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Nesting ecology of East Pacific green turtles at Playa Cabuyal, Gulf of Papagayo, Costa Rica

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Abstract

East Pacific green turtles (*Chelonia mydas*), often referred to as black turtles, are smaller and exhibit a lower reproductive output than other populations of green turtles in the Atlantic, Indian and Western Pacific Oceans. Knowledge of nesting ecology of East Pacific green turtles is limited to general descriptions. We conducted an exhaustive analysis of the nesting ecology of East Pacific green turtles at Playa Cabuyal, North Pacific Costa Rica. Compared with other populations of green turtles, East Pacific turtles exhibited smaller clutch sizes (mean ± SD: 76.9 ± 18.2 eggs per clutch), but the number of clutches (estimated clutch frequency (ECF): 4.3 ± 2.3 clutches) fell within the upper limit reported for green turtles. Clutch size and seasonal reproductive output (409 ± 135 eggs per female), but not ECF, increased with female size. The observed internesting period (OIP) between consecutive oviposition events (mean ± SD: 15.4 ± 2.9 days) increased as the season progressed and was approximately 2 days longer than the mean OIP reported for the species. Most clutches were laid in the upper vegetated part of beach (zone 3, 75%) and within this zone, tended to be located underneath trees (79%). Hatching success of clutches laid underneath trees was significantly higher (0.89 ± 0.17) than that of clutches laid in the exposed areas of zone 3 (0.75 ± 0.33). Mean duration of the nesting process (3:14 h) was on average 45 min longer than previously reported for the species. Frequency of false crawls was high (49% of nesting activities), and nesting success was low (54% of nesting attempts). Poaching of eggs, tourism and predation by dogs were important threats to this population. Conservation actions were being successfully implemented at the local level due to presence of beach patrollers, but official protection is needed for the preservation of the nesting population into the future.

Introduction

Green turtles (*Chelonia mydas*) have been extensively studied since Archie Carr's pioneering and prolific work begun in the 1950s (Carr & Caldwell 1956; Carr & Hirth 1961; Carr & Carr 1972; Carr 1975). However, despite the extensive scientific information available today on population biology (Bjorndal 1980; Limpus 1993; Troëng & Rankin 2005), nesting ecology (Hirth 1980; Bjorndal & Carr 1989; Broderick & Godley 1996; Godley *et al.* 2001) and migratory and diving behavior (Luschi *et al.* 1998; Hays *et al.* 2000, 2001) of green turtles, very few studies have focused on the Eastern Pacific populations, previously known as black turtles.

Taxonomic classification of black turtles was subject to great controversy for many years (Bowen & Karl 1999; Grady & Quattro 1999; Karl & Bowen 1999; Pritchard 1999; Shrader-Frechette & McCoy 1999), as some scientists considered them a different species than green turtles due to morphological, geographical and reproductive differences (Bocourt 1868; Figueroa & Alvarado 1991; Pritchard 1996). However, genetic studies show that there are minimal differences among populations (Karl & Bowen 1999) and that they are all members of one species.

Populations of leatherback turtles (*Dermochelys coriacea*) in the Eastern Pacific have smaller body sizes and exhibit lower reproductive outputs (mainly due to smaller clutch sizes) than populations in other ocean basins (Wallace & Saba 2009). Although similar differences have been reported for green turtles (reviewed by Hirth 1997), detailed studies on the life history of green turtles in the Eastern Pacific are scarce, and little information is available on their population biology and nesting ecology.

Primary nesting grounds of Eastern Pacific green turtles are found in Colola and Maruata beaches in Michoacán, Mexico (Cliffton *et al.* 1995; Alvarado-Díaz *et al.* 2003) and the Galapagos Islands, Ecuador (Green & Ortiz-Crespo 1982; Green 1984), and secondary nesting grounds are found throughout Central America. In Costa Rica, Cornelius (1976) described some aspects of the nesting behavior of green turtles at Playa Naranjo, Santa Rosa National Park, and suggested (Cornelius 1995) that the nesting season for green turtles in Northwest Costa Rica was long and could extend year round. Also in Costa Rica, green turtles stay in the vicinity of the nesting beaches during the internesting period and perform short distance migrations after nesting (Blanco 2010), which may affect their investment in reproduction.

The Gulf of Papagayo is a marine area of high productivity because of frequent occurrence of upwellings (Bianchi 1991; Jiménez 2001). The waters of the Gulf serve as an important internesting habitat for leatherback turtles (Shillinger *et al.* 2010), foraging grounds for green (Blanco *et al.* 2012a) and hawksbill turtles (*Eretmochelys imbricata*; unpublished information), and the beaches of the Gulf are suitable nesting grounds for green turtles, olive ridleys (*Lepidochelys olivacea*) and leatherback turtles (Cornelius 1976), and are sporadically used by hawksbill turtles.

