Reproductive biology of the loggerhead turtle (*Caretta caretta* L. 1758) on the island of Boavista (Cape Verde, West Africa)

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ABSTRACT

This paper presents the revised and up-dated data on the nesting population of loggerhead (*Caretta caretta*) on the island of Boavista, studied from 1998 to 2002. To date, a total of 2,856 females have been tagged on different beaches of the island. The number of nests counted in the study area (on the beaches of Calheta, Ervatão and Ponta Cosme), a total of 3.1 km of beach, was 833 and 1,917 (only for the years 2001 and 2002 respectively). Nesting success for these two years is around 26 %, with differences between one beach and another. The annual average curved carapace length for females is between 81.3 and 82.4 cm, and clutch size is between 78.3 and 91.5 eggs. The range of incubation times was 45-74 days, with differences between one year and another and between one beach and another. Hatching success does not appear to show inter-annual variations, but these results does vary from one beach to another. In 2000, a *hatchery* was built with nests from Ponta Cosme and Ervatão beaches, from areas where the eggs were unlikely to develop. Hatching success for the artificially incubated nests was higher than hatching success for Ponta Cosme beach and similar to the success rate for Ervatão beach.

INTRODUCTION

The loggerhead turtle, *Caretta caretta* (Linnaeus, 1758), is found in all the oceans of the world, with many known nesting sites, mainly in temperate, and sub-tropical zones (Dodd Jr, 1988; Marquez, 1990). One of these nesting sites, which has a large breeding population, is located in the Cape Verde Archipelago, in the eastern Atlantic Ocean (Cejudo et al., 1999).

This chain of islands is situated approximately 500 km off the west coast of Africa at its closest point (Verde cape on the coast of Senegal), between 14° 48' and 17° 18' north, and between 22° 42' and 25° 18' west. The archipelago is made up of 10 volcanic islands and several islets, with appreciable differences in terrain, climate and distance from the African coast (Figure 1). The easternmost islands (Sal, Boavista and Maio) are fairly arid and flan, with a large extension of beaches along their coasts.

The first records of marine turtles nesting in the Cape Verde islands dates back to the 16th century (see quotes in Parsons, 1962). It is now known that the island of

