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Evaluation of nest management phases for *Lepidochelys olivacea* at two beaches in Northwest Mexico

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Abstract The olive ridley turtle, *Lepidochelys olivacea*, is a vulnerable and endangered species according to the IUCN and Mexican Official Standard NOM-059, respectively. On most solitary nesting beaches of olive ridley turtles, the eggs are removed from the in situ nest to hatcheries due to the high incidence of predation, human poaching, and beach erosion; therefore, it is necessary to collect and analyze information on the protection activities conducted for this species from egg laying to hatchling release. In general, protection activities during nest management can be divided into 5 phases: nest logging (F1), egg collection (F2), egg transfer (F3), egg incubation and hatching (F4), and hatchling release (F5). This work was carried out on two Pacific beaches in northwestern Mexico, Ceuta Beach Sanctuary (CBS) during 2013–2019 and Caimanero Beach (CB) during the 2013–2018 nesting seasons, with the objective of quantitatively evaluating the management phases of the protection program for olive ridley turtles by

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assessing the nest, egg, and hatchling losses in each of the phases using the model of Godínez-Domínguez et al. (1991). The results of the statistical analyses indicate that the greatest losses occurred during the incubation phase (F4) at both beaches, with a 41.99% loss at CBS and a 33.09% loss at CB, followed by the F2 (with 15.56 and 27.27% losses, respectively) and F1 (21.28 and 25.56% losses, respectively) phases. Significant differences between the beaches were observed in F4, F5 and F3, with greater losses at CBS than at CB, indicating that the success of the management phases may vary among beaches. The results obtained show that it is necessary to focus on strategies for improving the success of mainly phase F4 and phases F1 and F2 at both beaches.

Keywords *Lepidochelys olivacea* · Management phases · Conservation · Nesting · Ceuta Beach Sanctuary · Caimanero Beach

Introduction

The olive ridley turtle (*Lepidochelys olivacea*) is currently classified as a vulnerable and endangered species by the International Union for Conservation of Nature (IUCN) and Mexican Official Standard NOM-059, respectively, and its conservation is therefore of concern. One of the strategies for conserving sea turtles is the protection of nesting beaches where females arrive to lay their eggs during their nesting phase; this strategy involves protecting nesting females and nests in situ or relocating the nests to hatcheries and releasing hatchlings at sea (Bjorndal & Bolten, 2003; Ehrenfeld, 1995; Frazer, 1984, 1992; Spotila et al., 2000). Despite monitoring at nesting beaches, information on the success of protection activities is limited (Bovery & Wyneken, 2015; Richardson, 2000); accordingly, there is controversy regarding some management actions at nesting sites. For example, there is no consensus on whether the relocation of nests to hatcheries or their protection in situ is better; the former may be an unnecessary manipulation and may affect hatching success, alter sex ratios, and have other phenotypic effects (Bárcenas-Ibarra & Maldonado-Gasca, 2009; Bell et al., 2004; Romero-Olmedo, 2015; Ware et al., 2019). The relocation of eggs from in situ nests to hatcheries is a strategy used to conserve some turtle species (Rangel-Mendoza & Weber, 2015); it should be undertaken in cases where there is a high incidence of predation, human poaching, beach erosion, or any dangerous circumstance leading to mortality that can approach 100% (Balladares & Dubois, 2015; Méndez-Rodríguez & Álvarez-Castañeda, 2016; Mortimer, 1999). Loss due to coyotes could reach 81.4% on the southwestern coast of Baja California (Méndez-Rodríguez & Álvarez-Castañeda, 2016), indicating the importance of relocating the nests.

Ceuta Beach Sanctuary (CBS) and Caimanero Beach (CB) are solitary nesting beaches of olive ridley turtles from Sinaloa, México; eggs at both beaches are relocated to hatcheries, as this management technique can be beneficial for their conservation, even considering the negative impacts it may cause. Therefore, it is necessary to collect and analyze information on the protection activities conducted for this species from egg laying to hatchling release.

Protection programs must generate information that allows us to determine hatching success as a fundamental part of conservation actions (Mazaris et al., 2017; Schoreder & Murphy, 2000; SEMARNAT, 2018). Therefore, evaluations must be carried out by monitoring activities at the nesting sites where eggs are collected and relocated to hatcheries in order to determine critical phases in terms of nest, egg, and hatchling losses, which will allow us to propose solutions to the causes of these losses and achieve an adequate cost–benefit ratio (Azanza-Ricardo et al., 2015). Therefore, the present work quantitatively assessed nest, egg, and hatchling losses using the model of Godínez-Domínguez et al. (1991) in the different management phases of protection activities during olive ridley turtle nesting where eggs were relocated to hatcheries on two beaches in northwestern Mexico—one with sanctuary protection status (from 2013 to 2019) and the other without such protection status under a legal framework (from 2013 to 2018).

Materials and methods

Study area

CBS, Elota, Sinaloa, Mexico, is located between the mouth of the Cospita River to the north (107° 11’ 00" west longitude and 24° 05’ 53.09" north latitude) and the mouth of the Elota River to the south (106° 55' 52.7" west longitude and 23° 52' 44.72" north latitude) (CONANP, 2018). CB is located in El Rosario, Sinaloa, Mexico. This beach is bounded to the north by the mouth of the Presidio River (106° 17' 21.7" west longitude and 23° 05' 29.95" north latitude) and to the south by the Baluarte River (106° 02' 24.07" west longitude and 22° 50' 12.96" north latitude) (INAFED, 2018). The total length of each beach is approximately 37 km. CBS was declared a reserve zone and refuge for the protection, conservation, repopulation, development, and control of various species of sea turtles by presidential decree on October 29, 1986 (DOF, 1986), and it was recategorized as a sanctuary for various species of nesting sea turtles by a presidential agreement published on July 16, 2002 (DOF, 2002). This beach is considered an important habitat for the refuge and nesting of flagship species such as shorebirds and sea turtles. Protection activities are carried out for CB but without protection status under a legal framework (Fig. 1).