Playa Cabuyal is an important nesting beach for green turtles in the Gulf of Papagayo but levels of nesting and the nesting ecology of the turtles were unknown. Playa Cabuyal is adjacent to the southern limit of Santa Rosa National Park and has no official protection. Like any other unprotected beaches in Central America, egg poaching has been a common practice for years. Additionally, Cabuyal was a popular destination for national tourism, mainly composed of families that camped on the beach, as the beach was not yet developed. Camping was very common on weekends and during vacation time in the dry season (Christmas, January, Easter and July) until the Ministry of Health forbade it in April 2011.

Here, we conducted an exhaustive analysis of the nesting ecology of green turtles on Playa Cabuyal, Gulf of Papagayo, Northwest Costa Rica, during two full seasons 2011–2012 and 2012–2013 and in the latter part of the 2010–2011 season. We estimated reproductive output, internesting intervals, nesting and hatching success, and described the nesting process for this population. We compared our results with those reported for green turtles in other ocean basins and for other sea turtle species that nest in the area. Finally, we assessed the importance of Cabuyal, as a green turtle nesting site in the Eastern Pacific and discussed the conservation challenges that these turtles may face in the near future.

Study site

Playa Cabuyal (10°40′N, 85°39′W) is located on the Gulf of Papagayo, in Northwest Costa Rica (Fig. 1). The site was 1.4 km long and was a high-energy beach, frequently changing within and between seasons; *e.g.* the northernmost 200 m of the beach were lost to erosion in 2011–2012 after storms in October, and were only redeposited the following season. The north end was rocky with sand patches that were sometimes suitable for nesting. An estuary opened at the south end, associated with a mangrove forest that extended behind most of the beach. There was a little unpaved road behind the beach where vehicles were driven before 2012, which passed through suitable nesting habitat.

Material and Methods

Beach coverage

We divided the beach from North to South into 14 sectors of 100 m and in sub-sectors of 25 m. We distinguished three zones from the water to the vegetation line: zone 1: below high tide line, zone 2: between high tide line and vegetation and zone 3 in the vegetation. For zone 3, we distinguished nests that were laid underneath trees and were in shaded areas, and nests that were laid on low vegetation areas (usually in the grass) and were therefore exposed to the sun.

We partially surveyed season 2010–2011 (15 January 15 2011–29 March 2011) and fully covered the seasons 2011–2012 (1 July 2011–30 April 2012) and 2012–2013

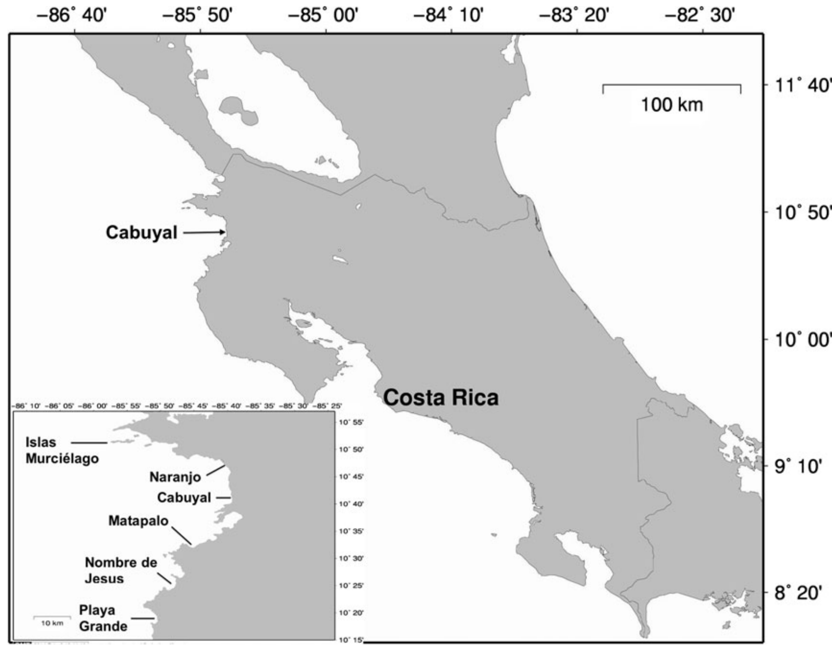

Fig. 1. Map of Playa Cabuyal and other nearby green turtle (*Chelonia mydas*) nesting beaches in North Pacific Costa Rica.

(10 August 2012–10 April 2013). During the peak season (November–March), we patrolled the beach at night between 20:00 and 04:00 h and during the low season (September, October and April) between 21:00 and 03:00 h. At night, we marked and identified all turtles encountered and recorded all nesting events. In the morning, we counted tracks to account for turtles that could have been missed the previous night and verified successful nesting events when possible. We estimated beach coverage as the number of identified turtles from any evening survey divided by the total number of body pits identified from the morning walks.

