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Body condition of loggerhead turtles *Caretta caretta* nesting in Cabo Verde is independent of their reproductive output

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RESUMO

A condição corporal das fêmeas adultas geralmente é um bom indicador da saúde das populações, especialmente importante em espécies ameaçadas. Este parâmetro e a relação deste com o sucesso reprodutor foram estudados na subpopulação Em Perigo da tartaruga-comum *Caretta caretta* do Nordeste Atlântico nidificante em Cabo Verde. O estudo de campo foi realizado durante quatro épocas completas de nidificação entre 2013 e 2016. Um total de 318 fêmeas marcadas foram estudadas. A massa corporal e o comprimento curvo da carapaça variaram de 42–116 kg e 73–99 cm, respectivamente. Apesar do pequeno tamanho corporal e da dieta pelágica de muitos indivíduos, todas as fêmeas apresentavam um índice de condição corporal relativamente elevado, 1,49 10^{-4} kg/ cm^3 em média. Foi detectada uma relação fraca e não linear do tamanho corporal na condição corporal (r^2= 0,18). Adicionalmente, a massa corporal média ao longo da temporada reduziu-se menos que o esperado e 28% das fêmeas aumentaram-na durante o período de nidificação. A condição corporal foi semelhante nos diferentes anos, sugerindo que fêmeas com boas condições corporais possam reproduzir-se a cada estação. Mas não houve influência da condição corporal na taxa reprodutora numa determinada estação nidificante, mostrando a necessidade de mais estudos.

Palavras-chave: ciclo de vida, conservação, Nordeste Atlântico, reprodução, massa corporal

ABSTRACT

The body condition of adult females is generally a good indicator of the physiological status of populations, especially important in threatened species. This parameter and its relationship with the reproductive output were studied in the Endangered loggerhead turtle *Caretta caretta* subpopulation of the Northeast Atlantic Ocean. The field study was conducted during four complete nesting seasons between 2013 and 2016. A total of 318 tagged females were studied. The body mass and curved carapace length varied from 42–116 kg and 73–99 cm, respectively. Despite the small body size and the oceanic diet of many individuals, all females had a relatively high body condition index, which averaged 1.49 10^{-4} kg/ cm^3. There was a weak and non-linear influence of body size on the body condition (r^2= 0.18). Furthermore, the reduction on mean body mass throughout the season was lower than expected and 28% of the females increased their body mass throughout the nesting period. The body condition was similar along the different years, suggesting that females with high body condition may breed every season. However, there was no influence of body condition in the reproductive output within a given season, showing the need of further studies.

Keywords: conservation, life cycle, Northeast Atlantic, reproduction

INTRODUCTION

Life history traits are constrained by the allocation of limited resources to multiple processes, generating life history trade-offs (Doughty & Shine 1997, Sinervo & Svensson 1998). Individuals better able to acquire or manage endogenous resources are expected to optimize these trade-offs more efficiently (Doughty & Shine 1997, Sinervo & Svensson 1998). A good external indicator of the energetic efficiency and nutritional status of many individuals is the body condition index, BCI (Schulte-Hostedde *et al.* 2001, 2005). A significant difference in the BCI among individuals of the same population is associated to changes in fitness in different vertebrates, including mammals (Schulte-Hostedde *et al.* 2001, 2005), amphibians (Lowe *et al.* 2006), birds (O'Dwyer *et al.* 2006) and reptiles (Willemsen & Hailey 2002, Litzgus *et al.* 2008). A wild animal with a good BCI reflects a better energetic status (Schulte-Hostedde *et al.* 2005). Furthermore, body condition is positively correlated with fecundity because energetic reserves limit the amount of energy that can be allocated to reproduction and can provide valuable information about fitness and health. This information can be especially relevant for threatened populations in order to identify priorities to improve conservation actions (Schulte-Hostedde *et al.* 2005).

