

Running against time: conservation of the remaining hawksbill turtle (*Eretmochelys imbricata*) nesting population in the Dominican Republic

OHIANA REVUELTA¹, YOLANDA M. LEÓN^{2,3}, FRANCISCO J. AZNAR¹, JUAN A. RAGA¹ AND JESÚS TOMÁS¹

¹Cavanilles Institute of Biodiversity and Evolutionary Biology, University of Valencia, Valencia, Spain, ²Grupo Jaragua, El Vergel 33, El Vergel, Santo Domingo, Dominican Republic, ³Instituto Tecnológico de Santo Domingo, Santo Domingo, Dominican Republic

Saona Island hosts the last hawksbill turtle (Eretmochelys imbricata) nesting population in the Dominican Republic, which has experienced a severe decline in the last decades, mostly due to illegal egg take. Here we present the results of an artificial incubation programme started in 2007 to protect the clutches from human predation. A preliminary survey in 2006 showed that about 60% of clutches laid were taken by humans. Over the study period (2007–2010) we recorded 400 clutches, of which 38.2% were predated by humans, 40.7% were artificially incubated and 21% were incubated in situ. Overall, the artificial incubation programme allowed the release of 12,340 hatchlings. No differences were found in hatching and emergence success between clutches incubated in situ and clutches artificially incubated. However, incubation temperatures and incubation durations recorded suggest a male-biased hatchling sex-ratio in artificially incubated clutches. Although artificial incubation may mitigate the effect of egg take, our results indicate that other measures, such as clutch relocation to protected sections of the beach should be taken. Beach patrolling and education are currently implemented so that artificial incubation will be eventually phased out in favour of in situ incubation.

Keywords: *Eretmochelys imbricata*, Dominican Republic, conservation, artificial incubation, human egg take, emergence success, sex-ratio

Submitted 8 September 2012; accepted 12 September 2012; first published online 29 October 2012

INTRODUCTION

The hawksbill marine turtle, *Eretmochelys imbricata*, is listed under the IUCN Global Red List as critically endangered (IUCN, 2011). In the Caribbean, this species has been exploited historically for its meat, eggs and shell (Meylan, 1999; Carrillo *et al.*, 1999; Fleming, 2001) leading to a noticeable reduction in nesting populations in the region (Meylan, 2002; McClenachan *et al.*, 2006). However, the regional management unit of Caribbean hawksbill is currently characterized as low risk but as high threat (Wallace *et al.*, 2010), and some populations are thought to be increasing (Puerto Rico: Meylan, 1999; Antigua: Richardson *et al.*, 2006; Barbados: Beggs *et al.*, 2007; Guadeloupe: Kamel & Delcroix, 2009). However, rookeries without protection in this basin are seriously threatened, particularly due to egg take (Lagueux & Campbell, 2005).

Increasing hatchling production is a necessary component of any strategy to recover depleted marine turtle populations (Dutton *et al.*, 2005; Sarti Martínez *et al.*, 2007). When clutches are at risk, relocation to different sections of the beach or to protected hatcheries have been common

management tools in many marine turtle conservation programmes (Pritchard, 1995; Kornaraki *et al.*, 2006; Marcovaldi *et al.*, 2007). However, this is not a perfect solution, as it has been reported that relocated clutches may experience lower hatching success and altered sex-ratios (Godfrey & Mrosovsky, 1999; Mortimer, 1999; Pintus *et al.*, 2009). Nevertheless, the intense pressures from human egg take in undeveloped countries leaves them with no other option than relocating clutches and using hatcheries (García *et al.*, 2003; Liles *et al.*, 2011) or even, in extreme situations, to incubate clutches in boxes (Dutton *et al.*, 1985). Therefore, clutch conservation strategies should rely on the evaluation of local characteristics, and should be adapted to the specific scenarios where they are intended to be applied (Eckert, 1999; Kornaraki *et al.*, 2006).

In the Dominican Republic (DR, North Caribbean), current estimates suggest a severe decline of the hawksbill nesting population, with sporadic nesting in few places around the country and only one remaining stable stock on the south coast of Saona Island, south-east DR (with a mean of 23 females nesting per year: Revuelta *et al.*, 2012). According to the estimation of 5000 females nesting annually in the Caribbean (Meylan, 1999), Saona Island hawksbill stock would represent close to 0.5% of the total number of nesting females in the region. The greatest threat to this nesting rookery comes from illegal egg take and deliberate capture of adults for meat (Revuelta *et al.*, 2012). Preliminary

Corresponding author:
J. Tomás
Email: jesus.tomas@uv.es

surveys in 2006 revealed that up to 60% of 41 nests recorded on the island were taken by humans, with up to 100% ($N = 13$) taken near the principal human settlement, Mano Juan (Revuelta *et al.*, unpublished data). This occurs even though it is illegal to harvest turtles or their products in the DR since 1966, and that Saona is part of a protected area since 1975 (Del Este National Park). This situation could potentially impact rookeries on a regional scale since Dominican hawksbills seem to disperse to several feeding grounds throughout the Caribbean after nesting; including distant areas in waters of Nicaragua and Honduras (Hawkes *et al.*, 2012).

It is well known that artificial incubation in boxes may introduce masculinizing biases in resulting hatchlings (Morreale *et al.*, 1982; Dutton *et al.*, 1985; Whitmore & Dutton, 1985). This is because sex in marine turtles is determined by the temperature at which eggs are incubated during the middle third of incubation, which is referred to as the thermosensitive period (Yntema & Mrosovsky, 1982). When boxes are used, the temperature during this period is often lower than pivotal temperature (that which produces 1:1 sex ratio: Mrosovsky & Pieau, 1991), thus resulting in a greater proportion of male hatchlings (Mrosovsky, 1994). However, given the high predation levels observed, in 2007, we initiated a programme of artificial incubation in boxes as an urgent measure to protect the clutches and increase hatchling recruitment while implementing other conservation measures, such as beach patrolling and education.