Nesting turtles

When we encountered a turtle, we recorded the local time for each of the following activities: emerging from the ocean, digging body pit, digging egg chamber, laying eggs, covering the nest and returning to the water. We recorded nesting status for each turtle encountered (or track seen when the turtle was missed) as (i) false crawl if the turtle did not make a body pit and returned to the ocean, (ii) aborted nest if the turtle made a body pit but did not lay eggs, (iii) nest if the turtle laid eggs and (iv) body pit if the turtle was missed but a body pit was found (we could not verify if the turtle had nested or aborted the nest). We estimated nesting success by dividing the number of nests by the sum of nests and aborted nests.

After turtles finished laying eggs, we checked for external and PIT tags and marked the turtles if they had none. We marked turtles with a single PIT (passive integrated transponder) tag and one INCONEL metal tag on the right front flipper after oviposition. The PIT tag is a permanent internal tag that lasted indefinitely and is frequently used in sea turtle research (Dutton & McDonald 1994; Steyermark *et al.* 1996). To identify the turtle in subsequent nestings within the same season or subsequent seasons, we used a hand-held AVID PIT scanner. We used PIT tags for the whole duration of the project and INCONEL tags for external identification only in 2012–2013. After identifying the turtle, we measured her curve carapace length (CCL) and width (CCW) with a flexible measuring tape (±0.05 cm) and checked whether turtles had any distinguishable characteristics such as scars or the presence of epibionts. We counted eggs with a mechanical counter during oviposition or at relocation time if the clutch was moved for protection.

We defined the observed internesting period (OIP) as the number of days between confirmed nesting events. Previous methodology with leatherback turtles (Reina *et al.* 2002) excluded values of OIP that were twice as long or longer than the minimum OIP, because the turtle could have been missed in between observed nesting events. We found a seasonal trend in the OIP of black turtles in Cabuyal, with OIPs being longer at the end of the season. To prevent eliminating good values, we calculated the minimum OIP for each fortnight and excluded values that were twice as long or longer than the minimum OIP for that time period. We estimated clutch frequency (ECF) for each turtle by dividing the number of days between her first and last nests by the average OIP of the season and added one to account for the first nest (Steyermark *et al.* 1996; Reina *et al.* 2002). We defined observed clutch frequency (OCF) as the number of confirmed nests for each turtle. We estimated seasonal reproductive output by multiplying the average number of eggs per clutch by the ECF of each female. We calculated nesting success, OIP, ECF, OCF and seasonal reproductive output for the two full seasons, 2011–2012 and 2012–2013.

Nests

We marked nests at night during or after oviposition and triangulated the location after the turtles left. To triangulate nests, we measured the distance from the nest to the closest beach marker to the north and to the south. We relocated clutches that were in danger of tidal inundation or of being poached. Clutches were relocated to safer areas of the beach immediately after egg laying. In some instances, clutches were relocated in the morning when the nesting event was missed at night but the eggs could be found in the morning.

We excavated nests to determine hatching success 2 days after observed hatchling emergence in 2012–2013, but excavated them the day after emergence in 2011–2012 because of the high risk of nests being excavated by people that year. At excavation, we counted the number of shells and classified unhatched eggs into four developmental categories (Santidrián Tomillo *et al.* 2009). We estimated hatching success using the formula $H = S/(S+U)$, where S was number of hatched eggshells and U is number of unhatched eggs. Hatchlings found alive were released after dark.

We used SPSS statistics v. 20.0 (IBM Corp 2011) to conduct statistical analyses. We used *t*-tests to compare differences between seasons in ECF, OCF, hatching success, clutch size and body sizes, and to compare hatching success of nests that were located in shaded and open areas. We used a chi-square test to analyse whether turtles showed preferences among nesting zones and linear regressions to examine the effect of size on the reproductive output.

Results

Beach coverage was 63%, 87% and 86% in 2010–2011, 2011–2012 and 2012–2013, respectively. Green turtles showed a preference to nest in zone 3 [χ^2 (2, n = 395) = 307.44, $P < 0.001$] over zones 1 and 2. We confirmed 395 nests of which 9, 17 and 75% were dug in zones 1, 2 and 3, respectively. Within zone 3, turtles preferred to nest in locations underneath trees over open grass areas [χ^2 (1, n = 262) = 90.52, $P < 0.001$]. Among clutches laid in zone 3, 79% were laid underneath trees and were shaded or partially shaded and 21% were laid in the low vegetation but in areas exposed to sun (grass).

Nesting females

We marked 181 black turtles on Cabuyal beach, 148 of them during the two full seasons (72 turtles in 2011–2012 and 76 turtles in 2012–2013), and 33 turtles from our surveys that were conducted only at the end of the 2010–2011 season. The peak of the nesting season occurred in December–January in 2011–2012 and approximately 1 month earlier in 2012–2013 (Fig. 2). We determined that 49% and 51% of turtle encounters were false crawls and nesting attempts (aborted and successful), respectively. Nesting success was 54%. The mean duration of the whole nesting process was 3:14 h (range 2:15–4:55 h). The mean (range) duration of emergence, digging body pit, digging egg chamber, egg laying and covering the nest were respectively 0:19 h (0:02–1:10), 0:38 h (0:18–3:13 h), 0:37 h (0:07–1:22 h), 0:19 h (0:02–1:13 h) and 1:19 h (0:17–2:40 h).