Field data

To evaluate the management process involved in the protection of *L. olivacea* nests at CBS and CB, five management phases were considered: nest logging (F1), which was evaluated by two daily nightly tours involving university staff and field volunteers along the 37 km of each beach during the annual season (July to December); for CBS, data were considered from 2013 to 2019, and for CB, from 2013 to 2018, based on the methodology proposed by Schoreder and Murphy (2000). The data collected included the numbers of nests registered (collected, poached, and predated). Egg collection (F2) involved the careful extraction of eggs from nests. Egg transfer (F3) consisted of transporting eggs either on foot or by vehicle

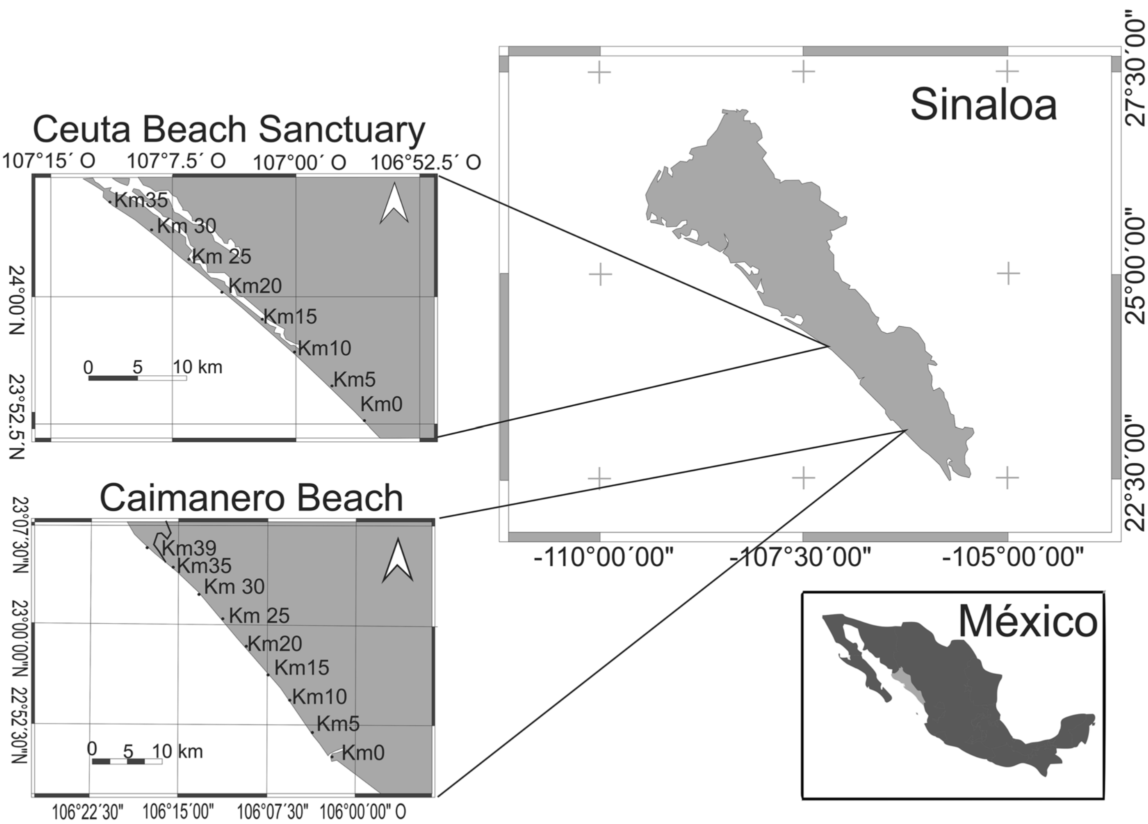

Fig. 1 Location of the nesting beaches of *Lepidochelys olivacea* in northwestern Mexico where the phases of nest management were evaluated

(quad bike) to biological stations located on each of the beaches for subsequent incubation in designated spaces provided for this management phase (hatcheries). In the egg incubation and hatching (F4) phase, the eggs were immediately incubated upon arrival, and the nests were sequentially numbered to facilitate monitoring (Márquez, 1976). After the period of incubation (45 ± 3 days), the number of hatched eggs was counted. The hatchling release (F5) phase consisted of releasing surviving hatchlings into the sea after being held in safeguard for a period of time until environmental conditions were suitable for their release.

Analysis of losses in the management phases

Assessments of nest, egg, and hatchling losses in each management phase were carried out using the model of Godínez-Domínguez et al. (1991), which was derived from a life table representing the main characteristics of the population under study (vulnerable stages and survival rates) by theoretical and quantitative approaches. This model is a basic tool used to develop control strategies (Herrera et al., 2017; Martella et al., 2012; Southwood & Henderson, 2000).

The model is as follows:

$$Lx = Fx - Nx$$

where *Lx* represents losses and is represented by the transition from one phase to the next phase; *Fx* is the number of nests, eggs, or hatchlings in each phase of protection; and *Nx* is the number of successful cases, that is, the number of nests, eggs, or hatchlings that continue to the next phase.

The losses of nests, eggs, and hatchlings corresponding to each phase were as follows: in F1, nests that were depredated, semipredated, poached, or eroded by the beach or tide; in F2, eggs that were broken during collection until before transfer; in F3, eggs that were broken during transfer until before incubation; in F4, incubated eggs that failed to hatch; and in F5, hatchlings that hatched but did not survive until their release to the sea.

The data obtained (losses of nests, eggs or hatchlings) in the different management phases (F1-F5) were expressed as percentages and normalized by arcsine transformation. This was performed by determining the angle at which the sine is the square root of the proportion (percentage/100) (Gabriel et al., 2017). Subsequently, 2-way analysis of variance (ANOVA) was applied with phases (considering all years) and years (considering all phases) as factors and the interaction between the two factors. The statistical analysis was performed with the programs SPSS 15.0 and SigmaPlot 11.

Kruskal–Wallis ANOVA (Zar, 1984) was applied to determine whether there were differences between years with respect to the numbers of nests registered, nests collected, eggs collected, nests poached, nests predated, and hatchlings released per beach, and the Mann–Whitney U test was performed in SigmaPlot 11 to compare the two beaches across the five management phases. All these comparisons met the significance criterion of $p < 0.05$.

Results

Nesting monitoring analysis of *L. olivacea* turtles

At CBS, from 2013 to 2019, a mean of 681 ± 174 nests per year was recorded, of which a mean of 576 ± 163 nests per year was collected (between 78 and 93% of registered nests), 60 ± 55 nests were predated (between 1 and 20% of registered nests), and 32 ± 27 nests (1 to 15% of registered nests) were poached. A mean of 51,507 ± 13,466 eggs were incubated, of which a mean of 31,801 ± 6,750 (between 56 and 68% of incubated eggs) gave rise to hatchlings released into the sea per year (Table 1). No significant differences were observed in the number of registered nests ($H = 1.58$, degrees of freedom (df) = 6, $p = 0.954$), collected nests ($H = 2.861$, df = 6, $p = 0.826$), predated nests ($H = 7.357$, df = 6, $p = 0.288$), poached nests ($H = 5.488$, df = 6, $p = 0.483$), eggs ($H = 2.769$, df = 6, $p = 0.873$), or released hatchlings ($H = 1.880$, df = 6, $p = 0.930$) over the years.