Here we present the results of a four year monitoring and conservation programme of the hawksbill nesting population of Saona Island, including the artificial incubation programme. Our main research questions were twofold: (1) are there differences in hatching and emergence success between artificially incubated clutches and *in situ* incubated clutches?; and (2) what is the sex-ratio produced in the artificially incubated clutches?

MATERIALS AND METHODS

Study site

The present study was conducted from 2007 to 2010 in Saona Island ($18^{\circ}07'N-68^{\circ}44'W$; Figure 1), which is included in the Del Este National Park (south-east DR). With an area of 110 km^2 , Saona is the largest island adjacent to the DR. There is one permanent human settlement in Saona, Mano Juan village, with a population of 300 inhabitants (Figure 1). Hawksbill nesting occurs across all of the 26.6 km of the south coast sandy beaches of Saona Island. However, nesting activity is concentrated in 12 narrow fine-grained coralline, white sand beaches (altogether comprising a total of 15 km; Table 1) interspersed with rocky areas. The neritic sea adjacent to the nesting beach is composed of coral reefs and seagrass beds. For the most part, beach vegetation is dominated by coconut (*Cocos nucifera*) plantations, sea purslane (*Sesuvium portulacastrum*), sea rosemary (*Suriana maritima*), sea grape (*Coccoloba uvifera*), goat's foot creeper (*Ipomoea pes-caprae*) and native grasses.

Beaches were grouped into 5 sampling areas: (1) Del Toro, with 1530 m length and mean beach width (range) of 7.9 (4–18) m; (2) Mano Juan, 2990×8 (2–20) m; (3) Boca Chica, with 12.9×4.4 m; (4) Canto de la Playa area, 4263×18 (8–30) m; and (5) Faro Punta Cana, 6084×10 (3–20) m (Figure 1). We patrolled the beaches at least once per week throughout the year, but in 2008 this was increased to 3–4 surveys per week during the peak nesting period (June to November). Also, in 2009, the farthest area (Faro Punta Cana; see Figure 1) was visited only monthly due to logistic limitations. We patrolled the beaches, by foot to detect all recent tracks of nesting females. All emergences of turtle females to nest were recorded. Clutches were confirmed by the presence of eggs in the nest chamber, or by signs of egg predation at

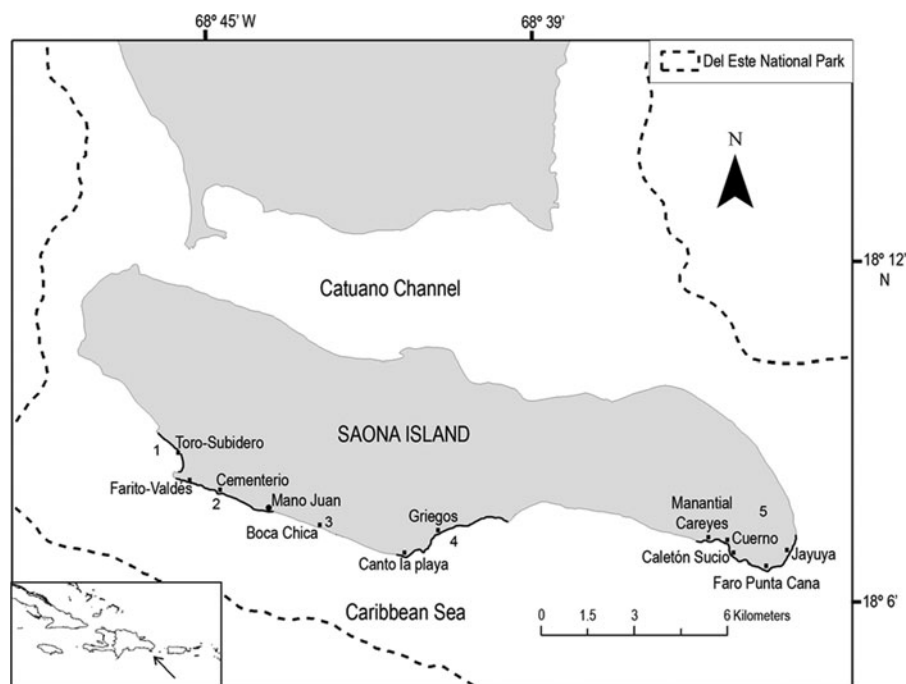


Fig. 1. Hawksbill turtle nesting areas ($N = 5$) and beaches surveyed ($N = 12$) in Saona Island in Del Este National Park, Dominican Republic. Inserted in the map is shown the location of the study area within the Caribbean Sea.

Table 1. Number of nests and distribution of hawksbill turtle nesting density per beach in Saona Island, during 2007–2010. BL, beach length (km); MANR, mean annual nests rate (nests.year^{s-1}); ND, nesting density (nests. year^{s-1}.km^{s-1}).

Area	Beach	BL (km)	N	MANR	ND
Toro	Toro-Subidero	1.5	39	9.0	6.0
Mano Juan	Farito-Vaidés	0.7	65	16.2	23.1
	Cementerio	0.29	52	13.0	44.8
	Mano Juan	2.0	18	4.5	2.2
Boca Chica	Boca Chica	0.01	23	5.7	438.4
Canto Playa	Canto Playa	1.2	66	16.5	13.7
	Griegos	3.1	11	2.7	0.8
F. Punta Cana	M. Careyes	0.8	6	1.5	1.8
	Cuerno	1.5	22	5.5	3.7
	Caletón Sucio	0.5	20	5.0	10.0
	F. Punta Cana	2.1	68	17.0	8.1
	Jayuya	1.2	10	2.5	2.1

the nesting site (see below). For each nest we recorded its GPS location, and position on the beach (open sand, vegetation border and within vegetation). We measured minimum distances from the nest to the high tide line. We classified nests as intact (eggs in nest chamber), or predated (no eggs in nest chamber, presence of probing sticks, eggshells and human footprints littering the nesting site). Owing to high levels of human egg take, the majority of clutches detected (N = 163) were removed for artificial incubation. In order to investigate the potential effects of artificial incubation on hatching and emergence success we studied 49 clutches incubated *in situ*, using them as controls. To reduce predation, all nests left *in situ* were camouflaged by erasing turtle tracks and other signs of nesting activity.

