Rican longline fishery on its bycatch of sharks, stingrays, bony fish, and Olive Ridley Turtles (*Lepidochelys olivacea*). *Journal of Experimental Marine Biology and Ecology* 448:228–239.
- Diario Oficial de la Federación (DOF). 2002. Acuerdo por el que se determinan como áreas naturales protegidas, con la categoría de santuarios, a las zonas de reserva y sitios de refugio para la protección, conservación, repoblación, desarrollo y control de las diversas especies de tortuga marina, ubicadas en los estados de Chiapas, Guerrero, Jalisco, Michoacán, Oaxaca, Sinaloa, Tamaulipas y Yucatán, identificadas en el decreto publicado el 29 de octubre de 1986. Gobierno Federal de México. https://www.dof.gob.mx/nota_detalle.php?codigo=723470&fecha=16/07/2002
- Dornfeld, T.C., N.J. Robinson, P.S. Tomillo, and F.V. Paladino. 2015. Ecology of solitary nesting Olive Ridley Sea Turtles at Playa Grande, Costa Rica. *Marine Biology* 162:123–139.
- Ehrhart, L.M., and L.H. Ogren. 1999. Studies in foraging habitats: capturing and handling turtles. Pp. 61–65 *In* Research and Management Techniques for the Conservation of Sea Turtles. Publication N° 4. Eckert, K.L., K.A. Bjorndal, F. A. Abreu-Grobois, and M. Donnelly (Eds.). International Union for Conservation of Nature/Species Survival Commission Marine Turtle Specialist Group, Blanchard, Pennsylvania, USA.

- Frazier, J.G. 1984. Analisis estadístico de la tortuga golfina *Lepidochelys olivacea* (Eschscholtz) de Oaxaca, Mexico. *Ciencia Pesquera* 4:49–75
- Figgenger, C., J. Bernardo, and P.T. Plotkin. 2022. Marine turtles are only minimally sexually size dimorphic, a pattern that is distinct from most nonmarine aquatic turtles. *Ecology and Evolution*, 12:1–10. <https://doi.org/10.1002/ece3.8963>.
- Fisher, R.A. 1958. *The Genetical Theory of Natural Selection*. 2nd Edition. Dover, New York, New York, USA.
- Fretey, J. 2001. Biogeography and conservation of marine turtles of the Atlantic coast of Africa. Convention on Migratory Species Technical Publication No. 6, United Nations Environment Programme/Convention on Migratory Species Secretariat, Bonn, Germany.
- García, A., G. Ceballos, and R. Adaya. 2003. Intensive beach management as an improved sea turtle conservation strategy in Mexico. *Biological Conservation* 111:253–261.
- Girard, A., N. Bréheret, G. Bal, J.G. Mavoungou, J.F. Tchibinda, F. Makaya, and M. Girondot. 2021. Unusual sexual dimorphism and small adult size for Olive Ridley Sea Turtles are linked to volumetric geometric constraints. *Marine Biology* 168:1–11. <https://doi.org/10.1007/s00227-020-03814-7>
- Godley, B.J., A.C. Broderick, J.R. Downie, F. Glen, J.D. Houghton, I. Kirkwood, S. Reece, and G.C. Hays. 2001. Thermal conditions in nests of Loggerhead Turtles: further evidence suggesting female skewed sex ratios of hatchling production in the Mediterranean. *Journal of Experimental Marine Biology and Ecology* 263:45–63.
- Gross, T.S., D.A. Crain, K.A. Bjorndal, A.B. Bolten, and R.R. Carthy. 1995. Identification of sex in hatchling Loggerhead Turtles (*Caretta caretta*) by analysis of steroid concentrations in chorioallantoic/amniotic fluid. *General and Comparative Endocrinology* 99:204–210.
- Hart, C.E., C. Ley-Quinonez, A. Maldonado-Gasca, A. Zavala-Norzagaray, and F.A. Abreu-Grobois. 2014. Nesting characteristics of Olive Ridley Turtles (*Lepidochelys olivacea*) on El Naranjo Beach, Nayarit, Mexico. *Herpetological Conservation and Biology* 9:524–534.
- Hays, G.C., A.C. Broderick, F. Glen, and B.J. Godley. 2003. Climate change and sea turtles: a 150-year reconstruction of incubation temperatures at a major marine turtle rookery. *Global Change Biology* 9:642–646.
- Hays, G.C., T. Shimada, and G. Schofield. 2022. A review of how the biology of male sea turtles may help mitigate female-biased hatchling sex ratio skews in a warming climate. *Marine Biology* 169:1–10. <https://doi.org/10.1007/s00227-022-04074-3>.
- Hernández-Echeagaray, O.E., R. Hernández-Cornejo, M. Harfush-Meléndez, and A. García-Gasca. 2012. Evaluation of sex ratios of the Olive Ridley Sea Turtle (*Lepidochelys olivacea*) on the arribada nesting beach, La Escobilla, Mexico. *Marine Turtle Newsletter* 133:12–16.
- James, R., and D. Melero. 2015. Anidación y conservación de la Tortuga Lora (*Lepidochelys olivacea*) en playa Drake, península de Osa, Costa Rica (2006 a 2012). *Revista de Biología Tropical* 63:117–129.
- Jensen, M.P., C.D. Allen, T. Eguchi, I.P. Bell, E.L. LaCasella, W.A. Hilton, C.A.M Hof, and P.H. Dutton. 2018. Environmental warming and feminization of one of the largest sea turtle populations in the world. *Current Biology* 28:154–159.
- Limpus, C.J. 1985. A study of the Loggerhead Sea Turtle, *Caretta caretta*, in eastern Australia. Ph.D. Dissertation, University of Queensland, Queensland, Australia. 212 p.
- Limpus, C.J., I. Bell, and J.D. Miller. 2009. Mixed stocks of Green Turtles foraging on Clack Reef, northern Great Barrier Reef identified from long-term tagging studies. *Marine Turtle Newsletter* 123:3–5.
- Martin-del-Campo, R., C.D. Ortega-Ortiz, A. Abreu-Grobois, L.M. Enríquez-Paredes, D. Petatán-Ramírez, A. García-Gasca, and S.I. Quijano-Scheggia. 2023. Genetic evidence for Indo-Western Pacific Olive Ridley Sea Turtles in Mexican waters. *Diversity* 15:1–14. <https://doi.org/10.3390/d15030430>.
- Martínez-Vargas, J.A., H. de la Cueva, M.A. Liñán-Cabello, and C.D. Ortega-Ortiz. 2022. Morphometry and allometry of free-living Olive Ridley Sea Turtles (*Lepidochelys olivacea*) from the Central Mexican Pacific. *Latin American Journal of Aquatic Research* 5:633–641.
- Merchant-Larios, H., and V. Díaz-Hernández. 2013. Environmental sex determination mechanisms in reptiles. *Sexual Development* 7:95–103.
- Merchant-Larios, H., S. Ruiz-Ramírez, N. Moreno-Mendoza, and A. Marmolejo-Valencia. 1997. Correlation among thermosensitive period, estradiol response, and gonad differentiation in