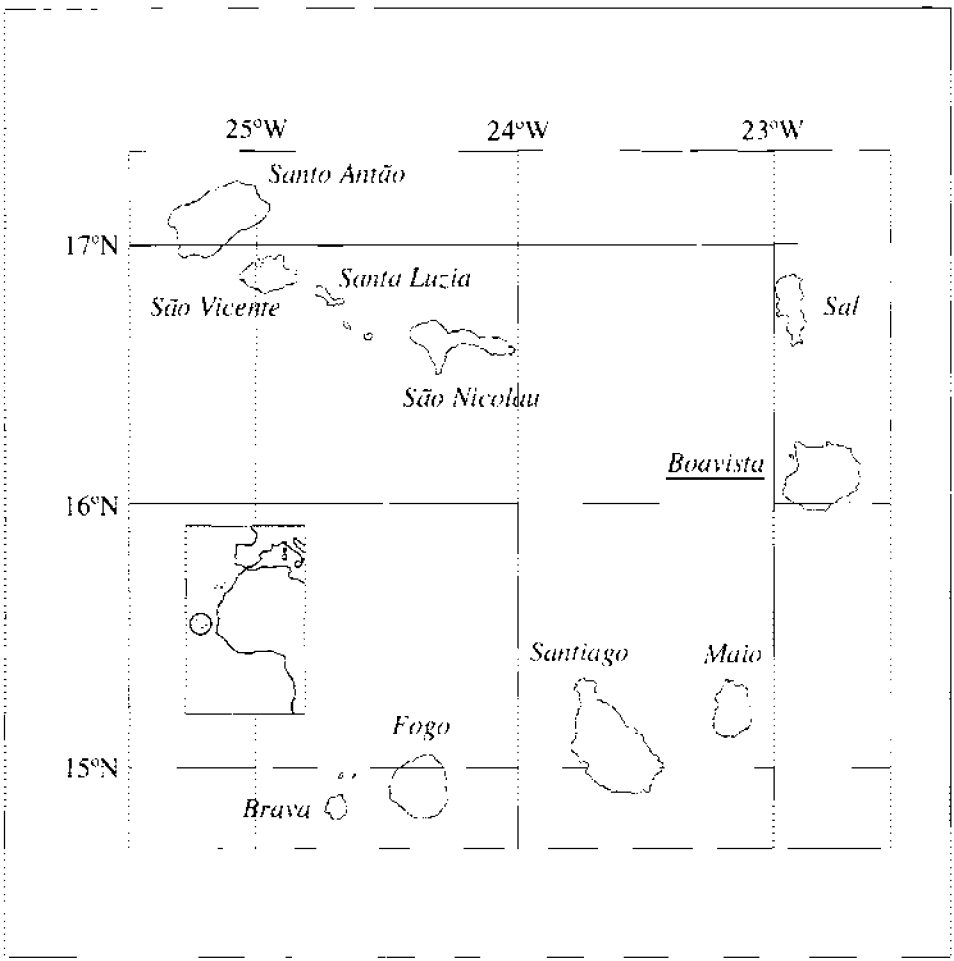

Figure 1. Cape Verde archipelago. Western Africa.

Boavista is the one with the largest population of nesting females, followed by Sal and Maio, and to a lesser extent, the other islands (Cejudo et al., 1999; López-Jurado et al., 1999a). Moreover, juvenile populations of green turtle (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) can be found off the coasts of the archipelago (Linnaeus, 1758) and (Linnaeus, 1766) (López-Jurado et al., 1999a).

A study of the breeding population of *C. caretta* has been on-going since 1998, focussed mainly on the island of Boavista. This article reviews and up-dates the data on their reproductive biology (see preliminary data in Cejudo et al., 1999).

MATERIAL AND METHODS

1. Study area

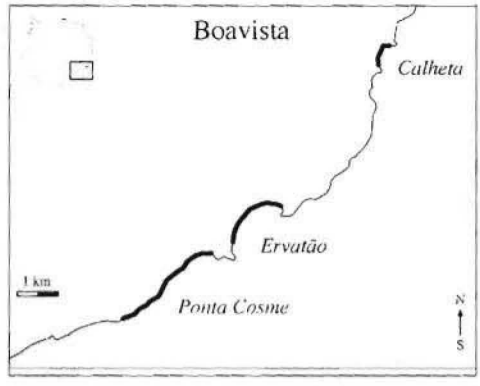

Figure 2. Study area in the island of Boavista.

All the beaches of the island of Boavista were examined in 1998, in search of signs of nesting. This showed that the main areas were to be found on the south-east coast (CEJUDO et al., 1999; CEJUDO et al., 2000). In later years, the study has focussed mainly on this area, although some females have been tagged at other sites. Nests were monitored and a daily record of tracks was kept only for three of these beaches: Calheta, Ervatão and Ponta Cosme (Figure 2). The three beaches are in close proximity to one another, but vary in physical appearance, enabling us to compare certain variables.

The beach of Ponta Cosme is the southernmost of the three and measures 1.7 km long (Figure 3). From north to south, in the first part of this beach, we find abundant vegetation that limits the width of the beach, and which is often reached by the high tide. The second area presents a substrate that is easily flooded and it consists of large

Figure 3. Ponta Cosme beach.

Figure 4. Ervatão beach.

Figure 5. Calheta beach.

amounts of clay. The third area is characterised by its high profile, very disperse vegetation and small dunes.

The beach of Ervatão is one kilometre north of Ponta Cosme beach. It measures 1.05 km in length, forming a bay. There is a ravine mouth at each end of the beach and the width of the beach is limited by vegetation and a stone wall. (Figure 4).

Calheta beach is located to the north of Ervatão, about 4 km away. It measures 350 m long. This is a wide beach with a high profile and little vegetation. (Figure 5).

2. Distribution of tracks and nests

The arrivals of female *C. caretta* were recorded on a daily basis during the 2001 and 2002 nesting seasons, by observing their tracks on the three study beaches. These registers recorded the presence or absence of nests. If we were not certain that there was a nest, it was marked down as doubtful. In 2001, the register started on the 7th of July (10 July in Calheta) and went on until the 22nd of October. In 2002, recordings started on the 14th of July and went through until the 12th of October (11th of October in Ponta Cosme), before the end of the season because of adverse weather conditions. There are some days on which, for different reasons, the track register was not made. The average of the number of tracks and nests counted three days beforehand and three days afterwards was assigned for these days for which no records were taken. These tracks account for 2.3 % of the total number of recordings for each year, and the nests account for 3.7% of nests recorded in 2001, and 2.2% in 2002.