Clutches moved for artificial incubation were carefully excavated by hand, and the eggs were relocated into polyethylene exterior boxes with polyurethane foam filling. Two to three centimetres of beach sand was put at the bottom and sides of the box to prevent contact of eggs with walls. We placed a TinyTag temperature logger (Gemini Data Loggers UK Ltd., Model TGP-4017; accuracy $\pm 0.3^{\circ}\text{C}$) inside a subsample of 22 artificially incubated clutches. Loggers were programmed to record temperatures at sampling intervals of 1 hour throughout the incubation duration. Extra care was taken when moving clutches, limiting shake and vibrations to avoid dislodging the embryo (Chan, 1989; Almeida & Mendes, 2007). Each box was labelled with a code indicating beach name, the laying date and number of eggs incubated. Boxes were placed in a facility located about 50 m from the beach of Mano Juan village. This facility (4 × 3 m (length × width)) had a sand-beach floor, walls made of wire mesh and corrugated metal panels, and roof made from palm leaves to protect boxes against rain and flooding. The boxes were checked daily throughout the incubation duration and lids opened for two to three hours a day to allow air to circulate in the otherwise air-tight box. Hatchlings were released at sunset one day after they emerged when they enter into frenzy.

To detect effects on hatchling fitness that might be due to artificial incubation, we compared the size and weight of hatchlings produced in boxes with those of hatchlings from other nesting rookeries in the Caribbean (e.g. Mona island, Puerto Rico: van Dam & Diez, 1998; Cuba: Moncada *et al.*, 1999; British Virgin Islands: Hillis & Phillips, 1996). Random samples of 20 hatchlings each from 24 artificially

incubated clutches in 2008 and 8 artificially incubated clutches in 2009 were measured (straight carapace length (SCL)) to the nearest 0.1 cm with a calliper, and weighed to the nearest 0.1 g with an electronic scale.

Artificially incubated and *in situ* clutches were studied, and clutch size, hatching and emergence success were considered according to definitions in Miller (1999). In this study, it could not be known in advance whether the clutches we collected for artificial incubation were a random subset of all the clutches on the beach. A way to shed light on this question could be to check whether clutch size differed between artificially incubated and *in situ* clutches (note that, in the latter, clutch size could only be determined after emergence of hatchlings). A two-way analysis of variance (ANOVA) revealed that the mean number of eggs per clutch did not differ with incubation type ($F_{(1,157)} = 0.85$, $P = 0.357$) or among years ($F_{(3,157)} = 2.46$, $P = 0.06$).

We tested whether incubation type affected hatching success or emergence success. Since data were gathered in 4 years, we used a full factorial two-way ANOVA, with ‘incubation type’ (*in situ*, artificial) and ‘year’ as fixed and random factors, respectively. Before statistical testing, data about hatching and emergence success were arcsin-transformed to achieve normality and homoscedasticity (Sokal & Rohlf, 1995).

For each clutch, incubation duration was defined as the number of days between egg-laying and the first emergence recorded. We used temperature data to provide an estimation of sex-ratio produced in the artificially incubated clutches. Since pivotal temperature has not been determined for hawksbill turtle in Saona, we used the published curve relating incubation temperature and hatchling sex-ratio derived from laboratory incubated eggs from the closest hawksbill nesting area at Mona Island, Puerto Rico (Mrosovsky *et al.*, 2009). We read off the means of temperature recorded in the thermosensitive period of the 22 clutches on the Mona laboratory curve to estimate female proportions. Examples of the use of this method and its validation are given in Wibbels (2003) and Öz *et al.* (2004).

RESULTS

Nesting density and nest site selection

Hawksbill turtles laid a mean of 100 nests.year^{s-1} (+/- standard deviation (SD) 8.4; range 93 to 111) on Saona Island. The highest mean annual nesting rate occurred at Mano Juan area (33.7 nests.year^{s-1}) followed by Faro Punta Cana area (31.5 nests.year^{s-1}), Canto de la Playa area (19.2 nests.year^{s-1}) and Del Toro area (9.0 nest.year^{s-1}). The mean nesting linear density over the 15 km of available nesting habitat was 6.6 nests.year^{s-1}.km^{s-1}. Apart from Boca Chica, an isolated small beach surrounded of rocky areas, with an average of 5.7 nests.year^{s-1}, the highest nesting density reported was on Mano Juan area (11.3 nests.year^{s-1}.km^{s-1}), followed by Del Toro area (6 nests.year^{s-1}.km^{s-1}), Faro Punta Cana (5.2 nests.year^{s-1}.km^{s-1}) and Canto de la Playa (4.5 nests.year^{s-1}.km^{s-1}) (see Table 1). We did not find significant correlation between beach width and number of clutches laid ($r_s = 0.451$, $P = 0.141$, $N = 12$).

Saona hawksbills laid their eggs mainly in zones with at least some vegetation (within vegetation: 26.5%, $N = 75$;

vegetation border: 56.0%, $N = 158$; open sand: 17.4%, $N = 49$). Overall, the mean distance from the nest to the high tide line was 8.9 m ($SD = 5.3$; range: 0.5–35 m). The beach with highest mean distance (16.7 m; $SD = 7.0$; range: 8–30) was Canto de la Playa beach, in Canto de la Playa area; and the beach with lowest mean distance (5.7 m; $SD = 3.2$; range: 2–13) was Cementerio beach, located in the Mano Juan area (Figure 1).

Predation levels and fate of clutches

In the four-year period we recorded a total of 400 hawksbill clutches in the 5 sampling areas. Considering the extensive experience detecting hawksbill tracks by the team and the low levels of nesting activity, we believe that weekly surveys allowed us to record close to 100% of clutches laid.