Sea turtles can be sensitive to significant decrease of their body condition because they are highly migratory and do not reproduce every year (Bjorndal *et al.* 2003). Females concentrate their reproduction in specific years followed by non-nesting years, thus reducing the number of breeding migrations between their distant nesting and feeding grounds (Bjorndal *et al.* 2000, Marco *et al.* 2011).

Although the loggerhead turtle is considered Vulnerable as a species by the IUCN (Casale & Tucker 2017), the subpopulation reproducing in Cabo Verde is considered Endangered (Casale & Marco 2015) and one of the most threatened subpopulations in the world and the second most threatened in the Atlantic (Wallace *et al.* 2011). Additionally, the existence in this subpopulation of three different trophic phenotypes, including one type with a poor oceanic diet (Eder *et al.* 2012, Cardona *et al.* 2017, Cameron *et al.* 2019), makes it very interesting to determine the influence of the type and quality of diet and trophic habitat in the body condition and reproductive output.

The main goal of the present study was to evaluate the body condition of nesting females of the Northeast Atlantic subpopulation of loggerhead turtles in order to estimate their physiological status and the relationship with their reproductive output.

MATERIAL AND METHODS

The study was conducted in the Northeastern Atlantic, on Boavista Island, Cabo Verde Archipelago (16°01'N; 22°44'W). Experienced researchers daily conducted nocturnal patrols on the southeastern beaches of João Barrosa (Turtle Nature Reserve) during four consecutive nesting seasons (from mid-June to mid-October, from 2013 to 2016). We identified and studied 318 females tagged with passive integrated transponders. Eighteen of these were studied in two different occasions during the same year. All selected females were retained *in situ* on the beach after nesting and weighted with a digital balance (PCE-ES300) with an accuracy of 0.05 kg. Sand was carefully removed from the carapaces to reduce bias in the body mass (BM) measures. Each female was wrapped in a sand-free net square (1.5 x 1.5 m), hooked to a balance and hung using a 2-meter carbon fibre bar supported horizontally by at least two field assistants. All the weighting process took less than 5 min per female without apparent damage to the turtles. The curved carapace length from the nuchal notch to the posterior notch (CCL) was measured with a plastic tape (± 0.5 cm).

The clutch size was counted in 206 egg masses during oviposition, and 96 of these were carefully extracted from the nest chamber immediately after egg laying. The eggs were carefully weighed within a fabric bag. The methodology of the relocation and study of eggs, incubation, and hatchlings was conducted following Marco *et al.* (2012b).

There are several methods to estimate BCI in sea turtles (Stevenson & Woods 2006, Li *et al.* 2015). Since we are studying an Endangered population, we selected a less invasive method than tissue/ blood collection based on the measurement of body length and mass (Green 2001), the Fulton's condition factor (Bolger & Conolly, 1989). We chose this BCI because of its simplicity and historical precedence (Stevenson & Woods 2006) and its previous use in sea turtles (Bjorndal *et al.* 2000, Seminoff *et al.* 2003). Several studies have correlated BCI with biochemical and physiological parameters (Barco *et al.* 2016, Stacy *et al.* 2018).

The BCI was calculated using Bjorndal *et al.* (2000)'s formula: BCI= (BM x 10000)/ SCL^3 (kg/ cm^3). Values of CCL were converted in straight carapace length (SCL) using a sample of 1067 females from Boavista, from whose both measurements (CCL and SCL) were taken, and the equation: SCL= 0.8456 x CCL + 5.6372 (Varo-Cruz *et al.*, 2007). For repeated measures, we used mean values of each variable in the population analysis. For each nest, we calculated a mean value for all used variables of eggs and hatchlings. We calculated descriptive statistics for all parameters. We compared pairs of continuous variables using Pearson correlation. We evaluated seasonal variation among years and fortnights using General Linear Model.