For the analysis of the data, the tracks and nests were grouped together in intervals of seven days, except for the last interval in 2002, which only covered three days.

3. Tagging and biometry

Night patrols were mounted on the three beaches during the nesting season from 1998 to 2002, apart from sampling at different levels of intensity on other beaches of the island. On their way back to the sea, the turtles were stopped, measured and tagged, except in 2001, when most of the turtles were tagged while they were laying, in an attempt to reduce the stress the turtles were subjected to during handling on their way back to the sea.

Metal caliper were used for taking straight measurements for the biometric data, and flexible tape measures for curved measurements. The following measurements were taken (Bolten, 1999): minimum curved carapace length (CCL), curved carapace width (CCW), minimum straight carapace length (SCL), straight carapace width (SCW).

The type of external tags used was a Monel Tag applied to each front flipper, on the second scale, i.e. the largest in size (Balazs, 1999). These tags have a unique, four digit serial number engraved on one, and a Cape Verde Government registration number on the other. An AVID® PIT (Passive Integrated Transmitter) was injected intra-muscularly into the right flipper.

4. Monitoring nests

During the 1998 and 1999 seasons, eggs were counted by taking them out of the nest once the female had returned to the sea. The depth of the top and bottom eggs in the clutch was also measured (only in 1999). In the following years (2000, 2001 and 2002), the eggs were counted during nesting. Nests with a low number of eggs, leading us to think they were partial nests (Miller, 1999), were excluded from the results. Nests were marked with a numbered stick to enable them to be identified and monitored later.

The variables associated with nest monitoring (incubation period, percentage of eggs hatched, etc.) were studied from 1999 through 2002. A daily check was done on the nests from the first day of incubation (night and day time patrols) and especially when the nests reached day 45 (Hays et al., 1992). On day 45, a plastic mesh was placed around the nest to allow monitoring the day the hatchling emerged.

Incubation time was considered as the number of days from nesting (day 0) to the time the first hatchling appeared (Pimckney, 1990; Godfrey et al., 1996).

For calculating the percentage of successfully hatched eggs, two different methodologies were used. The first method, defined as "hatching success" in MILLER (1999), is calculated by dividing the number of empty shells found in the nest, by the number of shells plus un-hatched eggs. This formula does not take into account the size of the initial clutch. 9.5% of nests were excluded, as the amount of remains found was abnormally low (less than 20 eggs). The second method, the "excavation success" method, used by PINCKNEY (1990), is calculated as the difference between the initial number of eggs and the number of un-hatched eggs (undeveloped and partially developed), all divided by the initial number of eggs.

5. Artificial incubation experience

During the 1999 nesting season, hatching success was observed to be low on the beaches of Ervatão and Ponta Cosme in comparison with the rate for Calheta (Table 6; CEJUDO et al., 2000). For this reason, an experiment in artificially incubating *C. caretta* nests was carried out in 2000, on a small beach known as Benguinho, situated between Ervatão and Ponta Cosme.

For the experiment, a 225 m^2 area of the beach was prepared with 100 $1m^2$ plots. A total of 100 nests were transferred from Ervatão and Ponta Cosme beaches. The relocated nests were originally sited in areas considered to be highly unlikely to be successful, such as areas liable to flooding. Clutch sizes were counted at the time the eggs were placed in the artificial nest, and all the rest of the methodology used for monitoring these nests and hatching was exactly the same as for natural nests.

RESULTS

1. Tagged and recaptured females

Between 1998 and 2002, a total of 2,856 female *C. caretta* were tagged on the island of Boavista. Annual distribution and total number of recaptures can be seen in table 1. 87.6% were tagged on the 3.1 km of coastline that is the total length of Ponta Cosme, Ervatão and Calheta beaches.

Table 1. Number of tagged females of *C. caretta*, and number of recaptures from each of the five study seasons in Boavista.

		Recaptures				
	Tagged	1998	1999	2000	2001	2002
1998	92	51	-	-	-	-
1999	510	-	377	-	-	-
2000	740	14	7	446	-	-
2001	487	10	40	1	494	-
2002	1027	8	70	101	1	783

8.8% of the turtles tagged have been recaptured in later years: 9 of them the following year, 155 two years later, 80 three years later and 8 four years later (Figure 6). These data should be taken with caution, however, because tagged turtles may have come ashore on one of the three beaches of the study area, or, indeed, on any other beach that was not under study, without being detected.