The majority of recorded clutches were artificially incubated ($N = 163$), while 146 clutches had already been predated by humans when found and 91 were left *in situ* (Figure 2). Humans took an additional 7 of these 91 clutches left *in situ*, and other 15 clutches of them were affected by tropical storms. We could not find (likely due to erosion and wash-out) another 20 of the 91 clutches left *in situ*. These events left a total of 49 clutches incubated *in situ* for the study.

Hence, in total we include in the study 365 clutches of three different fates: (i) predated by humans ($N = 153$); (ii) incubated artificially ($N = 163$); and (iii) incubated *in situ* ($N = 49$). However, for the estimations of hatching and emergence success we only considered clutches that were studied by the authors ($N = 119$) and ($N = 46$) artificially incubated clutches and *in situ* clutches, respectively. Figure 3 shows the annual variation on the percentages of these categories. All the clutches that were not artificially incubated or camouflaged *in situ* were found predated by humans in all beaches of the five areas of study. When humans predated a clutch, 100% of eggs were always taken. No evidence of natural predation (i.e. by crabs, ants, or feral pigs) on eggs was observed during the study period.

Hatching success and emergence success

Hatching and emergence success of 46 *in situ* incubated clutches and 119 artificially incubated clutches are shown in Table 2.

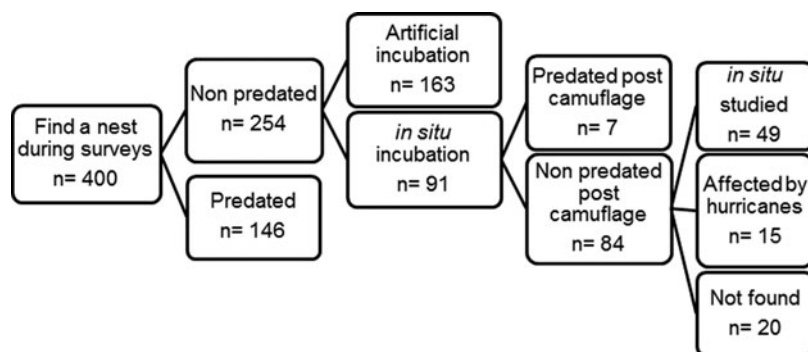


Fig. 2. Clutch fate: number of clutches laid and their fate in Saona Island during the period 2007–2010. N , total number of clutches; predated, number of clutches predated by humans; artificial incubation, number of clutches removed for their incubation in boxes; *in situ* incubation, number of clutches camouflaged and left incubating on the beach; predated post-camouflage, number of clutches predated by humans after we camouflaged it; *in situ* studied, clutches found and studied after being camouflaged; affected by hurricanes, number of clutches incubating on beach when a hurricane made landfall in the island; not found, number of camouflaged clutches we could not find again due to beach dynamics.

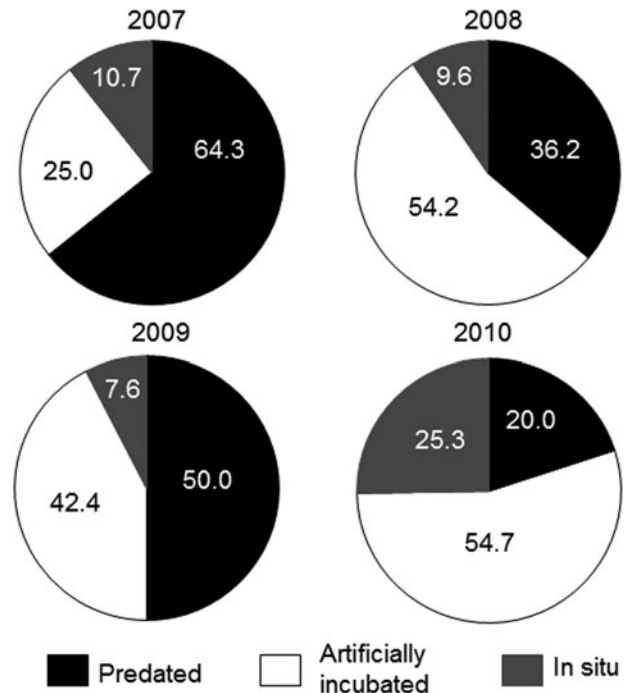


Fig. 3. Percentages of clutches that were incubated artificially, clutches that were poached and clutches that hatched successfully *in situ* from the total of studied clutches every year ($N = 84$; $N = 94$; $N = 92$ and $N = 95$) respectively.

We did not detect significant effects of artificial incubation in hatching success between years (two-way ANOVA: $F_{(3,157)} = 1.45$, $P = 0.383$), incubation type ($F_{(1,157)} = 0.7$, $P = 0.45$); or their interaction ($F_{(3,157)} = 0.52$, $P = 0.669$). Likewise, there was no significant difference in emergence success between years (two-way ANOVA: $F_{(3,157)} = 1.1$, $P = 0.469$), incubation type ($F_{(1,157)} = 1.28$, $P = 0.327$); or their interaction ($F_{(3,157)} = 0.68$, $P = 0.563$) compared to *in situ* incubation.

In total, 12,340 hatchlings were produced under artificial conditions and released to the sea (1731 in 2007, 4522 in 2008, 2664 in 2009 and 3423 in 2010). Mean carapace length and weight of hatchlings was 3.8 ± 0.1 cm (range: 3.2–4.2) and 14.8 ± 1.2 g (range: 10.5–18.7) in 2008 ($N = 480$) and 3.8 ± 0.2 cm (range: 3.0–4.0) and 15.1 ± 1.1 g (range: 12.6–18.2) in 2009 ($N = 160$).

Table 2. Number of yolked eggs (YE), hatching success (HS), emergence success (ES) and incubation duration (ID) per clutch of hawksbill turtles reared under natural (*in situ*) and artificial conditions in Saona Island during the four years of study. N, number of clutches.