At CB, from 2013 to 2018, a mean of 2,278 ± 714 nests per year was recorded, of which a mean of 1,848 ± 690 nests per year were collected (between 70 and 94% of registered nests), 184 ± 105 nests were predated (between 3 and 19% of registered nests), and 247 ± 125 nests were poached (between 3 and 19% of registered nests). The mean number of incubated eggs was 198,117 ± 110,681, of which a mean of 137,892 ± 61,763 were hatchlings released into the sea per year (57 and 83% of incu-

Table 1 Monitoring of olive ridley sea turtle nesting at Ceuta Beach Sanctuary (2013–2019) and Caimanero Beach (2013–2018), Sinaloa, Mexico

	Ceuta Beach Sanctuary (Mean ± SD)	Caimanero Beach (Mean ± SD)
Registered nests	680.6 ± 174.4	2278.2 ± 713.9
Collected nests	576.3 ± 163.2	1847.6 ± 690.2
Predated nests	60.4 ± 54.6	183.8 ± 105.3
Poached nests	31.6 ± 27.3	246.6 ± 124.7
Hatching eggs	51,507.4 ± 13,466.4	198,116.5 ± 110,681.4
Hatchlings released	31,801 ± 6750.0	137,891.5 ± 61,762.8

SD standard deviation

bated eggs) (Table 1). There were no significant differences from year to year in the number of registered nests ($H = 2.044$, df = 5, $p = 0.843$), collected nests ($H = 2.464$, df = 5, $p = 0.782$), predated nests ($H = 8.583$, df = 5, $p = 0.127$), poached nests ($H = 7.846$, df = 5, $p = 0.165$), eggs ($H = 7.464$, df = 5, $p = 0.188$), or released hatchlings ($H = 8.258$, df = 5, $p = 0.143$).

Evaluation of losses in *L. olivacea* nest management phases and over the years at CBS and BC

The annual losses recorded at CBS (Fig. 2) were between 13.25 and 32.21% (0.345 and 0.600 arcsine) during F1, between 6.89 and 22.40% (0.251 and 0.462 arcsine) during F2, between 0.18 and 14.87% (0.027 and 0.319 arcsine) during F3, between 32.16 and 52.40% (0.596 and 0.819 arcsine) during F4, and between 1.09 and 21.66% (0.093 and 0.451 arcsine) during F5. According to the 2-way ANOVA results, there was no significant effect ($F = 1.121$, df = 24, $p = 0.325$) of the interaction between phase and year at CBS when considering the data provided by the model. The comparison between management phases revealed a statistically significant difference ($F = 39.408$, df = 4, $p = 0.001$), with F4 exhibiting the highest mean loss of 41.99% (0.702 ± 0.253 arcsine), followed by F1 and F2, with a mean loss of 21.27% (0.445 ± 0.214 arcsine) and

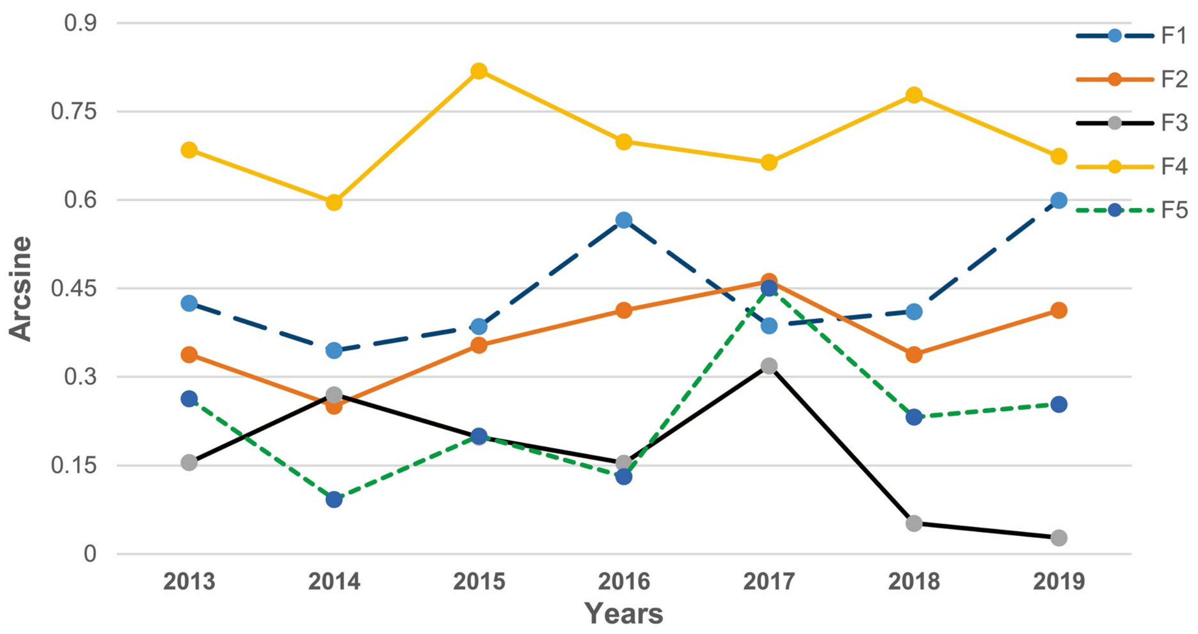

Fig. 2 Losses of eggs and hatchlings (arcsine transformed) of olive ridley sea turtles during the phases of nest management at Ceuta Beach Sanctuary during 2013–2019. F1 = nest logging, F2 = egg collection, F3 = egg transfer, F4 = egg incubation and hatching, and F5 = hatchling release

15.56% (0.367 ± 0.198 arcsine), respectively. These loss rates were significantly higher than those of the other phases (F4, F3, and F5) but not significantly different from each other. Moreover, although the 2014 season had the lowest mean loss of 12.34% (0.311 ± 0.211 arcsine) and the 2017 season had the highest mean loss of 23.17% (0.457 ± 0.329 arcsine), no significant differences were observed in the comparison of losses by year at CBS ($F = 1.221$, df = 6, $p = 0.298$).