RESULTS

The mean BM of the loggerhead females was 63.3 kg and their mean CCL was 82.1 cm (Table 1). There was a strong correlation between BM and CCL (r^2 = 0.80, p< 0.0001, Fig. 1A). The correlation between SCL and CCL in the females were both measurements were taken was statistically significant (r^2= 0.90, p< 0.0001). Over 99% of females had BCI larger than 1.2 and less than 22% of females had a BCI lower than 1.4. There was a weak though significant negative linear relationship between BCI and CCL (r^2= 0.05, p< 0.0001), and a significant and stronger non-linear correlation (r^2= 0.18, p< 0.0001), with medium-sized females presenting lower BCI than large and small ones (Fig. 1B).

Table 1. Descriptive statistics of the different parameters measured to females, clutches, eggs and hatchlings of the studied loggerhead turtle population. Mean values of eggs and hatchlings were calculated using mean values of each clutch. For females with several measurements, the mean value is provided. N stands for sample size, SD for standard deviation, Min for minimum, Max for maximum, BM for body mass, BCI for body condition index, and CCL/ SCL for curved/ straight carapace length, respectively.

	N	Mean	SD	Min	Max
Female CCL (cm)	315	82.14	4.70	73.0	99.0
Female BM (kg)	316	63.30	11.31	42.00	116.00
BCI (kg/cm^3)	315	1.49	0.13	1.16	1.99
Clutch size	195	82.4	17.0	22	138
Clutch mass (kg)	96	3.48	1.24	1.45	12.80
Egg diameter (mm)	80	38.92	2.19	32.64	42.79
Egg mass (g)	81	33.02	6.74	20.69	43.85
Hatchling SCL (mm)	58	42.62	1.26	39.53	45.79
Hatchling BM (g)	58	17.51	1.95	11.59	24.12

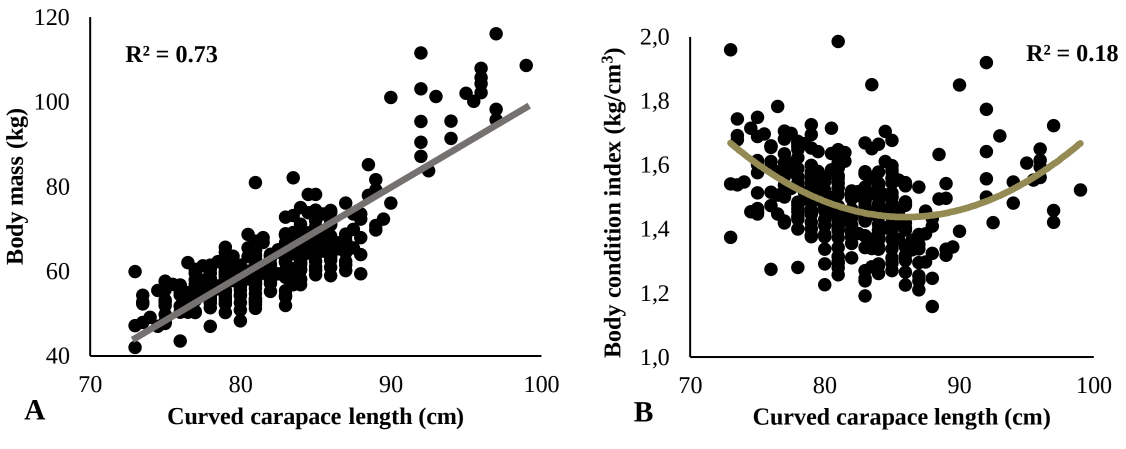

Fig. 1. Health status of loggerhead turtles nesting in Cabo Verde. **A**) Relationship between curved carapace length and body mass **B**) and body condition index. Values refer to four nesting seasons (2013–2016).

The mean annual BM varied from 60.8 to 69.3 kg (Table 2) and varied among years (ANOVA: $F_{(3,335)}$= 7.589, p< 0.001), but there was no significant difference in mean BCI among years (ANOVA: $F_{(3,333)}$= 1.501, p= 0.214). Thus, data from the four years were analysed together. There were significant differences in mean BM (ANOVA: $F_{(7,333)}$= 2.527, p= 0.015) and BCI (ANOVA: $F_{(5,323)}$= 3.070, p= 0.010) throughout the nesting season. BM varied from 67.3 kg in the first half of July to 59.1 kg in the second half of September. Mean BCI varied from 1.55 kg/ cm^3 in the first half of July to 1.46 kg/ cm^3 in the second half of September (Fig. 2). The mean individual BM loss per 15 days was 0.53±0.33 kg, varying from -8.91 to 6.16, but 27.8 % of the females gained mass throughout the season.