Year	N	YE	HS			ES			N	ID		
			Range	Mean	SD	Range	Mean	SD		Range	Mean	SD
<i>In situ</i>												
2007	9	1092	37.0–92.6	72.3	16.6	35.2–92.6	71.1	17.6	4	57–64	60.6	3.4
2008	9	1392	5.1–96.5	73.3	30.9	5.1–96.5	72.1	30.3	4	68–90	80.7	9.3
2009	7	929	52.8–91.4	78.3	12.8	34.9–91.4	72.0	21.0	0	—	—	—
2010	21	3034	7.1–98.3	71.8	25.5	7.1–98.3	67.0	25.7	16	50–79	60.9	8.0
Total	46	6447	5.1–98.3	73.2	23.1	5.1–98.3	69.5	24.0	24	50–90	64.2	10.6
Artificial												
2007	20	2513	28.9–99.2	72.3	20.3	28.9–99.2	68.9	20.2	14	52–66	59.8	3.7
2008	41	5667	44.5–98.5	81.8	13.9	32.1–98.5	79.8	14.7	25	53–85	62.6	9.5
2009	25	3501	40.4–97.6	77.5	13.3	39.4–97.6	76.1	13.9	21	56–71	59.4	4.1
2010	33	4588	27.6–100	76.7	20.6	27.6–100	74.6	20.4	24	53–85	62.3	8.4
Total	119	16269	27.6–100	77.9	17.1	27.6–100	75.5	17.6	84	52–85	61.3	7.3

Incubation temperature and incubation duration

Since beaches were not daily patrolled, recording the exact laying date was not possible in all cases. However, we were able to determine incubation duration for 84 out of the 119 artificially incubated clutches and 24 out of 46 *in situ* incubated clutches studied (Table 2). Temperatures in artificially incubated clutches ranged from 22.2 to 36.4°C, with mean values ranging from 26.8 to 30.2°C (N = 22). During the thermosensitive period temperatures recorded ranged from 22.2 to 33.8°C, with mean values ranging from 25.7 to 29.8°C. Incubation duration was strongly correlated with mean temperature during the thermosensitive period ($F = 70.7$, $P < 0.001$, $df = 1$; Figure 4).

In 21 of the 22 artificially incubated clutches mean temperature during the thermosensitive period was lower than the pivotal temperature derived from laboratory studies (29.6°C: Mrosovsky *et al.*, 2009) (Figure 5), suggesting a male bias in artificially incubated clutches. The highest estimated female percentages (42% and 73%) were recorded in two clutches laid during the first half of August, and the estimated percentage of females was 0% in all artificially incubated clutches laid after the second half of August (Figure 5). Accordingly, we found a great intra-seasonal

variation in incubation duration in artificially incubated clutches every year, with longer incubation duration during colder months (October–December).

DISCUSSION

The present study provides, for the first time, detailed information about the reproductive biology of the remaining, threatened hawksbill nesting population of Saona Island, as well as the results of the conservation programme that we carried out to mitigate egg take.

Nesting density and nest site selection

Hawksbill females on Saona mainly nest in vegetated areas, this has also been noted in other studies of the species in other Caribbean rookeries (Pérez-Castañeda *et al.*, 2007; Kamel & Delcroix, 2009). Other authors have proposed that this could be because areas with vegetation might be less compact making hatchling emergence easier; also, the shade provided by vegetation might help keep temperature constant (Horrocks & Scott, 1991; Kamel & Mrosovsky, 2006). Moreover, the two beaches with the highest nest density in

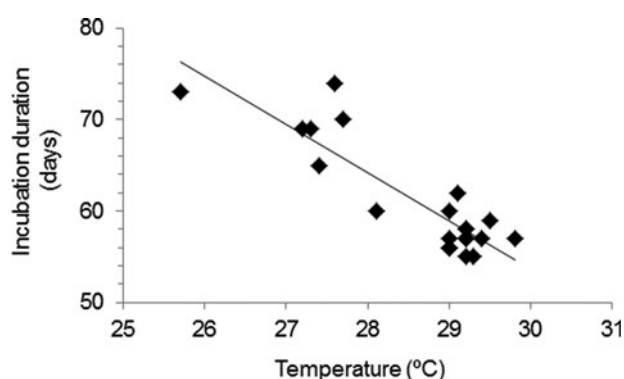


Fig. 4. Relationship between incubation duration and mean temperature during the thermosensitive period in the 22 artificially incubated clutches controlled during the study (Equation: $ID = 211 - 5.26$ mean temperature during the thermosensitive period, r -square = 0.78).

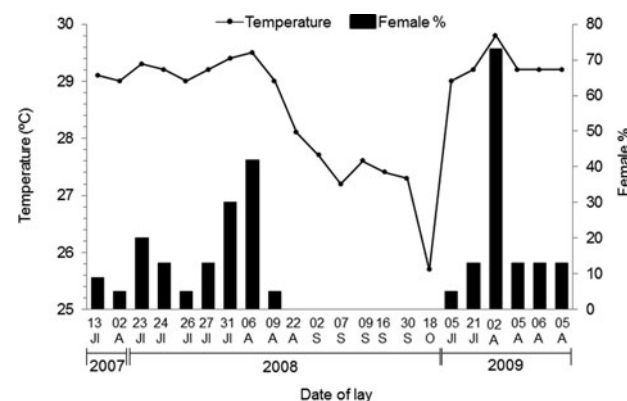


Fig. 5. Laying date, mean incubation temperature during thermosensitive period (dots) and estimated female proportion (bars) of artificially incubated clutches (N = 22) in which temperature was monitored during the study period.

Saona (Boca Chica and Cementerio) have certain characteristics which make them suitable for nesting: an accessible vegetation area, a reef in front of the beach which protects them against surf and makes beach access easier, and fine grain sand that allows turtles digging their nests easily.

Predation levels and fate of clutches

Our results show the need to continue patrol and conservation work in Saona, since most *in situ* clutches not promptly camouflaged or relocated for artificial incubation, were predated by humans. In fact, in 2009, as a result of the decrease in surveys at the Faro Punta Cana area, 28 out of the 30 clutches laid were taken. In other words, the current level of egg take is unsustainable for the long term preservation of this nesting population.