The OIP (mean ± SD) was 15.4 ± 2.9 days, and was significantly longer in 2011–2012 (16.1 ± 2.2 days, n = 109) than in 2012–2013 (14.4 ± 2.8 days, n = 118; $P < 0.001$). In both years the OIP also became longer as the season progressed (Fig. 3; 2011–2012: $r^2 = 0.388$, $P < 0.001$; 2012–2013: $r^2 = 0.351$, $P < 0.001$). The ECF and OCF (mean ± SD) were respectively 4.3 ± 2.3 clutches (n = 120) and 3.3 ± 2.0 clutches (n = 120). The most common ECFs were one and six clutches in 2011–2012 and 1, 5 and 6 clutches in 2012–2013 (Fig. 4). There were no significant differences in ECF, OCF, clutch size and size of turtles (CCL and CCW) among seasons (all $P > 0.05$). The CCL was (mean ± SD) 86.2 ± 4.7 cm and CCW was 80.6 ± 4.9 cm (n = 110). Turtles laid on average 76.9 ± 18.2 eggs per clutch (n = 118) and the average seasonal reproductive output was 409 ± 135 eggs

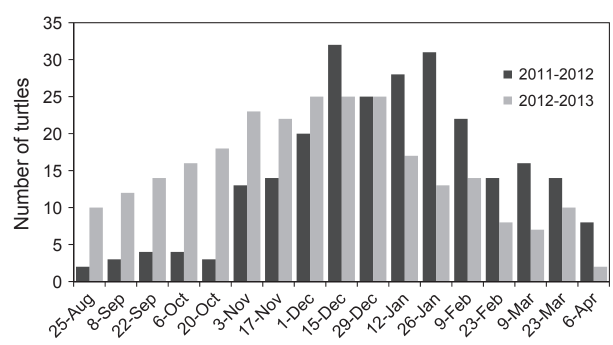

Fig. 2. *Chelonia mydas*. Temporal distribution of nesting at Playa Cabuyal, Northwestern Costa Rica. Number of individual turtles identified per fortnight at Cabuyal in 2011–2012 and 2012–2013.