Figure 7 shows the frequency distribution of recaptures of female *C. caretta* during the same season, grouped into two-day intervals. The analysis excludes recaptures that are less than five days or more than 26 days apart (ALVARADO & MURPHY, 1999).

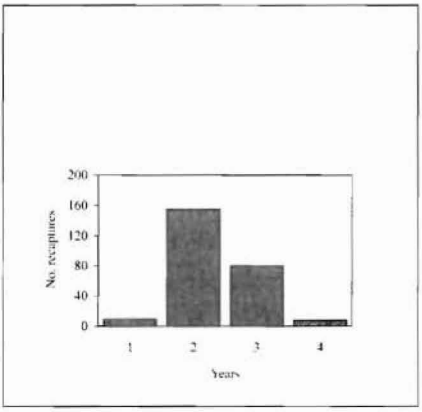

Figure 6. Frequency distribution of remigration interval (years) for loggerhead in Boavista.

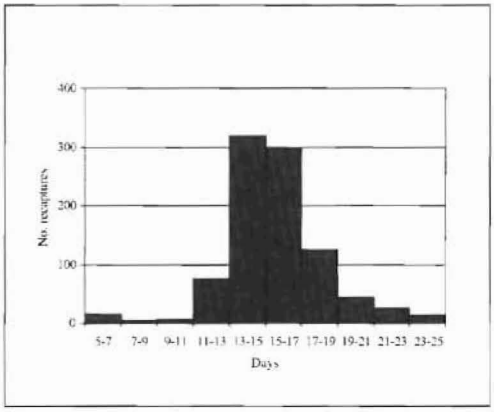

Figure 7. Frequency distribution of loggerhead recaptures in the same season, grouped in two days intervals.

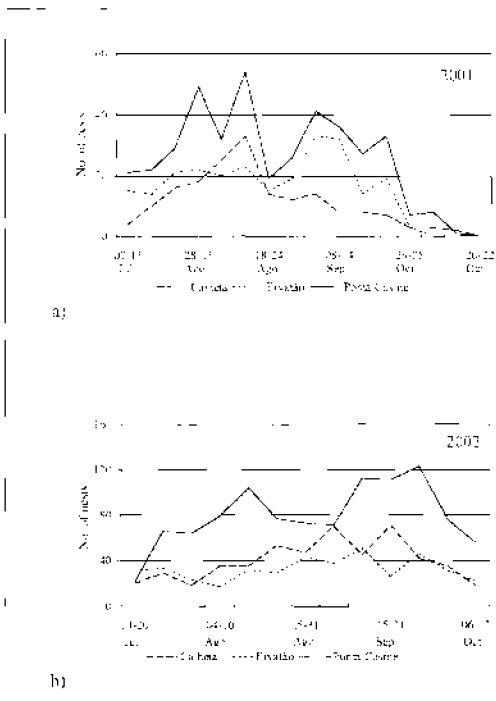

Figure 8. Distribution of nests of loggerhead in the three beaches studied in Boavista in 7 days intervals (a, 2001 season; b, 2002 season).

2. Distribution of nests and nesting success

In 2001, sampling started in the first week in July, when there were already some nests to be found on the beaches. There was no more than one nest per beach found after the 13th of October. In 2002, sampling started after nesting activity had commenced, and the entire season could not be covered due to adverse weather conditions in the month of October.

Concerning the time distribution of nests in 2001, in intervals of one week (Figure 8a), we can observe a fall over the last ten days of August on all three beaches, just as there is in the second ten days of September, although this fall is not as sharp. In 2002, however (Figure 8b), nest distribution shows no pronounced changes.

For the three beaches under study, a total of 3,188 female *C. caretta* tracks were counted in 2001. In the 2002 season, the number increased to a total of 7,444. The distribution by beaches is shown in table 2. Nesting success, i.e. the percentage of tracks that lead to a nest was, in general, similar in the two seasons (Table 2), with differences between the three beaches. This value could be underestimated due to the fact that it was impossible to determine the presence or absence of a nest in 8.0% of tracks in 2001, and in 8.9% of tracks in 2002.