Nesting beaches in Saona are scattered along the coastline and some of them can only be reached by boat, considerably raising monitoring costs. Also, the funding available did not allow the employment of personnel to make daily patrols over all the nesting beaches or nest surveillance. This left us with two options, i.e. relocating or camouflaging all clutches that were non-predated at the time of finding. Camouflage was considered to be an insufficient conservation measure since substantial amounts of camouflaged clutches were eventually predated by humans. The same situation has been described in other studies with similar conditions (Sato & Madriasau, 1991; Lagueux *et al.*, 2003). On the other hand, tropical storms that hit the island affected camouflaged clutches (4 affected by Noel in 2007, 7 by Hanna in 2008 and 4 by Earl and Fiona in 2010) making excavation and study impossible. It has been reported that excessive rainfall and floods can greatly reduce egg viability, thus reducing clutch survivorship (Martin, 1996; Kamel & Delcroix, 2009). Obviously, these threats are natural and unavoidable, but they add significant losses to the already depleted population. For all these reasons, and due to shortage of human and economic resources, we decided to incubate clutches in polyurethane hermetic boxes with constant monitoring and protection, as an alternative option to ensure hatchling recruitment.

Effects of artificial incubation

Physical handling of eggs can reduce hatching and emergence success in relocated clutches (Eckert & Eckert, 1990; Pintus *et al.*, 2009). However, in the present study, we found no significant differences in hatching and emergence success between *in situ* and artificially incubated clutches, indicating that handling was correctly carried out and that incubation conditions in boxes was suitable for hawksbill embryos development, as reported also for other species (e.g. Whitmore & Dutton, 1985).

Concerning hatchling fitness, our results suggest that artificially incubated hatchlings from Saona are smaller than hatchlings from other Caribbean natural nesting rookeries, Mona Island (SCL = 4.0 cm: van Dam & Diez, 1998), Cuba (SCL = 4.0 cm: Moncada *et al.*, 1999) and the Virgin Islands (SCL = 4.1 cm: Hillis & Phillips, 1996). However, the weight of Saona hatchlings seems to be similar to those from other Caribbean rookeries (14.8 g, Mona Island and 14.7 g, Virgin Islands).

Nonetheless, the use of boxes for incubation entails the risk of bias in the sex-ratio in favour of males (Dutton *et al.*, 1985; Whitmore & Dutton, 1985). Mean temperatures of 21 artificially incubated clutches during the thermosensitive period were below the pivotal temperature reference value from Mona Island (29.6°C), suggesting that those temperatures are likely to have resulted in a male-skewed clutch sex-ratio. Moreover, since we found a clear relationship between temperature and incubation duration recorded in Saona, the long incubation durations recorded are also indicative of a male-skewed sex-ratio. The low percentages of female hatchling production inferred from our clutch temperature data, calls for urgent changes in the conservation strategy adopted in Saona, since a lengthy lack of female production would prevent population growth.

Forward strategies

Due to the rampant egg take, *in situ* incubation on the beaches is not an acceptable management practice for a long term conservation of this population. Hence, the primary goals in the near future would be: (1) to increase female production in boxes; and (2) to start a programme of relocation of clutches to safer areas (Pritchard, 1995; DeGregorio & Southwood Williard, 2011) while progressively reducing incubation in boxes. For the first goal, boxes are being exposed to direct sunlight during a few hours a day to raise incubation temperatures and increase the proportion of females produced (see Chantrapornsy, 1992). For the second goal, financial resources must be invested to strengthen the protection of a beach section near Mano Juan village as a safe area for clutch relocation.

Further research on beach temperature patterns is needed to increase understanding of the natural sex-ratio at Saona in order to improve conservation measures.

Together with the artificial incubation programme we carried out additional measures such as hiring people from the local community to work as field technicians, organizing workshops and meetings with authorities, as well as environmental education and awareness programmes. These measures have apparently positively influenced local attitudes and perceptions toward marine turtles in Saona (White *et al.*, 2011) which we strongly believe will favour a future programme of clutch relocation on the beach.

ACKNOWLEDGEMENTS

The present study is included as part of a conservation programme funded by the Spanish International Cooperation Agency (AEI, projects: A/2991/05 and A/5641/06), the Spanish Ministry of Education and Sciences (CGL2006-02936-BOS), the General Foundation of the University of Valencia, and the European Union (Marie Curie grants, FP6 & 7). We specially thank the support of the Dominican non-governmental organization Grupo Jaragua and of The Nature Conservancy (TNC). The project counts on the support of the Dominican Environmental authorities (Office of Protected Areas and Biodiversity of the Environmental Ministry) and the rangers of the Del Este National Park. We are very grateful to fieldwork assistants especially to Pelagio Paulino 'Negro' and Bernardo Paulino 'Mico' for their help during fieldwork in Saona and their hard work in the conservation of Saona marine turtles. We

extend our thanks to the Dominican and international students, volunteers and local villagers who helped in different tasks of the project and who lent their help and friendship during the work in the Dominican Republic. J. Azar, J.A. Raga and J. Tomás are supported by project Prometeo/2011/40 of Conselleria de Educacio (Generalitat Valenciana) and project CGL2011-30413 of the Spanish Ministry of Sciences and Innovation. We thank an anonymous referee for helpful comments and suggestions that improved the manuscript.