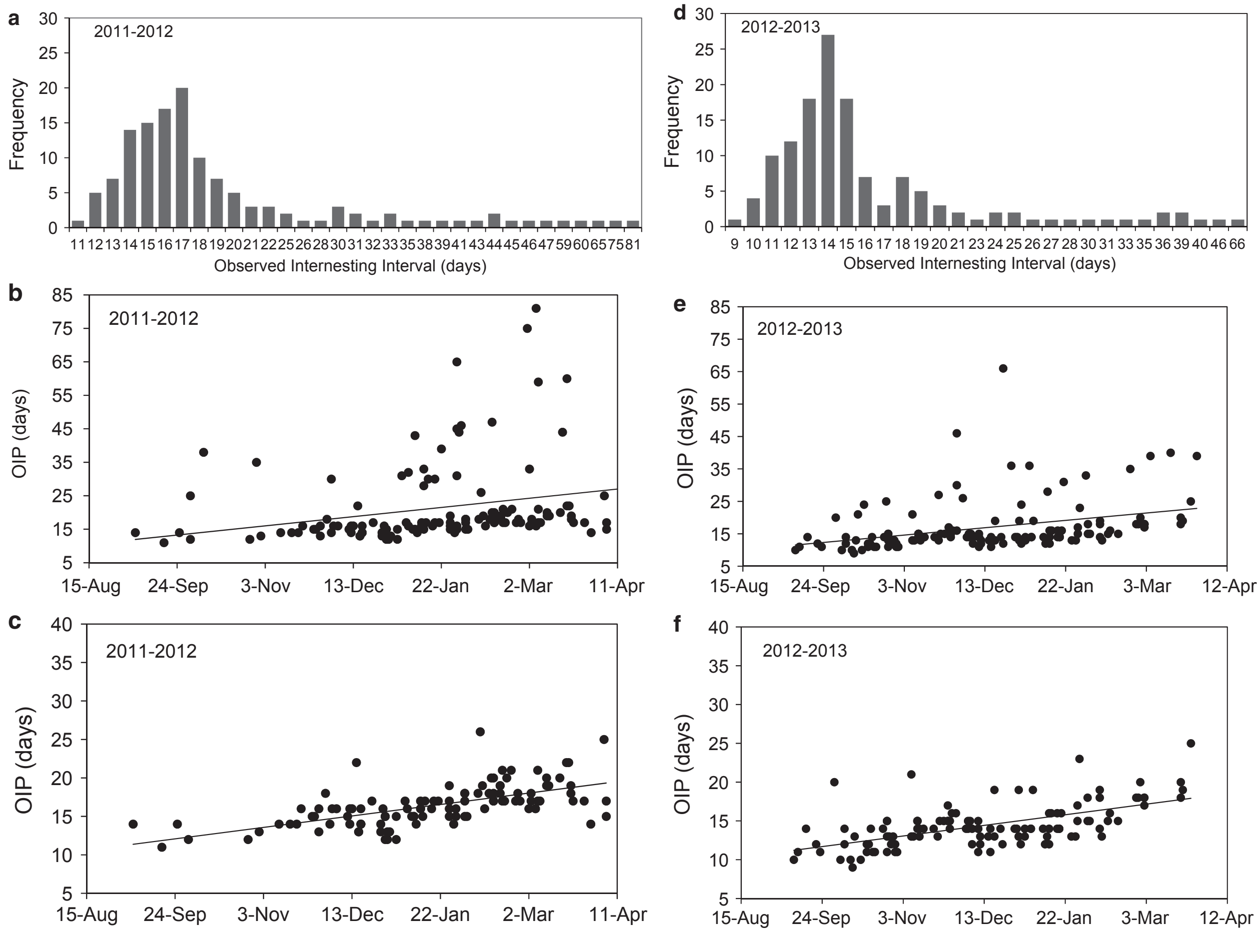

Fig. 3. *Chelonia mydas*. Observed internesting interval (OIP) at Playa Cabuyal, northwestern Costa Rica in 2011–2012 and 2012–2013. (a, d) OIP frequencies including all observations. (b, e) Seasonal OIP including all observations (2011–2012: $r^2 = 0.065$, $P = 0.003$; 2012–2013: $r^2 = 0.119$, $P < 0.001$). (c, f) Seasonal OIP excluding values that were twice as long or longer than the minimum OIP for each fortnight (2011–2012: $r^2 = 0.388$, $P < 0.001$; 2012–2013: $r^2 = 0.351$, $P < 0.001$).

per female (n = 67). Bigger turtles laid bigger clutches ($r^2 = 0.373$, $P < 0.001$) but not more clutches in the season ($P = 0.972$). The seasonal reproductive output also increased with size ($r^2 = 0.147$, $P = 0.006$) (Fig. 5).

Nests

We marked a total of 298 nests (120 were relocated and 178 remained *in situ*) during the two full seasons. Most of them were undisturbed during incubation (66%), 7% were eroded or inundated by high tides (even after the relocation process), 3% were poached (eggs taken by people) and 4% partially poached, 12% were predated, mainly by dogs (especially during hatchling emergence) and 2% were excavated by people after hatchling emergence and therefore we could not quantify success. We could not find 6% of the nests at excavation time (Table 1).

Average hatching success of nests that were unaltered (excluding nests eroded, predated, poached and dug by people) was 0.85 ± 0.24 and 0.83 ± 0.22 for *in situ* and relocated nests respectively, but the difference between them was not statistically significant ($P > 0.05$). There were no significant differences in hatching success between the two seasons ($P > 0.05$). However, among natural clutches laid in the vegetation area (zone 3), hatching success of nests located in exposed areas (0.75 ± 0.33) was significantly lower that of nests that were laid underneath trees (0.89 ± 0.17; $P = 0.007$). Average depth of nests (bottom egg chamber – surface) and body pits (top of neck of the nest – surface) were 68.1 ± 7.4 and 25.6 ± 6.1 cm, respectively (n = 121). The average length of the incubation period was 53.5 ± 5.2 days (n = 94). We released a total of 775 hatchlings that were found alive at the excavations.

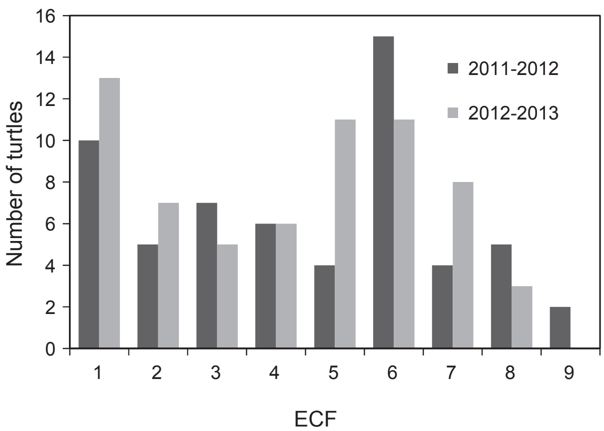

Fig. 4. *Chelonia mydas*. Number of turtles at Playa Cabuyal, Northwestern Costa Rica *versus* their estimated clutch frequency (ECF) in 2011–2012 and 2012–2013.