- the sea turtle *Lepidochelys olivacea*. *General and Comparative Endocrinology* 107:373–385.
- Morreale, S.J., P. Plotkin, D.J. Shaver, and H.J. Kalb. 2007. Adult migration and habitat utilization. Pp. 213–229 *In* *Biology and Conservation of Ridley Sea Turtles*. Plotkin, P. (Ed.). Johns Hopkins University Press, Baltimore, Maryland, USA.
- Mrosovsky, N., and J. Provancha. 1992. Sex ratio of hatchling Loggerhead Sea Turtles: data and estimates from a 5-year study. *Canadian Journal of Zoology* 70:530–538.
- Owens, D.W. 1997. Hormones in the life history of sea turtles. Pp. 315–341 *In* *The Biology of Sea Turtles*. Lutz, P.L., and J.A. Musick (Eds.). CRC Press Inc, Boca Raton, Florida, USA.
- Patrício, A.R., M.R. Varela, C. Barbosa, A.C. Broderick, P. Catry, L.A. Hawkes, A. Regalla, and B.J. Godley. 2019. Climate change resilience of a globally important sea turtle nesting population. *Global Change Biology* 25:522–535.
- Peavey, L.E., B.N. Popp, R.L. Pitman, S.D. Gaines, K.E. Arthur, S. Kelez, and J.A. Seminoff. 2017. Opportunism on the high seas: foraging ecology of olive ridley turtles in the eastern Pacific Ocean. *Frontiers in Marine Science* 4:1–14. <https://doi.org/10.3389/fmars.2017.00348>.
- Pritchard, P.C.H. 1969. Studies of the systematics and reproductive cycles of the genus *Lepidochelys*. Ph.D. Dissertation, University of Florida: Florida, USA. 227 p.
- Pritchard, P.C.H. 2007. Arribadas I have known. Pp. 7–21 *In* *Biology and Conservation of Ridley Sea Turtles*. Plotkin, P. (Ed.). Johns Hopkins University Press, Baltimore, Maryland, USA.
- R Development Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing: Vienna, Austria. <http://www.R-project.org/>
- Rostal, D.C. 2007. Reproductive physiology of the Ridley Sea Turtle. Pp. 151–165 *In* *Biology and Conservation of Ridley Sea Turtles*. Plotkin, P. (Ed.). Johns Hopkins University Press, Baltimore, Maryland, USA.
- Sandoval-Espinoza, S. 2012. Proporción sexual en crías de tortuga *Lepidochelys olivacea* en corrales de incubación del Pacífico Mexicano. Ph.D. Dissertation. Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas: La Paz, Baja California Sur, Mexico. 137 p.
- Shanker, K., A. Abreu-Grobois, V. Bezy, R. Briseño, L. Colman, A. Girard, M. Girondot, M. Jensen, M. Manohar Krishnan, J.M. Rguez-Baron, et al. 2021. Olive Ridelys: the quirky turtles that conquered the world. *State of the World's Sea Turtles* 16:24–31.
- Shaver, D.J. 1991. Feeding ecology of wild and head-started Kemp's Ridley Sea Turtles in south Texas waters. *Journal of Herpetology* 25:327–334.
- Silver-Gorges, I., J. Koval, C.J. Rodriguez-Zarate, F.V. Paladino and M. Jordan. 2020. Large-scale connectivity, cryptic population structure, and relatedness in Eastern Pacific Olive Ridley Sea Turtles (*Lepidochelys olivacea*). *Ecology and Evolution* 10:8688–8704. <https://doi.org/10.1002/ece3.6564>.
- Tezak, B., I. Sifuentes-Romero, S. Milton, and J. Wyneken. 2020. Identifying sex of neonate turtles with temperature-dependent sex determination via small blood samples. *Scientific Reports* 10:1–8. <https://doi.org/10.1038/s41598-020-61984-2>.
- Tripathy, B. 2008. An assessment of solitary and arribada nesting of Olive Ridley Sea Turtles (*Lepidochelys olivacea*) at the Rushikulya rookery of Orissa, India. *Asiatic Herpetological Research* 11:136–142.
- Vilaça, S.T., A.T. Hahn, E. Naro-Maciel, F.A. Abreu-Grobois, B.W. Bowen, J.C. Castilhos, C. Ciofi, N.N. FitzSimmons, M.P. Jensen, A. Formia, et al. 2022. Global phylogeography of Ridley Sea Turtles (*Lepidochelys* spp.): evolution, demography, connectivity, and conservation. *Conservation Genetics* 23:995–1010.
- Wibbels, T. 1999. Diagnosing the sex of sea turtles in foraging habitats. Pp. 139–143 *In* *Research and Management Techniques for the Conservation of Sea Turtles*. Publication N° 4. Eckert, K.L., K.A. Bjorndal, F.A. Abreu-Grobois, and M. Donnelly (Eds.). International Union for Conservation of Nature/Species Survival Commission Marine Turtle Specialist Group, Blanchard, Pennsylvania, USA.
- Wibbels, T. 2003. Critical approaches to sex determination in sea turtles. Pp. 103–134 *In* *The Biology of Sea Turtles*. Volume 2. Lutz, P.L., J.A. Musick, and J. Wyneken (Eds.). CRC Press Inc., Boca Raton, Florida, USA.
- Wibbels, T. 2007. Sex determination and sex ratios in Ridley Turtles. Pp. 167–189 *In* *Biology and Conservation of Ridley Sea Turtles*. Plotkin, P. (Ed.). Johns Hopkins University Press, Baltimore, Maryland, USA.
- Wilson, K., and I.C.W. Hardy. 2002. Statistical analysis of sex ratios: an introduction. Pp. 48–92 *In* *Sex Ratios: Concepts and Research Methods*. Hardy, I.C.W. (Ed.). Cambridge University Press,