REFERENCES

- Almeida A.P. and Mendes S.L. (2007) An analysis of the role of local fishermen in the conservation of the loggerhead turtle (*Caretta caretta*) in Pontal do Ipiranga, Linhares, ES, Brazil. *Biological Conservation* 134, 106–112.
- Beggs J.A., Horrocks J.A. and Krueger B.H. (2007) Increase in hawksbill sea turtle *Eretmochelys imbricata* nesting in Barbados, West Indies. *Endangered Species Research* 3, 159–168.
- Carrillo E., Webb G. and Manolis C. (1999) Hawksbill turtles (*Eretmochelys imbricata*) in Cuba: an assessment of the historical harvest and its impacts. *Chelonian Conservation and Biology* 3, 264–280.
- Chan E.H. (1989) White spot development, incubation and hatching success of leatherback turtle (*Dermochelys coriacea*) eggs from Rantau Abang, Malaysia. *Copeia* 1, 42–47.
- Chantrapornsy S. (1992) Artificial incubation and embryonic development of olive ridley turtle eggs. *Phuket Marine Biological Center Research Bulletin* 57, 41–50.
- DeGregorio B.A. and Southwood Williard A. (2011) Incubation temperatures and metabolic heating of relocated and *in situ* loggerhead sea turtle (*Caretta caretta*) nests at a northern rookery. *Chelonian Conservation and Biology* 10, 54–61.
- Dutton P.H., Whitmore C.P. and Mrosovsky N. (1985) Masculinisation of leatherback turtle *Dermochelys coriacea* hatchlings from eggs incubated in Styrofoam boxes. *Biological Conservation* 31, 249–264.
- Dutton D.L., Dutton P.H., Chaloupka M. and Boulon R.H. (2005) Increase of a Caribbean leatherback turtle *Dermochelys coriacea* nesting population linked to long-term nest protection. *Biological Conservation* 126, 186–194.
- Eckert K.L. (1999) Designing a conservation program. In Eckert K.L., Bjorndal K.A., Abreu-Grobois F.A. and Donnelly M. (eds) *Research and management techniques for the conservation of sea turtles*. IUCN/SSC Marine Turtle Specialist Group Publication No. 4, pp. 6–8.
- Eckert K.L. and Eckert S.A. (1990) Embryo mortality and hatch success in *in situ* and translocated leatherback sea turtle *Dermochelys coriacea* eggs. *Biological Conservation* 53, 37–46.
- Fleming E.H. (2001) *Swimming against the tide: recent surveys of exploitation, trade, and management of marine turtles in the northern Caribbean*. Washington, DC: TRAFFIC North America.
- García A., Ceballos G. and Adaya R. (2003) Intensive beach management as an improved sea turtle conservation strategy in Mexico. *Biological Conservation* 111, 253–261.
- Godfrey M.H. and Mrosovsky N. (1999) Estimating hatchling sex ratios. In Eckert K.L., Bjorndal K.A., Abreu-Grobois F.A. and Donnelly M. (eds) *Research and management techniques for the conservation of sea turtles*. IUCN/SSC Marine Turtle Specialist Group Publication No. 4, pp. 6–8.
- Hawkes L.A., Tomás J., Revuelta O., León Y.M., Blumenthal J.M., Broderick A.C., Fish M., Raga J.A., Witt M.J. and Godley B.J. (2012) Migratory patterns in hawksbill turtles described by satellite tracking. *Marine Ecology Progress Series* 461, 223–232.
- Hillis Z.M. and Phillips B. (1996) The year of expanding, standardizing and planning for the future of hawksbill turtle research at Buck Island reef NM. In *Proceedings of the 15th Annual Symposium on Sea Turtle Biology and Conservation*, 20–25 February 1995. Hilton Head, South Carolina, USA. [Abstract.]
- Horrocks J.A. and Scott N. McA. (1991) Nest site location and nest success in the hawksbill turtle *Eretmochelys imbricata* in Barbados, West Indies. *Marine Ecology Progress Series* 69, 1–8.
- IUCN (2011) *Red list of threatened species*. Available at URL: <http://www.iucnredlist.org> (accessed 19 November 2011).
- Kamel S.J. and Mrosovsky N. (2006) Deforestation: risk of sex ratio distortion in hawksbill sea turtles. *Ecological Applications* 16, 923–931.
- Kamel S.J. and Delcroix E. (2009) Nesting ecology of the hawksbill turtle, *Eretmochelys imbricata*, in Guadeloupe, French West Indies from 2000–07. *Journal of Herpetology* 43, 367–376.
- Kornarakis E., Matossiana D.A., Mazarisa A.D., Matsinos Y.G. and Margaritoulis D. (2006) Effectiveness of different conservation measures for loggerhead sea turtle (*Caretta caretta*) nests at Zakynthos Island, Greece. *Biological Conservation* 130, 324–330.
- Lagueux C.J. and Campbell C.L. (2005) Marine turtle nesting and conservation needs on the south-east coast of Nicaragua. *Oryx* 39, 398–405.
- Lagueux C.J., Campbell C.L. and McCoy W.A. (2003) Nesting and conservation of the hawksbill turtle, *Eretmochelys imbricata*, in the Pearl Cays, Nicaragua. *Chelonian Conservation and Biology* 4, 588–602.
- Liles M.J., Jandres M.V., López W.A., Mariona G.I., Hasbún C.R. and Seminoff J.A. (2011) Hawksbill turtles *Eretmochelys imbricata* in El Salvador: nesting distribution and mortality at the largest remaining nesting aggregation in the eastern Pacific Ocean. *Endangered Species Research* 14, 23–30.
- Marcovaldi M.A., Lopez G., Soares L.S., Santos A., Bellini C. and Barata P. (2007) Fifteen years of hawksbill sea turtle (*Eretmochelys imbricata*) nesting in northern Brazil. *Chelonian Conservation and Biology* 6, 223–228.
- Martin R.E. (1996) Storm impacts on loggerhead turtle reproductive success. *Marine Turtle Newsletter* 73, 10–12.
- McClenachan L., Jackson J.B.C. and Newman M.J.H. (2006) Conservation implications of historic sea turtle nesting beach loss. *Frontiers in Ecology and the Environment* 4, 290–296.
- Meylan A.B. (1999) Status of the hawksbill turtle, *Eretmochelys imbricata*, in the Caribbean region. *Chelonian Conservation and Biology* 3, 177–184.
- Meylan A.B. (2002) *Global Status Review of the hawksbill turtle (Eretmochelys imbricata), with an emphasis on the wider Caribbean. An Addendum for the Second CITES wider Caribbean hawksbill turtle dialogue meeting, Cayman Islands (U.K.) 21–23 May 2002*. In Marine Turtle Specialist Group 2007 IUCN red list status assessment.
- Miller J.D. (1999) Determining clutch size and hatch success. In Eckert K.L., Bjorndal K.A., Abreu-Grobois F.A. and Donnelly M. (eds) *Research and management techniques for the conservation of sea turtles*. IUCN/SSC Marine Turtle Specialist Group Publication No. 4, pp. 6–8.
- Moncada F., Carrillo E., Saenz A. and Nodarse G. (1999) Reproduction and nesting of the hawksbill turtle, *Eretmochelys imbricata*, in the Cuban Archipelago. *Chelonian Conservation and Biology* 3, 257–263.
- Morreale S.J., Ruiz G.J., Spotila J.R. and Standora E.A. (1982) Temperature-dependent sex determination: current practices threaten conservation of sea turtles. *Science* 216, 1245–1247.
- Mortimer J.A. (1999) Reducing threats to eggs and hatchlings: hatcheries. In Eckert K.L., Bjorndal K.A., Abreu-Grobois F.A. and