Threats and conservation efforts

Camping (tents, campfires and people) was common on the beach at night when the project started in 2011. We counted a total of 120 tents between 16 January and 27 March in 2011, and a maximum of 39 tents in a single night. The numbers decreased after the Ministry of Health forbade camping before Easter 2011. Poaching of eggs was also a common practice at the beginning of the monitoring efforts. Poachers were frequently identified on the beach at night in 2010–2011 (identified around 33% of nesting turtles) but their presence was greatly reduced in 2011–2012 and 2012–2013 (poachers were identified around 2% and 4% of nesting turtles). Egg poaching was prevented when patrolling teams were present at night, but eggs were also poached during the day, as 3% and 4% of the nests were found poached and partially poached, respectively, at the time of excavation (Table 1).

We also observed fishing activities near the beach at night and during the day. Fishing was mainly done with small *pangas* that operated gillnets in areas close to the mouth of the estuary and to the north end of the beach. In 2010–2011 there was a permanent camp of fishermen settled on the beach that claimed to have been camping in Cabuyal for years during the dry season (December–March). The Ministry of Health dismantled the camp in February 2011.

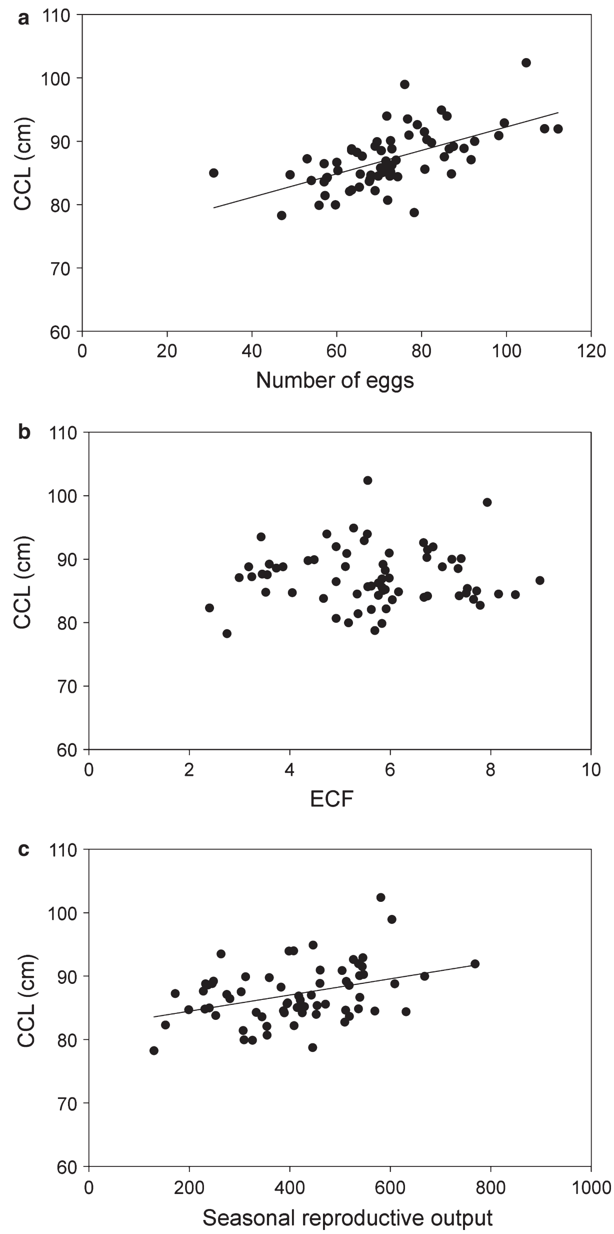

Fig. 5. *Chelonia mydas*. Relationship between the curve carapace length (CCL) of green turtles at Playa Cabuyal in Northwestern Costa Rica and (a) clutch size ($r^2 = 0.373$, $P < 0.001$), (b) estimated clutch frequency (ECF) ($P = 0.972$) and (c) seasonal reproductive output ($r^2 = 0.147$, $P = 0.006$).

Discussion

We found some differences in the nesting behavior of East Pacific green turtles compared with that of other populations of green turtles and other sea turtle species. A majority of green turtle nests on Playa Cabuyal were placed in zone 3. This behavior is different from that of leatherback and olive ridley turtles that nest in this region, which usually lay their clutches in the open area between the high tide line and the vegetation (Cornelius 1976; Reina *et al.* 2002). However, it is similar to the nesting behavior of hawksbill turtles, which tend to nest in the vegetation, under bushes or trees, and in areas of low vegetation (Diamond 1976; Kamel & Mrosovsky 2005; Kamel 2013). The tendency of green turtles in Cab-

Table 1. *Chelonia mydas*. Outcome of marked natural and relocated clutches during 2011–2012 and 2012–2013 seasons.