Table 2. Body mass (BM) and curved carapace length (CCL) of loggerhead turtles from Cabo Verde in the four study years. N stands for sample size, SD for standard deviation.

	2013	**2014**	**2015**	**2016**
N	27	57	89	146
Average BM (kg)	69.31	63.30	66.47	60.78
SD	12.52	11.35	13.49	32.04
Minimum BM (kg)	43.50	48.25	46.95	42.00
Maximum BM (kg)	102.00	105.65	116.00	111.50
Mean CCL (cm)	84.36	76.89	77.82	76.24

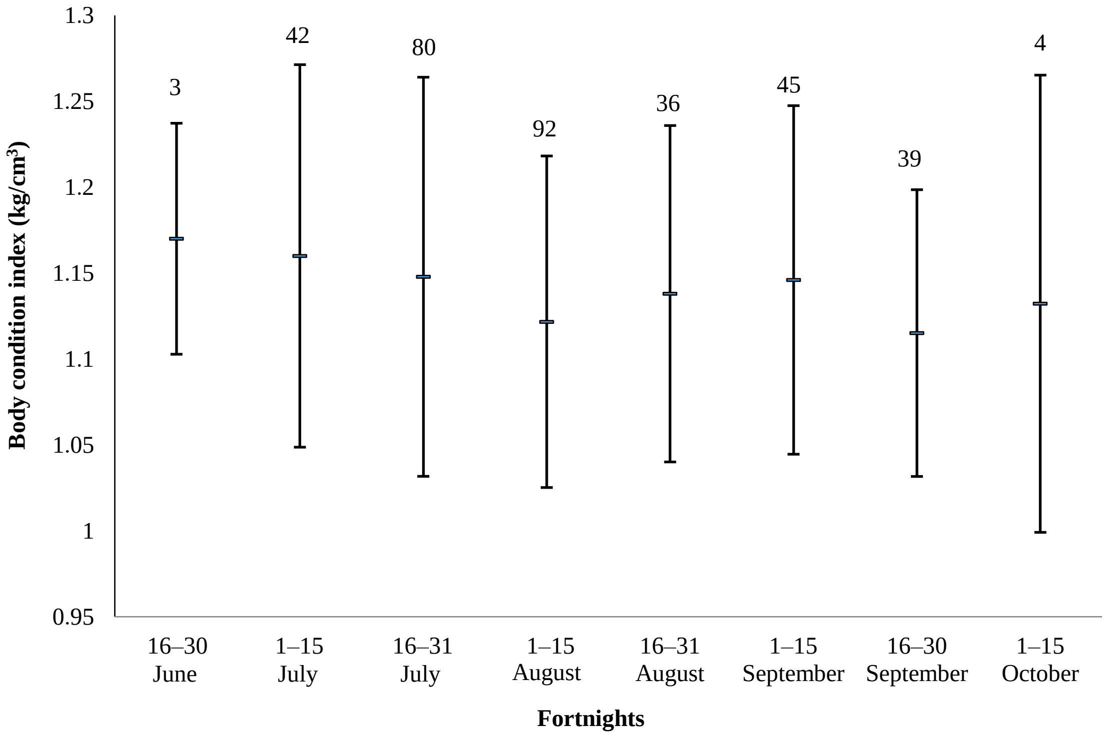

Fig. 2. Seasonal variation of the mean BCI index of loggerhead nesting in Cabo Verde. Each mean value of BCI correspond to data from the four study nesting seasons (2013–2016). The vertical bars indicate the standard deviation and the numbers over each bar correspond to the sample size.