At CB, the annual losses recorded (Fig. 3) were between 9.47 and 49.24% (0.221 and 0.709 arcsine) during F1, between 13.61 and 44.02% (0.326 and 0.737 arcsine) during F2, between 0.05 and 20.00% (0.019 and 0.267 arcsine) during F3, between 16.41 and 50.35% (0.416 and 0.961 arcsine) during F4, and between 0.81 and 22.18% (0.088 and 0.354 arcsine) during F5. According to the 2-way ANOVA results, the interaction between phase and year at CB did not have a significant effect ($F = 0.520$, df = 20, $p = 0.952$). The comparison between management phases revealed a statistically significant difference ($F = 8.675$, df = 4, $p = 0.001$), with F4 exhibiting the highest mean loss of 33.09% (0.625 ± 0.369 arcsine), F1 exhibiting a mean loss of 25.56% (0.500 ± 0.381 arcsine), and F2 exhibiting a mean loss of 27.27% (0.509 ± 0.432 arcsine), all of which were significantly higher than the loss rates of the other management phases. On the other hand, at CB, 2014 showed the highest mean loss of 33.65% (0.567 ± 0.643 arcsine), and there were significant differences in the comparison of losses by year ($F = 2.348$, df = 5, $p = 0.047$).

Comparisons between CBS and CB of the percentages of nests, eggs,and hatchling losses in the five management phases considering the studied nesting seasons were performed, and significant differences in F3, F4, and F5 were observed ($p < 0.05$) (Table 2). Regarding F4, there was greater loss at CBS than at CB, with a mean of 41.99% (0.702 ± 0.253 arcsine) at CBS and 33.09% (0.625 ± 0.369 arcsine) at CB. The same trend occurred for F3, where there was greater loss at CBS than at CB, with a mean of 5.26% (0.168 ± 0.172 arcsine) at CBS and 4.57% (0.102 ± 0.321 arcsine) at CB, and for F5, with a

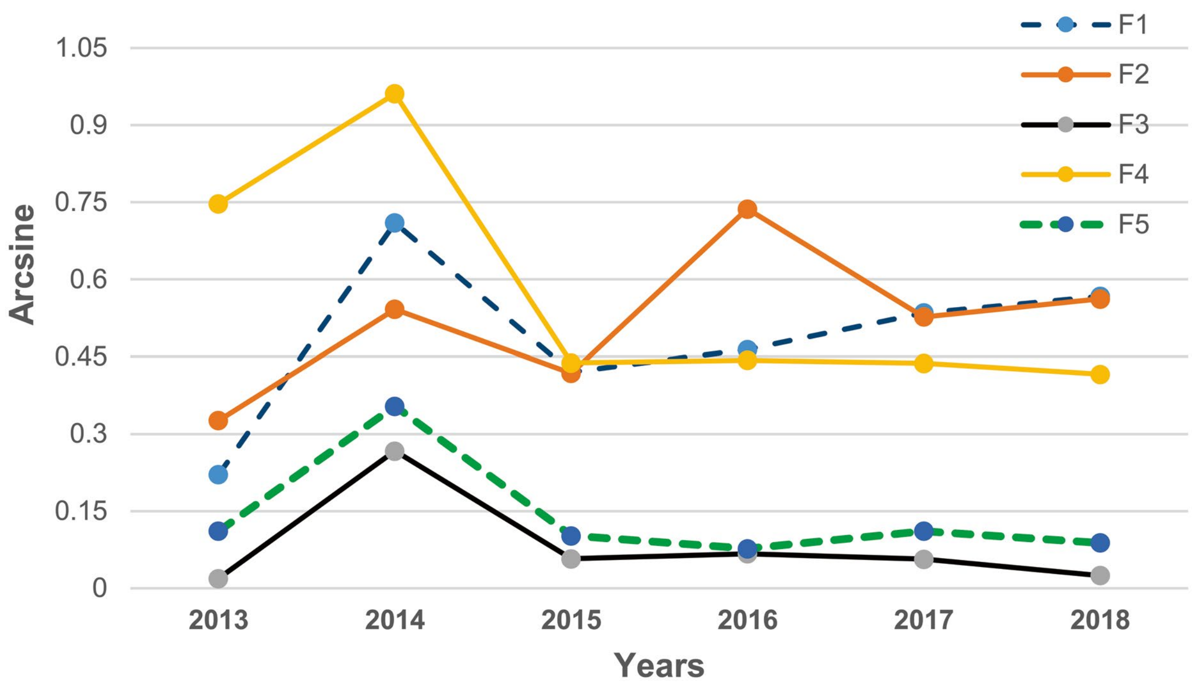

Fig. 3 Losses of eggs and hatchlings (arcsine transformed) of olive ridley sea turtles during the phases of nest management at Caimanero Beach during 2013–2018. F1 = nest logging, F2 = egg collection, F3 = egg transfer, F4 = egg incubation and hatching, and F5 = hatchling release

Table 2 Comparisons of the percentages of egg and hatchling losses of olive ridley sea turtles between Ceuta Beach Sanctuary (CBS) and Caimanero Beach (CB) in Sinaloa, Mexico, during the phases of nest management (2013–2019)

	Beach		
MP	**CBS**	**CB**	***p* value**
	% (arcsine)	% (arcsine)	
F1	21.28 (0.446 ± 0.215)	25.56 (0.501 ± 0.381)	Mann–Whitney U = 471, $T = 771$, $p = 0.875$
F2	15.56 (0.367 ± 0.198)	27.27 (0.509 ± 0.432)	Mann–Whitney U = 396, $T = 846$, $p = 0.235$
F3*	5.26 (0.168 ± 0.172)	4.57 (0.102 ± 0.321)	Mann–Whitney U = 250.5, $T = 526.5$, $p = 0.001$
F4*	41.99 (0.702 ± 0.253)	33.09 (0.625 ± 0.369)	Mann–Whitney U = 297, $T = 573$, $p = 0.011$
F5*	7.43 (0.232 ± 0.243)	5.68 (0.165 ± 0.312)	Mann–Whitney U = 263.5, $T = 539.5$, $p = 0.003$

(Mean ± SD). *statistically significant value. *MP* management phase, *F1* nest logging, *F2* egg collection, *F3* egg transfer, *F4* egg incubation and hatching, and *F5* hatchling release

mean of 7.43% (0.232 ± 0.243 arcsine) at CBS and 5.68% (0.165 ± 0.312 arcsine) at CB.