Cambridge, UK.

Wyneken, J. 2001. The anatomy of sea turtles. NOAA Technical Memorandum, NMFS-SEFSC-470. U.S. Department of Commerce, Miami, Florida, USA.

Wyneken, J., S.P. Epperly, L.B. Crowder, J. Vaughan, and K. Blair Esper. 2007. Determining sex in post hatchling Loggerhead Sea Turtles using multiple gonadal and accessory duct characteristics. *Herpetologica* 63:19–30.

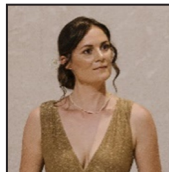
Zepeda-Borja, K.M., C.D. Ortega-Ortiz, E. Torres-Orozco, and A. Olivos-Ortiz. 2017. Spatial and

temporal distribution of sea turtles related to sea surface temperature and chlorophyll-a in Central Mexican Pacific waters. *Revista de Biología Marina y Oceanografía* 52:375–385.

Zug, G.R., M. Chaloupka, and G.H. Balazs. 2006. Age and growth in Olive Ridley Sea Turtles (*Lepidochelys olivacea*) from the North-central Pacific: a skeletochronological analysis. *Marine Ecology* 27:263–270.



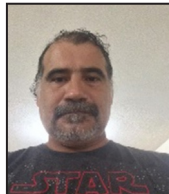
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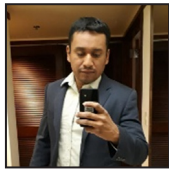
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