- Donnelly M. (eds) *Research and management techniques for the conservation of sea turtles*. IUCN/SSC Marine Turtle Specialist Group Publication No. 4, pp. 6–8.
- Mrosofsky N. (1994) Sex ratios of sea turtles. *Journal of Experimental Zoology* 270, 16–27.
- Mrosofsky N. and Pieau C. (1991) Transitional range of temperature, pivotal temperatures and thermosensitive stages for sex determination in reptiles. *Amphibia-Reptilia* 12, 169–179.
- Mrosofsky N., Kamel S.J., Diez C.E. and van Dam R.P. (2009) Methods of estimating natural sex ratios of sea turtles from incubation temperatures and laboratory data. *Endangered Species Research* 8, 147–155.
- Öz M., Erdogan A., Kaska Y., Düsen S., Aslan A., Sert H., Yavuz M. and Tunc M.R. (2004) Nest temperatures and sex-ratio estimates of loggerhead turtles at Patara beach on the south western coast of Turkey. *Canadian Journal of Zoology* 82, 94–101.
- Pérez-Castañeda R., Salum-Fares A. and Defeo O. (2007) Reproductive patterns of the hawksbill turtle *Eretmochelys imbricata* in sandy beaches of the Yucatan Peninsula. *Journal of the Marine Biological Association of the United Kingdom* 87, 815–824.
- Pintus K.J., Godley B.J., McGowan A. and Broderick A.C. (2009) Impact of clutch relocation on green turtle offspring. *Journal of Wildlife Management* 73, 1151–1157.
- Pritchard P. (1995) Recovered sea turtle populations and U.S. recovery team efforts. In Bjorndal K. (ed.) *Biology and conservation of sea turtles*. Washington, DC: Smithsonian Institution Press, pp. 503–511.
- Revuelta O., León Y.M., Feliz P., Godley B.J., Raga J.A. and Tomás J. (2012) Protected areas host important remnants of marine turtle nesting stocks in the Dominican Republic. *Oryx* 46, 348–358.
- Richardson J.I., Hall D.B., Mason P.A., Andrews K.M., Bjorkland R., Cai Y. and Bell R. (2006) Eighteen years of saturation tagging data reveal a significant increase in nesting hawksbill sea turtles (*Eretmochelys imbricata*) on Long Island, Antigua. *Animal Conservation* 9, 302–307.
- Sarti Martínez L., Barragán A.R., García Muñoz D., García N., Huerta P. and Vargas F. (2007) Conservation and biology of the leatherback turtle in the Mexican Pacific. *Chelonian Conservation and Biology* 6, 70–78.
- Sato F. and Madriasau B.B. (1991) Preliminary report on natural reproduction of hawksbill sea turtles in Palau. *Marine Turtle Newsletter* 55, 12–14.
- Sokal R.R. and Rohlf F.J. (1995) *Biometry: the principles and practice of statistics in biological research*. 3rd edition. New York: W.H. Freeman and Co.
- van Dam R.P. and Diez C.E. (1998) Caribbean hawksbill turtle morphometrics. *Bulletin of Marine Science* 62, 145–155.
- Wallace B.P., Dimatteo A.D., Hurley B.J., Finkbeiner E.M., Bolten A.B., Chaloupka M.Y., Hutchinson B.J., Abreu-Grobois F.A., Amorcho D., Bjorndal K.A., Bourjea J., Bowen B.W., Briseño Dueñas R., Casale P., Choudhury B.C., Costa A., Dutton P.H., Fallabrino A., Girard A., Girondot M., Godfrey M.H., Hamann M., López-Mendilaharsu M., Marcovaldi M.A., Mortimer J.A., Musick J.A., Nel R., Pilcher N.J., Seminoff J.A., Troëng S., Whiterington B. and Mast R.B. (2010) Regional management units for marine turtles: framework for prioritizing conservation and research across multiple scales. *PloS One* 5, 1–11. doi:10.1371/journal.pone.0015465.
- White T.H. Jr, Jhonson Camacho A., Bloom T., Lancho Diéguez P. and Sellares R. (2011) Human attitudes and perceptions regarding endangered species conservation: a case study of Saona Island, Dominican Republic. *Latin American Journal of Conservation* 2, 18–29.
- Whitmore C.P. and Dutton P.H. (1985) Infertility, embryonic mortality and nest-site selection in leatherback and green sea turtles in Suriname. *Biological Conservation* 34, 251–272.
- Wibbels T. (2003) Critical approaches to sex determination in sea turtles. In Lutz P.L., Musick J.A. and Wyneken J. (eds) *The biology of sea turtles. Volume II*. Boca Raton, FL: CRC Press, pp. 103–134.
- and
- Yntema C.L. and Mrosofsky N. (1982) Critical periods and pivotal temperatures for sexual differentiation in loggerhead turtles. *Canadian Journal of Zoology* 60, 1012–1016.

Correspondence should be addressed to:

J. Tomás
Cavanilles Institute of Biodiversity and Evolutionary Biology
University of Valencia, Valencia, Spain
email: jesus.tomas@uv.es