Discussion

Evaluation of management phases for *L. olivacea* where laid eggs are transferred to hatcheries is of great importance for the collection and analysis of information from egg laying to hatchling release. In this study, CB showed more than three times the mean annual values of registered and collected nests, incubated eggs, and hatchlings released than CBS; on average, 1848 and 576 nests were collected, and 198,116 and 51,507 hatchlings were released annually over the study period at CBS and CB, respectively. No significant differences in the numbers of registered nests, collected nests, predated nests, poached nests, hatching eggs, or released hatchlings were observed over the years at either beach.

Nest, egg, and hatchling losses during the five phases of *L. olivacea* nest management at CBS and CB were monitored over 7 and 6 years, respectively. The greatest losses were recorded in F4, followed by F1 and F2, which indicates that more attention should be given to these phases to avoid further losses.

At CBS, the comparison of the losses between management phases showed that F4 had the highest loss statistically, with a mean of 41.99% (Fig. 2), followed by F1 and F2, with a mean loss of 21.28 and 15.56%, respectively, which were significantly higher than the losses at the other phases but not significantly different from each other (F1 and F2). In the comparison of management phases at CB (Fig. 3), the greatest losses were observed in F4, F2, and F1, with means of 33.09, 27.27, and 25.56%, respectively ($p < 0.05$). Furthermore, at CB, when comparing the losses per year, a significant difference was observed in 2014, with the highest mean of 33.65%, while no significant difference was observed at CBS. Additionally, a comparison of losses between the two beaches in each management phase revealed a greater loss at CBS during F4, F3, and F5 ($p < 0.05$, Table 2).

Losses in F4 could be due to climatic conditions (humidity and temperature), direct and indirect anthropogenic disturbances, climatic factors (storms, floods, and erosion), microbiological contamination of hatching eggs, and hatchling management (Ackerman, 1997; Arzola-González, 2007; Eckert & Eckert, 1990; Rondon-Medicci et al., 2010; Sundaram et al., 2019; Velásquez et al., 2014). At CBS and CB, the main cause could be the high temperatures that occur during incubation, as temperatures close to or above the threshold temperature (> 34 °C) for embryonic mortality were recorded (Sandoval, 2012). To reduce the impact of high temperatures during incubation of the relocated nests, the use of shade structures on the hatcheries of both beaches was implemented. The use of mesh for shade is a strategy that has been applied to reduce solar radiation exposure and, at the same time, protect hatchlings from the sun if they emerge during the day; without this protective measure, these hatchlings would die within a few hours (Arzola-Gonzalez et al., 2019; Vázquez-Sauceda et al., 2008). Although one type of mesh has been used for shade at CB since 2015 and an apparent decrease in losses was observed from that year onward (Fig. 3), statistical tests of the % shade, color, and shading height of different mesh sizes are necessary to determine which mesh is the most suitable for these beaches. The greater loss in F4 observed at CBS compared to CB could be due to the use of suboptimal mesh for shade at CBS. It is also likely that more time elapses from egg collection to incubation at CBS, as there are fewer staff than at CB (4 vs. 10 to 15 staff, respectively), as losses may occur and effects may be evident until F4 (Enciso-Padilla, 1991).

Losses in F1 at both beaches are mainly related to predation and human poaching (Balladares & Dubois, 2015; Hinestroza & Páez, 2001) but also to beach erosion. If the effort during monitoring is reduced on some nightly tours along each beach (37 km long each), because of difficulties in accessing the area, a lack of permanent staff, a lack of monitoring support infrastructure or limited availability of additional resources (such as fuel and food) required for fieldwork, this could encourage nest poaching and predation on both beaches, which could have long-term consequences for sea turtle populations (Leighton et al., 2011; Tomillo et al., 2008). There are records from previous years to the present study at both beaches that losses of up to 90% of nests to predation and human poaching can occur when the nests are left in situ, and relocating nests to hatcheries has reduced these losses (da Silva et al., 2007). Therefore, it is important to increase monitoring efforts during F1 to increase the success of protection activities (Garcıía et al., 2003). At CB, there was a higher density of nests and greater proximity to coastal communities, which facilitated nest poaching by community residents (increased from 3 to 18.6% during the study period). Perhaps an alternative to reduce these losses could be to implement environmental education strategies in the surrounding coastal human communities, mainly at CB, so that hatcheries could be established and attended by the communities, thus avoiding nest losses (F1) and egg collection (F2) at CB (Fig. 3, Table 1). With participatory community action, nest predation is likely to decrease, and in turn, nest collection and good hatchery management are likely to increase.

Losses in F2 could be mainly due to humans, as insufficient training of personnel in egg collection may cause the loss of some eggs, in addition to their fragility. Although there are more personnel at CB than at CBS, only one person is a trained technical manager, and the other people who participate in the collection belong to neighboring communities, have temporary jobs, and are dependent on private companies that donate resources to support the conservation of this species. Losses in F2 would be reduced if staff had substantial training in nest management, including the removal of eggs from natural nests, their transfer, and their subsequent incubation in hatcheries.

Although the per beach losses in F3 and F5 were low, in the comparison between the two beaches, the losses were greater at CBS ($p < 0.05$, Table 2). In F3, the increased loss at CBS could be due to the physical characteristics of the beach, which are very dynamic and include monthly variability in the profile, wave dynamics, and littoral transport (Sosa et al., 2019). These physiographic variables of the beach give it a very irregular surface, and consequently, during the transport of the nests to the hatcheries on a motorized vehicle (quad bike), the vibration is intense, which could cause internal damage to the eggs (detachment of their poles) or the breakage of some of them (Hur & Lee, 2010). CB is less dynamic, and the egg transfer losses at CB were lower than those at CBS. Each beach has unique spatiotemporal dynamics with respect to some of its physical, chemical, and environmental properties that change in response to anthropogenic (habitat modification) and environmental pressures (Cabrera-Ramírez et al. 2018; Mir-Gual, 2009). In addition, the period of nest transfer to the hatchery and the possible movement of eggs also decreased because there were more staff at CB than at CBS.

One possible explanation for the greater loss in F5 at CBS than at CB (Table 2) is that in 2017 and 2018, predators (raccoons, opossums, and badgers) were able to tear into the mesh hatchery and access the incubation areas at CBS, increasing the mortality of hatchlings.

In the comparison of mean losses by year, CB showed the highest loss in 2014; this may have been due to trained staff being absent for periods during the season, leaving support staff in charge but not fully trained. In addition, two weather events (Hurricanes Vance and Odile) may also have caused the increase in losses during the year. At CBS, no significant differences were observed over the years.