Table 2. Number of crawls, nests, and nesting success of loggerhead in the three beaches studied during 2001 and 2002 seasons.

		Tracks	Nests	Nesting success (%)
2001	Calheta	356	177	49.7
	Ervatão	899	251	27.9
	Ponta Cosme	1.933	405	20.9
	Total	3.188	833	26.1
2002	Calheta	1.198	518	43.2
	Ervatão	1.653	420	25.4
	Ponta Cosme	4.593	1.033	22.5
	Total	7.444	1.971	26.5

3. Biometry of nesting females

Table 3 shows the distribution of biometric data by years, from 1998 to 2002. For the females that came ashore more than once in the same year, only the measures taken the first time they came ashore are recorded. These results include the data for untagged females.

Table 3. Biometry of nesting females of loggerhead in Boavista during five years of study (LCC, curve carapace length; LRC, straight carapace length; SD, standard deviation; N, sample size).

	1998	1999	2000	2001	2002
CCL (cm)	82.4	81.9	81.3	81.8	81.5
SD	4.98	4.6	3.99	4.39	3.6
Range	75.0-103.0	72.0-106.0	72.3-104.0	73.0-106.0	67.0 101.0
N	85	479	714	518	1 086
SCL (cm)	77.3	76.3	75.7	76.2	76,0
SD	5.00	4.30	3.99	4.05	3.40
Range	64.0-96.0	66.0-100.0	60.2-96.5	66.0-100.0	59.6-95.4
N	81	386	699	519	1 094

4. MONITORING NESTS

4.1. Size and depth of clutches

The figures for average clutch size obtained for the five years of study (1998-2002) appear in table 4.

Table 4. Clutch size of loggerhead in 1998-2002 seasons in Boavista (SD, standard deviation; N, sample size).

	1998	1999	2000	2001	2002
Nº eggs	90.6	91.5	82.4	[illegible]	[illegible]
SD	16.17	17.00	16.70	[illegible]	[illegible]
Range	60-137	33-140	24-143	45-124	[illegible]
N	90	378	353	263	[illegible]

An ANOVA shows us that there are significant differences in the size of clutches from one season to another ($F_{4,}$[illegible] = 30.909, $p < 0.0001$). A later Fischer test shows significant differences between years (Table 5), with the figures being similar in 1998 and 1999, and between 2000 and 2002. In 2001, clutch size was significantly smaller than in other years.

Table 5. Significance levels for the clutch size between different years using an a posteriori Fischer's test.

	1998	1999	2000	2001	2002
1998		ns	*	**	**
1999			**	**	**
2000				*	ns
2001					*
2002					

(ns = not significant; * = p<0.005; ** = p<0.0001)

The lower depth of the clutch of eggs varied from 29 cm to 96 cm, with annual means of 47.1 cm in 1998 and 47.8 cm for 1999. The upper depth range varied from 3.0 to 44.0 cm, with annual means of 28.8 cm in 1998 and 26.9 cm in 1999.

4.2. Incubation times and hatching success

Average incubation times in the nests studied in the seasons from 1999 to 2002 can be seen in table 6. The incubation time for *C. caretta* in Boavista encompasses a range that varies between 45 and 74 days, with significant differences from one year to another (transformation [1/x]; ANOVA: $F_{3,377} = 47.98$, $p < 0.0001$).

Table 6. Incubation duration (d, days) of loggerhead nests in Boavista in the period 1999-2002.

	1999	2000	2001	2002
Incubation (d)	57.9	59.1	54.2	60.9
SD	4.69	4.20	3.55	4.62
Range	47-74	50-73	45-65	47-74
N	78	88	101	114

Hatching and excavation success turned out to be significantly different ($t = -8.447$, $p < 0.0001$). Excavation success turned out to be higher (Mean = 54.8 %, SD = 36.37, N = 389), than hatching success (Media = 46.0 %, SD = 36.07, N = 542). In later analyses, only hatching success has been used.

Table 7. Hatching success of loggerhead in the three beaches studied in the years 1999-2002.