	In situ nests		Relocated clutches	
Outcome of nests	2011–2012	2012–2013	2011–2012	2012–2013
Completed development	39	84	40	34
Eroded/ inundated	4	8	3	5
Poached	2	3	3	1
Partially poached	0	2	9	0
Predated	4	16	3	14
Excavated by people	2	0	4	0
Lost	9	5	4	0
Total	60	118	66	54

uyal to nest on zone 3 may be explained by the high probability of erosion and tidal inundation of nests laid in zones 1 and 2 on this type of high-energy beach. Risk of erosion and tidal inundation was high in Cabuyal even among nests that were considered to be in safe locations, as 7% of these clutches (*in situ* and relocated), were inundated or eroded. Without relocation of doomed clutches, the levels of erosion would have been much higher. Hawksbill turtles also nest in areas with high levels of erosion where hurricanes occur (Mrosovsky *et al.* 1992; Fortuna & Hillis 1998); similarly, clutches placed in the vegetation may have a greater probability of survival.

Within zone 3, green turtles in Cabuyal laid most clutches underneath the trees. Hawksbill turtles also exhibited this behavior in Guadeloupe, French West Indies, where high vegetation coverage increased shade and lowered the incubation temperature of developing eggs (Kamel 2013). However, those authors did not find any differences in the hatching success of hawksbill clutches in relation to vegetation coverage in Guadaloupe, and we found that clutches underneath the trees had significantly higher hatching success than clutches placed in the low vegetation area. Several factors may contribute to the optimal environmental conditions experienced by nests located underneath the trees in Cabuyal. For example, lower incubation temperatures, decreased dehydration created by the shade and fewer superficial roots, compared with nests laid in the grass, may all increase the success of clutches laid underneath the trees. Likewise, nesting in the vegetation may also have advantages under future scenarios of sea level rise.

The distribution of the timing of the nesting season or phenology varied between years. In particular, the peak of the nesting season occurred 1 month earlier in 2012–2013 than in 2011–2012. Changes in the timing of nesting have been related to sea surface temperature (SST) in sea turtles. Increased SST before the onset of the nesting season was related to earlier nesting in loggerhead (Weishampel *et al.* 2004, 2010; Mazaris *et al.* 2008) and green turtles (Weishampel *et al.* 2010). The SST or weather conditions on the nesting beach may also affect nesting phenology in this population. However, this study needs to be extended to include additional seasons and direct analyses need to be performed to test the effect of environmental conditions on the nesting phenology.

The peak of the nesting season for green turtles at Cabuyal was similar to the peak for leatherback turtles nesting on nearby beaches (Reina *et al.* 2002). However, the nesting season was more protracted, with about 9 months of actual nesting, *versus* 5 months for the leatherback turtles nesting about 40 km south at Parque Nacional Marino Las Baulas, and with some levels of nesting possibly occurring during the rest of the year (as suggested by Cornelius 1995). Because green turtles tended to nest underneath trees, conditions may be suitable for development during the hottest months of the year (February–April), when high temperatures reduce the survival of olive ridley and leatherback turtle embryos in Northwestern Costa Rica (Santidrián Tomillo *et al.* 2009, 2012; Valverde *et al.* 2010). Because green turtles in Cabuyal nest in shaded areas, they are able to have longer nesting seasons than other species in the area.

The average length of the nesting process was longer than reported for other sea turtles in the area (~2 h for leatherbacks, Reina *et al.* 2002) and other sea turtles in general (Hirth 1980; Miller 1997). Green turtles at Cabuyal spent on average 45 more minutes on the beach than the average time reported for other green turtles (~2 h 30 min, Hirth 1980, 1997). Although Eastern Pacific green turtles are normally perceived as skittish by local biologists, false crawls frequently occurred with and without presence of observers (when only tracks were found), suggesting that human presence was not the main cause of this behavior. Nesting success in Cabuyal was also lower than for leatherback turtles that nest in the area (>90% in leatherback turtles, Reina *et al.* 2002) with only ~50% of the nesting attempts resulting in oviposition. However, this is similar to green and loggerhead turtles in Florida, where a high number of non-nesting emergences (~50%) were reported (Weishampel *et al.* 2003) and in general, this trend has been reported for loggerhead turtles around the world, in which both false crawls and aborted nests are common (Dodd 1988).

Mean OIP reported for green turtles is ~13 days (range 12–15 days, Hirth 1997), and mean OIP previously reported for green turtles in Santa Rosa National Park (Cornelius 1976) and Mexico (Alvarado-Díaz *et al.* 2003) was 12 days. The average OIP in Cabuyal was ~2 days longer (15.4 days) than the reported mean for the species. Furthermore, mean OIP recorded at Cabuyal in 2011–2012 (16.1 days) was the longest mean OIP reported for this species in the synopsis of data for green turtles (Hirth 1997) and later research (Bjorndal *et al.* 1999; Hays *et al.* 2002). The length of the internesting interval is affected by water temperature, with shorter IP occurring at high temperatures (Sato *et al.* 1998; Hays *et al.* 2002). It is likely that the cold upwelling waters that occur later in the season in the Gulf of Papagayo, increased the OIP of green turtles at Cabuyal towards the second part of the nesting season. Water temperature in the Gulf of Papagayo is warm during the rainy season (May–November) and cold during the dry season (December–April) as a consequence of coastal upwellings (Bianchi 1991; Jiménez 2001). Waters colder than 20 °C have been registered in this area during the dry season (Bianchi 1991).