Importantly, in the absence of protection programs in these areas, nest depredation and poaching, killing of nesting females and embryo mortality would be very high, affecting the recovery of this chelonid (James & Melero, 2015; Mazaris et al., 2017), although da Silva et al. (2007), Hart et al.

(2018), and Muñoz and Arauz (2015) mention that the population of *L. olivacea* is recovering.

The present study determined the losses of nests, eggs, and hatchlings during different management phases at two solitary nesting beaches of olive ridley turtles, with the objective of determining the differences within and between the beaches, as well as the temporal variability, to suggest modifications to the techniques used. The use of a model to evaluate the management phases at CBS and CB allowed us to identify a problem of losses, mainly in F4 and in F1 and F2 for both beaches. The results obtained in the present work show that it is necessary to focus on strategies to reduce losses in these phases, such as increasing monitoring intensity efforts during the different phases or incubating some eggs in situ and monitoring them intensively for a few months, as suggested by Revuelta et al. (2013). However, where appropriate, long-term ecotourism activities could make these programs self-sustainable (Pegas & Stronza, 2010; Wilson & Tisdell, 2003) and hence obtain funding. It is also necessary to monitor the temperature of nests in hatcheries, optimize the % shade as well as the color and height of the mesh shade, and thus decrease mortality losses and increase the success of protection activities. Additionally, it is important that BC be given protection status under a legal framework and that financial support is provided for better training of staff and the acquisition of equipment and infrastructure required for field work (Sosa et al., 2021).

The model used in this study can be used by others in the field of turtle research worldwide to identify which management phases to improve.

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Author contribution ISC contributed to the experimental activities and the data analysis and interpretation. LIPG contributed to the data analysis and interpretation. HRCA contributed to the analysis and manuscript editing. FES contributed to the analysis and manuscript editing. MSB contributed to the analysis and manuscript editing. IEP contributed to the analysis and manuscript editing. SCL contributed to the study design and the data analysis and interpretation. All authors contributed to the writing and revision of the first manuscript as well as its subsequent and final versions.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare no competing interests.

References

Ackerman, R. A. (1997). The nest environment and the embryonic development of sea turtles. In P. Lutz & J. Musick (Eds.), *The biology of sea turtles* (pp. 83–107). CRC Marine Science Series.

Arzola-González, J. F. (2007). Humedad y temperatura en nidos naturales y artificiales de tortuga golfina *Lepidochelys olivacea* (Eschssholtz 1829). *Revista De Biología Marina y Oceanografía, 42*(3), 377–383. https://doi.org/10.4067/s0718-19572007000300017

Arzola-Gonzalez, J. F., Barrón-Hernandez, J., Gutiérrez-Rubio, Y., Voltolina, D., & Ramírez-Pérez, J. S. (2019). Anidación e incubación artificial de huevos de tortuga golfina *Lepidochelys olivacea* (Testudines: Cheloniidae). *Ecosistemas y Recursos Agropecuarios*, *6*(18), 595–599. https://doi.org/10.19136/era.a6n18.1971

Azanza-Ricardo, J., Gerhartz-Muro, J. L., Martín-Viaña, Y. F., & Moncada-Gavilán, F. (2015). Efectividad del monitoreo de la anidación de tortugas marinas para determinar el éxito reproductivo en playas del sur de Cuba. *Latin American Journal of Aquatic Research, 43*(3), 548–556. https://doi.org/10.3856/vol43-issue3-fulltext-16

Balladares, C., & Dubois, E. (2015). Saqueo y depredación de nidadas de tortugas marinas, durante las temporadas 2003 a 2012, en seis playas del Golfo de Paria, Venezuela. *UNED Research Journal*, *6*(2), 239–244. https://doi.org/10.22458/urj.v6i2.630

Bárcenas-Ibarra, A., & Maldonado-Gasca, A. (2009). Malformaciones en embriones y neonatos de tortuga golfina (*Lepidochelys olivacea*) en Nuevo Vallarta, Nayarit. *México. Veterinaria Mexico, 40*(4), 371–380.

Bell, B. A., Spotila, J. R., Paladino, F. V., & Reina, R. D. (2004). Low reproductive success of leatherback turtles, *Dermochelys coriacea*, is due to high embryonic mortality. *Biological Conservation, 115*(1), 131–138. https://doi.org/10.1016/s0006-3207(03)00102-2

Bjorndal, K. A., & Bolten, A. B. (2003). From ghosts to key species: Restoring sea turtle populations to fulfill their ecological roles. *Marine Turtle Newsletter, 100*, 16–21.

Bovery, C. M., & Wyneken, J. (2015). Seasonal variation in sea turtle density and abundance in the southeast Florida current and surrounding waters. *PLoS One, 10*(12), e0145980. https://doi.org/10.1371/journal.pone.0145980

Cabrera-Ramirez, M., Carranza-Edwards, A., & Leonardo, E. (2018). Influence of the Cozoaltepec River sediment on turtle nesting at La Escobilla beach in Oaxaca, on the Mexican Pacific coast. *Hidrobiologica*, *28(1)*, 71–81. https://doi.org/10.24275/uam/izt/dcbi/hidro/2017v28n1/Cabrera

CONANP. (2018). *Ficha SIMEC (Sistema de información, monitoreo y evaluación para la conservación) del Santuario Playa Ceuta, Elota, Sinaloa.* https://simec.conanp.gob.mx/ficha.php?anp=11&reg=2

da Silva, A. C. C. D., de Castilhos, J. C., Lopez, G. G., & Barata, P. C. R. (2007). Nesting biology and conservation of the olive ridley sea turtle (*Lepidochelys olivacea*) in Brazil, 1991/1992 to 2002/2003. *Journal of the Marine Biological Association of the United Kingdom, 87*(4), 1047–1056. https://doi.org/10.1017/s0025315407056378

DOF (Diario Oficial de la Federación). (1986). *DECRETO por el que se determinan como zonas de reserva y sitios de refugio para la protección, conservación, repoblación, desarrollo y control, de las diversas especies de tortuga marina, los lugares en que anida y desova dicha especie.* Gobierno Federal de México. https://dof.gob.mx/nota_detalle.php?codigo=4815894&fecha=29/10/1986

DOF (Diario Oficial de la Federación). (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. págs. 35−36. SEMARNAT*. Retrieved Julio 16, 2002, from https://www.dof.gob.mx/nota_detalle.php?codigo=723470&fecha=16/07/2002

Eckert, K. L., & Eckert, S. A. (1990). Embryo mortality and hatch success in *in situ* and translocated leatherback sea turtle *Dermochelys coriacea* eggs. *Biological Conservation, 53*(1), 37–46. https://doi.org/10.1016/0006-3207(90)90061-s

Ehrenfeld, D. (1995). Options and limitations in the conservation of sea turtles. In K. Bjorndal (Ed.), *Biology and conservation of sea turtles* (pp. 457–463). Smithsonian Institution Press.