		1999	2000	2001	2002
Calheta	Mean	76.2	67.0	72.9	79.9
	SD	24.38	32.19	29.01	25.67
	Rango	0.0-98.1	0.0-98.2	0.0-100.0	0.0-98.8
	N	19	21	15	22
Ervatão	Mean	51.1	63.5*	58.4	45.7
	SD	32.84	36.20	35.21	35.12
	Range	0.0-100.0	0.0-100.0	0.0-100.0	0.0-97.6
	N	31	48	57	53
Ponta Cosme	Mean	42.2	33.3*	23.2	32.4
	SD	35.09	34.63	25.69	30.84
	Mean	0.0-97.8	0.0-100.0	0.0-91.2	0.0-94.8
	N	61	57	81	77
TOTAL	Mean	50.5	50.4	41.2	43.9
	SD	34.85	37.97	35.55	35.39
	Range	0.0-100.0	0.0-100.0	0.0-100.0	0.0-98.8
	N	111	126	153	152

(SD = standard deviation; N = sample size).

* Nest of the hatchery (artificial incubation experiment) not included.

If we analyse global hatching success (the three beaches as a whole) between the different seasons (Table 7), we can see that this is similar (Kruskal-Wallis: H = 6.94, p = 0.071). However, the behaviour on each beach varies if we take each season separately ($p < 0.005$ in all cases), and Calheta is the beach with the highest hatching success in all cases, and Ponta Cosme the lowest. Ervatão varies from one year to another.

5. Artificial incubation of nests

Incubation times for *hatchery* nests (Mean = 58.9 days, SD = 3.10, Range = 51-66, N = 91) were not significantly different (t = 1.252, p = 0.21) from eggs incubated on the original beaches in 2000 (Table 6).

Hatching success for the *hatchery* (Mean = 61.6 %, SD = 24.51, N = 100) is significantly greater than that of Ponta Cosme beach ($p < 0.0001$), but similar to the figures obtained for Ervatão (p = 0.062) in 2000 (see figure 9; GARCIA et al., 2001). Some of the *hatchery* nests came from unlikely sites on the beaches of Ervatão and Ponta Cosme (12 and 82 nests respectively), so the natural hatching success of the nests laid on these beaches could be over-estimated for that year. Therefore, we have compared the results of the *hatchery* for 2000, with the beaches of Ponta Cosme and Ervatão in the preceding year (1999), which shows that hatching success in the *hatchery* is significantly higher than at Ponta Cosme (p = 0.001), but similar to the success rate of Ervatão (p = 0.199).

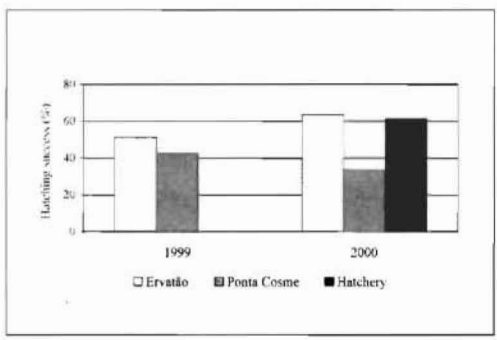

Figure 9. Hatching success in the hatchery, and Ervatão and Ponta Cosme beaches in 1999 and 2000 seasons.

DISCUSSION

The number of female *C. caretta* tagged in Boavista gives different values over the five years of study (Table 1), in which the sampling effort was similar, except in

1998, when the number of staff and time used was less. These data, along with the data for successive years, suggest that the *C. caretta* population in Cape Verde is one of the largest in the Atlantic Ocean (Brongersma, 1982; Marquez, 1990; Ross, 1995; Fretey, 2001).

The number of tracks recorded in the 2001 and 2002 seasons is high (Table 2), bearing in mind that only 3.1 km of beach were sampled. But, as an overall average, only one of every four tracks emerging from the sea leads to a nest (Table 2), a low result if we compare it to the literature (Dodd Jr, 1988). One explanation of this result could lie in the physical characteristics of the beaches themselves, as there is no other kind of disturbance like lights or other activities associated with man, apart from those of the observers. Causes could include the excessive humidity of the substrate on the edge of the water courses, or the presence of stones or other obstacles that make it difficult to dig a nest, especially on the beaches of Ponta Cosme and Ervatão (Lopez et al., 2002); barriers of this kind, or damp zones are not evident on the beach of Calheta, where nesting success is around 50 %.

The average size of nesting female *C. caretta* on the island of Boavista is, in general, small (Table 3), in comparison with most populations of the world (Balliel et al., 2001; see review in Dodd Jr, 1988). They are slightly larger than those found in the Mediterranean (Margaritoulis, 1982; Erk'akan, 1993; Broderick & Godley, 1996), although the minimum values found are similar to those from Cyprus (Broderick & Godley, 1996). Table 8 shows these values for different populations.