The ECF of 4.3 clutches was higher than previously reported for green turtles in Mexico (Alvarado-Díaz *et al.* 2003) and Costa Rica (Cornelius 1976), and also at the upper limit of ECF reported for other green turtle populations (Hirth 1997). It is possible that green turtles lay more clutches in Cabuyal than at other locations in the Eastern Pacific, but it could also be the result of higher fidelity of turtles to Cabuyal and/or a greater beach coverage. Cabuyal is a smaller beach (1.4 km) than Naranjo, Costa Rica and Colola, Mexico (both ~5 km); it is easy to patrol and we covered the beach for a greater portion of the year compared with the other two locations (Cornelius 1976; Alvarado-Díaz *et al.* 2003). Additionally, a recent study showed that ECF using ultrasonography (5.1 clutches) was higher than the estimation based on the beach monitoring program at the same site (3.7 clutches). ECF probably was underestimated on the beach, resulting from some level of exchange between nesting beaches and/or relatively low beach coverage (Blanco *et al.* 2012b).

Clutch size and CCL and CCW were lower than those in other ocean basins, confirming previous reports (reviewed in Hirth 1997). In comparison with Mediterranean green turtles, which are also considered small in size (~91 cm CCL), females in Cabuyal laid more clutches (4.3 clutches at Cabuyal versus ~3 clutches at Cyprus) but fewer eggs per clutch (~76.9 eggs *versus* 115 eggs) (Broderick *et al.* 2003), resulting in similar reproductive outputs. It is possible that the temperate nature of the Mediterranean region constricts the nesting seasons, forcing turtles to lay fewer but bigger clutches in the Mediterranean than the Eastern Pacific. Likewise, the number of eggs increased with size of the turtle at Cabuyal, as well as the seasonal reproductive output, but not the clutch frequency. Similar findings were reported for green and loggerhead turtles in the Mediterranean (Broderick *et al.* 2003) and in the Eastern Pacific leatherback turtles that nest in the region (Price *et al.* 2004).

Playa Cabuyal is a nesting beach with medium nesting levels for green turtles (~70–75 females per year). The number of turtles is much lower than at Colola beach, Mexico where current levels are ~1500–2000 green turtles per season, and where historical records reached ~25,000 nesting females per year (Delgado-Trejo & Alvarado Diaz 2012). However, to assess properly the number of turtles in the Northwestern Costa Rican nesting population, the data from Cabuyal need to be combined with information from other adjacent beaches north of the Gulf of Papagayo, where there are beaches with higher numbers of turtles (L. Fonseca, personal communication) and to the south of Papagayo, where nesting occurs but where nesting levels have not been quantified. Additionally, Playa Nombre de Jesús, located further south than the Gulf of Papagayo, also has high levels of nesting, with two to four times the number of turtles observed at Cabuyal (R. Piedra, personal communication). An initial estimate of the nesting population on the beaches for the Costa Rican North Pacific is at least 500–2000 nesting female green turtles. Therefore, we consider the regional nesting population of green turtles in Northwestern Costa Rica an important component of the green turtle metapopulation in the Eastern Pacific Ocean. The advantage of small beaches such as Cabuyal, where the number of turtles is not overwhelming and the beach coverage is high, is that a great proportion of nests and females can be monitored and in-depth nesting ecology studies can be carried out.

Threats and conservation efforts

Threats to conservation at Cabuyal were similar to those reported elsewhere in Costa Rica. Poaching of eggs, impacts from tourism and domestic animals were common occurrences. Egg poaching was greatly reduced by the presence of patrollers on the beach. However, since a large proportion of beaches in Costa Rica are unprotected (there is no physical presence of guards), poachers that come from the outside can easily move to a different beach where monitoring programs are nonexistent or that have low beach coverage. Therefore, the threat from poaching does not disappear but only moves somewhere else. Some level of poaching, possibly from local inhabitants, still remained after the project started, but poaching levels were much lower. Predation from domestic animals was also high and mainly occurred after hatchling emergence or just prior to emergence from the nest, which still needs to be reduced.

The presence of tourists decreased at night on the beach after the Ministry of Health banned camping, but still occurred during the day, mainly on weekends and during the holidays. Unlike most unprotected beaches in Guanacaste, there are no publically known major ongoing plans to develop Cabuyal for regular tourism. However, to preserve the nesting habitat in its existing form, official protection is needed. In conclusion, at the present time, Cabuyal is a suitable nesting beach with medium levels of nesting for green turtles, where conservation actions are starting to be successfully implemented. However, greater protection is needed in the future for preservation and needs to be extended to other beaches where monitoring projects are currently absent or not fully implemented.

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