Enciso-Padilla, I. (1991). Evaluación cuantitativa de los resultados de las actividades de protección a la tortuga marina *Lepidochelys olivacea* en el Playón de Mismaloya Jalisco temporadas 1987, 1988 y 1989 [Licenciatura en Biología Thesis, Facultad de Ciencias, Universidad de Guadalajara]. http://repositorio.cucba.udg.mx:8080/xmlui/bitstream/handle/123456789/2552/Enciso_Padilla_Ildefonso.pdf?sequence=1

Frazer, N. B. (1984). A model for assessing mean age-specific fecundity in sea turtle populations. *Herpetologica, 40*(3), 281–291.

Frazer, N. B. (1992). Sea turtle conservation and halfway technology. *Conservation Biology, 6*(2), 179–184. https://doi.org/10.1046/j.1523-1739.1992.620179.x

Gabriel, J., Ganchozo, B. I., Valverde, A., & Piguave, C. C. (2017). *Diseños experimentales: Teoría y práctica para experimentos agropecuarios*. GRUPO COMPÁS.

García, A., Ceballos, G., & Adaya, R. (2003). Intensive beach management as an improved sea turtle conservation strategy in Mexico. *Biological Conservation, 111*(2), 253–261. https://doi.org/10.1016/s0006-3207(02)00300-2

Godínez-Domínguez, E., Silva-Bátiz, F., & Enciso-Padilla, I. (1991). *Manual de técnicas y procedimientos para la protección en el campo de la tortuga marina en el estado de Jalisco. Programa institucional de protección y conservación de la tortuga marina en el estado de Jalisco. SEDUE, SEPESCA, COESE, U de G.* Facultad de Ciencias Biológicas, Universidad de Guadalajara.

Hart, C. E., Maldonado-Gasca, A., Ley-Quiñonez, C. P., Flores-Peregrina, M., Romero-Villarruel, J., Aranda-Mena, O. S., Plata-Rosas, L. J., Tena-Espinoza, M., Llamas-González, I., Zavala-Norzagaray, A. A., Godley, B. J., & Abreu-Grobois, F. A. (2018). Status of olive ridley sea turtles (Lepidochelys olivacea) after 29 years of nesting rookery conservation in Nayarit and Bahía de Banderas. *Mexico. Chelonian Conservation and Biology, 17*(1), 27–36. https://doi.org/10.2744/ccb-1255.1

Herrera, M. E., Dagatti, C. V., & Becerra, V. C. (2017). Tabla de vida y parámetros poblacionales de *Lobesia botrana* (Den. et Schiff.) en condiciones de laboratorio. *Revista de la Sociedad Entomológica Argentina*, *76*(3–4), 27–32. https://doi.org/10.25085/rsea.763404

Hinestroza, L., & Páez, V. P. (2001). Anidación y manejo de la tortuga golfina (*Lepidochelis olivacea*) en la playa La Cuevita, Bahía Solano, Chocó. *Colombia. Cuadernos De Herpetología, 14*(2), 131–144.

Hur, J. W., & Lee, J. Y. (2010). Effects of chronic vibration stress on liver, kidney and testes of the soft-shelled turtle *Pelodiscus sinensis*. *Journal of Applied Animal Research, 37*(2), 241–245. https://doi.org/10.1080/09712119.2010.9707133

INAFED. (2018). *Instituto nacional para el federalismo y el desarrollo municipal. Enciclopedia de los municipios y delegaciones de México*. Estado de Sinaloa. Municipio de Elota. http://www.inafed.gob.mx/work/enciclopedia/EMM25sinaloa/index.html

James, R., & Melero, D. (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*(1), 117–129. https://doi.org/10.15517/rbt.v63i1.23099

Leighton, P. A., Horrocks, J. A., & Kramer, D. L. (2011). Predicting nest survival in sea turtles: When and where are eggs most vulnerable to predation? *Animal Conservation, 14*(2), 186–195. https://doi.org/10.1111/j.1469-1795.2010.00422.x

Márquez, R. (1976). *Reservas naturales para la conservación de las tortugas marinas en México*. Instituto Nacional de Pesca.

Martella, M. B., Trumper, E. V., Bellis, L. M., Renison, D., Giordano, P. F., Bazzano, G., & Gleiser, R. M. (2012). Manual de Ecología. Poblaciones: Demografía, crecimiento e interacciones. *Reduca (Biología)*, *5*(1), 32–70.

Mazaris, A. D., Schofield, G., Gkazinou, C., Almpanidou, V., & Hays, G. C. (2017). Global sea turtle conservation successes. *Science Advances, 3*(9), e1600730. https://doi.org/10.1126/sciadv.1600730

Méndez-Rodríguez, L., & Álvarez-Castañeda, S. T. (2016). Predation on turtle nests in the southwestern coast of the Baja California Peninsula. *Revista Mexicana De Biodiversidad, 87*(2), 483–488. https://doi.org/10.1016/j.rmb.2016.02.005

Mir-Gual, M. (2009). Modificaciones del perfil de playas en las Islas Baleares (playas de Can Picafort y Es Comú de Muro). *Investigaciones Geográficas* (50), 191–207. https://doi.org/10.14198/ingeo2009.50.10

Mortimer, J. A. (1999). Reducing threats to eggs and hatchlings: Hatcheries. In K. L. Eckert, K. A. Bjorndal, F. A. Abreu-Grobois, & M. Donnelly (Eds.), *Research and management techniques for the conservation of sea turtles* (pp. 175–178). IUCN/SSC Marine Turtle Specialist Group.

Muñoz, S. V., & Arauz, R. (2015). Conservación y actividad reproductiva de tortuga lora (*Lepidochelys olivacea*) en la playa de anidación solitaria Punta Banco, Pacifico Sur de Costa Rica. Recomendaciones de manejo a través de dieciséis años de monitoreo. *Revista de Biología Tropical*, *63*(1), 383–394. https://doi.org/10.15517/rbt.v63i1.23117

Pegas, F. V., & Stronza, A. (2010). Ecotourism and sea turtle harvesting in a fishing village of Bahia. *Brazil. Conservation and Society, 8*(1), 15–25. https://doi.org/10.4103/0972-4923.62676

Rangel-Mendoza, J. A., & Weber, M. (2015). Physical examination of Central American river turtle, *Dermatemys mawii*, in captivity in Tabasco. *Mexico. Agrociencia, 49*(5), 499–511.