The smaller size of clutches laid in the 2000, 2001 and 2002 seasons could be due to the method used for counting the eggs. The method used in 1998 and 1999, extracting the eggs once the female returned to the sea, seems more accurate than the method of counting the eggs as they leave the cloaca, used in later years, as it is sometimes difficult to count them correctly this way. According to the results obtained, in the latter case, we would be under-estimating clutch size, so we would suggest using the former method, or use another method that allows a more accurate count without the need to open up the nests. Our attention was, in turn, also drawn to the smaller clutch size recorded 2001. At the beginning of this season, females were experimentally measured and tagged while they were laying their eggs, in an attempt to reduce stress levels. In some cases, anomalous nesting behaviour was observed, so, approximately half way through the season, we returned to using the usual tagging methodology. Tagging during laying could be one of the causes of the smaller clutch size in 2001.

A maximum difference of six days was observed between average incubation times, in 2001 and 2002, possibly due to the temperature conditions in which the nests were incubated. We also observed differences in incubation times between the different beaches (not included in this study), so a more detailed study will be required later on.

Table 8. Curve (CCL) and straight (SCL) carapace length in different nesting populations around the world (N, sample size). See revision in Dodd (1988), Erk'akan (1993) and Broderick & Godley (1996).

		CCL (cm)	SCL (cm)
Florida	Mean (cm)	98.9	93.9
(USA)	Range	87.9-108.9	82.5-104.4
	N	119	114
Masirah Island	Mean (cm)	-	92
(Oman)	Range	-	79.0-101.0
	N	-	-
Natal	Mean (cm)	84.7	79.2
(South Africa)	Range	71.0-94.0	65.1-87.1
	N	23	23
Zakynthos	Mean (cm)	80.4	-
(Greece)	Range	69.5-95.0	-
	N	27	-
Dalyan Beach	Mean (cm)	-	73.1
(Turkey)	Range	-	60.2-83.9
	N	-	49
Northern	Mean (cm)	73.4	-
Cyprus	Range	65.0-86.5	-
	N	78	-

There are significant differences between the two methods used to count the percentage of eggs from each nest that have been successfully incubated. The first of these, the so called "hatching success" (Miller, 1999), can be applied if the eggs have not been counted initially. But, if the counting error is calculated (when the initial number of eggs is known), we have observed that this varies in many cases. Nests in which, once opened, the clutch size is less than 20 eggs, have been excluded from the

analysis (we do not know if the low number was due to predation by ghost crabs, *Ocypode* sp., or to other causes). In any event, a general criterion has to be established for excluding nests from the analysis, depending on counting error. In the second method, the "excavation success", values are significantly higher than in the first method. In this case, once the nest is opened, one only has to count the un-hatched eggs, so the rest (the difference between the number of un-hatched eggs and the initial number of eggs) gives us the number of hatched eggs. We could assume that not all the eggs laid by the female are in the nest (due to predation or other reasons), so the figure will be an over-estimation. As both methods seem to over-estimate the percentage of eggs that hatch, we use the first method for the analysis, which, in our opinion, is closer to the real value.

Although the hatching success does not seem to vary from one season to another, the results suggest that the conditions of each beach studied for incubating eggs, does differ. So, Calheta beach seems to have the best conditions, while the beach of Ponta Cosme has the lowest values every year, perhaps due to the high percentage of the beach that has a low profile, making it susceptible to flooding, or the excessive level of dryness in other areas of the beach.

The artificial incubation experience enabled us to increase hatching success for Ponta Cosme beach, bearing in mind that this may have been even lower if many of these nests had not been re-located to the *hatchery*. However, there were no differences in comparison with the figures obtained for Ervatão (Figure 9). The possibility of relocating nests from Ponta Cosme, and in some cases from very unlikely areas of Ervatão, to other areas of the beach, or to a *hatchery*, should be given consideration in the future, with a view to increasing the hatching success of a population that suffers strong pressure from predation by man (LOPEZ-JURADO et al., 1999b). This task should, however, be addressed with caution, as we may be altering important population parameters like the sex ration (MROSOVSKY, 1994; GODFREY & MROSOVSKY, 1999; MORTIMER, 1999).

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