Revuelta, O., León, Y. M., Aznar, F. J., Raga, J. A., & Tomás, J. (2013). Running against time: Conservation of the remaining hawksbill turtle (*Eretmochelys imbricata*) nesting population in the Dominican Republic. *Journal of the Marine Biological Association of the United Kingdom, 93*(4), 1133–1140. https://doi.org/10.1017/s0025315412001518

Richardson, J. (2000). Prioridades para los estudios sobre la biología de la reproducción y de la anidación. In K. L. Eckert, K. A. Bjorndal, F. A. Abreu-Grobois, & M. Donnelly (Eds.), *Técnicas de investigación y manejo para la conservación de las tortugas marinas* (pp. 9–12). UICN/CSE Grupo Especialista en Tortugas Marinas Publicación No. 4.

Romero-Olmedo, B. E. (2015). *Comparación de éxito de eclosión y morfometría en crías de tortuga verde (Chelonia mydas Linnaeus, 1758), en dos condiciones de incubación: In situ y en cajas de polietileno en el centro tortuguero de Santander, Veracruz. Temporada 2011.* Licenciatura en Biología, Thesis, Universidad Veracruzna.

Rondon-Medicci, M., Buitrago, J., & Guada, H. J. (2010). Biología reproductiva de la tortuga cardón (*Dermochelys coriacea*) en playas de la península de Paria, Venezuela, durante las temporadas de anidación 2000–2006. *Interciencia, 35*(4), 263–270.

Sandoval, S. (2012). *Proporción sexual en crías de tortuga Lepidochelys olivacea en corrales de incubación del Pacífico mexicano.* Doctorado en Ciencias Marinas Thesis, Centro Interdisciplinario de Ciencias Marinas (CICIMAR-IPN). La paz, B.C.S., México. http://www.repositoriodigital.ipn.mx/handle/123456789/13058

Schoreder, B., & Murphy, S. (2000). Prospecciones poblacionales (terrestres y aéreas) en playas de anidación. In K. L. Eckert, K. A. Bjorndal, F. A. Abreu-Grobois, & M. Donnelly (Eds.), *Técnicas de investigación y manejo para la conservación de las tortugas marinas* (pp. 51–63). UICN/CSE Grupo Especialista en Tortugas Marinas Publicación No. 4.

SEMARNAT. (2018). Programa de Acción para la Conservación de la Especie Tortuga Golfina (*Lepidochelys olivacea*), SEMARNAT/CONANP, México (Año de edición 2018). https://www.gob.mx/cms/uploads/attachment/file/443997/PACE_Tortuga_Golfina.pdf

Sosa, I., Moran, R. E., Enciso, F., Barraza, M. A., Contreras, H., & Sosa, R. (2019). Características físicas y químicas del sustrato arenoso de la zona de anidación de la tortuga marina *Lepidochelys olivacea* en Playa Ceuta, Sinaloa, México. In E. A. C. Flores, V. G. Hernández, J. J. Guerra Santos, & G. A. Rivas Hernández (Eds.), *El uso del conocimiento de las tortugas marinas como herramienta para la restauración de sus poblaciones y hábitats asociados* (pp. 151–160). Universidad Autónoma del Carmen.

Sosa-Cornejo, I., Martín-del-Campo, R., Contreras-Aguilar, H. R., Enciso-Saracho, F., González-Camacho, Z. B., Guardado-González, J. I., Campista-Leon, S., & Peinado- Guevara, L. I. (2021). Nesting trends of olive ridley sea turtles *Lepidochelys olivacea* (Testudinata: Cheloniidae) on two beaches in Northwestern Mexico after 30 and 40 years of conservation. *Revista de Biología Tropical, 69*(3):1124–1137. https://doi.org/10.15517/rbt.v69i3.46490

Southwood, T. R. E., & Henderson, P. A. (2000). *Ecological methods*. Willey-Blackwell publishing.

Spotila, J. R., Reina, R. D., Steyermark, A. C., Plotkin, P. T., & Paladino, F. V. (2000). Pacific leatherback turtles face extinction. *Nature, 405*, 529–530. https://doi.org/10.1038/35014729

Sundaram, S., James, N., & Saleem, A. (2019). Conservation activities carried out on olive ridley turtles, *Lepidochelys olivacea* (Eschscholtz, 1829) and observations on its hatching from Chavakkad beach, Kerala. *India. International Journal of Life Sciences, 7*(1), 83–91.

Tomillo, P. S., Saba, V. S., Piedra, R., Paladino, F. V., & Spotila, J. R. (2008). Effects of illegal harvest of eggs on the population decline of leatherback turtles in Las Baulas Marine National Park. *Costa Rica. Conservation Biology, 22*(5), 1216–1224. https://doi.org/10.1111/j.1523-1739.2008.00987.x

Vázquez-Sauceda, M., Aguirre-Guzmán, G., Pérez-Castañeda, R., Sánchez-Martínez, J., Martín-del Campo, R., Loredo-Osti, J., & Rábago-Castro, J. (2008). Evaluación de la influencia de dos cajas de transporte de huevos sobre la incubación, la eclosión y el nacimiento de crías de tortuga lora (*Lepidochelys kempii*). *Ciencias Marinas, 34*(1), 101–105.

Velásquez, F., Prieto, A., & Prieto, E. (2014). Mortalidad embrionaria en cuatro nidos de tortuga cardón *Dermochelys coriacea* en playa San Luis, sector los chivos, Cumaná, estado Sucre. *SABER. Revista Multidisciplinaria del consejo de investigación de la Universidad de Oriente*, *26*(3), 243–248.

Ware, M., Long, J. W., & Fuentes, M. M. P. B. (2019). Using wave runup modeling to inform coastal species management: An example application for sea turtle nest relocation. *Ocean & Coastal Management*, *173*, 17–25. https://doi.org/10.1016/j.ocecoaman.2019.02.011

Wilson, C., & Tisdell, C. (2003). Conservation and economic benefits of wildlife-based marine tourism: Sea turtles and whales as case studies. *Human Dimensions of Wildlife, 8*(1), 49–58. https://doi.org/10.1080/10871200390180145

Zar, J. H. (1984). *Biostatistical analysis*. 2nd Edition. Prentice Hall.