The correlations between BCI and clutch size (r^2 = 0.01, p= 0.208, N= 206), egg mass (r^2= 0.00, p= 0.554, N= 83) and hatchling mass (r^2= 0.01, p= 0.512) were not significant (raw data available at https://figshare.com/articles/Pina_et_al_ZC_raw_data/12424343).

DISCUSSION

All females of the studied loggerhead turtle population of Boavista showed relatively high values for the BCI (e.g. Bjorndal *et al.* 2000, Seminoff *et al.* 2003, Barco *et al.* 2016, Stacy *et al.* 2018). These results suggest that nesting females have no nutritional problems and no difficulties to find food in their feeding grounds. Perhaps only adult females with large fat reserves migrate to Cabo Verde for nesting (Jessop *et al.* 2004). Females that do not get an optimal BCI would not begin the vitellogenesis process and would delay their reproduction remaining on their feeding grounds. On the other hand, adult females with poor BCI that try to nest could die during migration or immediately after the arrival to their nesting beaches. Several impacts threatening adult turtles in Cabo Verde, such as fishery bycatch (Coelho *et al.* 2015) or poaching on the beach (Marco *et al.* 2011, 2012a) may especially affect females with lower body condition. Moreover, we found no interannual variability in mean BCI of adult females. This result suggests that potential environmental differences among years in food availability to sea turtles could be affecting the mean BCI in the feeding ground and the percentage of females breeding in the next nesting season, but not the BCI of nesting females. Alternatively, the BCI could be a bad estimator of the physiological or health status of sea turtles (e.g. Flint *et al*. 2010). It would be very interesting to evaluate the variability of BCI of adults in feeding grounds to untangle this.

In oceanic females (< 85 cm CCL, Eder *et al.* 2012) there is a decrease of BCI with body length. Perhaps there is an ageing effect on the ability to maintain a good condition. However, neritic females (> 85 cm) have a better condition than large oceanic females. Heavier females have a larger reproductive output (Eder *et al*. 2012). However, body length only explained 4.8 % of variation in BCI. In this population, larger females have longer migration routes to rich neritic habitats, while smaller females feed in oceanic habitats between Cabo Verde and the continental African coast (Hawkes *et al.* 2006, Eder *et al.* 2012, Cameron *et al.* 2019). Migration has a significant energetic cost together with a higher risk and time cost (Bonte *et al.* 2012). Longer reproductive migrations for neritic females could consume higher amounts of energy counterbalancing the benefits of their better diet, explaining the hump-shaped curve in our results. Moreover, the remigration intervals could be also different as a function of body size. Larger females feeding in neritic habitats (Eder *et al.* 2012, Cardona *et al.* 2017, Cameron *et al.* 2019) could remigrate earlier having less time to store fat reserves, and thus, having similar body condition than smaller females with a poorer diet who could remain more years in the feeding grounds between consecutive breeding migrations.

The decline in BCI throughout the nesting season is likely caused by the successive egg depositions associated with a lack of feeding of females in the mating and nesting grounds (Hays *et al.* 2002, Santos *et al*. 2010, Vieira *et al.* 2014). Furthermore, their strong effort to come out to the beach, crawl on the sand, dig, and camouflage their nests involves a high energy and fat consumption. Vieira *et al.* (2014) showed that nesting females on Boavista in the beginning of the nesting season exhibited higher nucleic acid concentrations and better physiological condition than those sampled at the end of the season. This would explain why many females loose mass throughout the season. However, BM and BCI of some females are similar or even experiment an increase throughout the nesting season. These individual differences suggest the existence of different feeding strategies during the nesting season that should be explored. Moreover, the difference in mean BM across the nesting season corresponds to the mean mass of 2.4 nests of this population, but each female is laying an average of five nests per season in Cabo Verde (Varo-Cruz *et al.* 2007). A significant part of this difference in mass could correspond to water added to the eggs by the females. However, the possibility of females feeding during the internesting periods may also explain this change.

CONCLUDING REMARKS

All adult females in the Endangered Northeast Atlantic loggerhead turtle subpopulation presented relatively high BCI despite the poor feeding habitat. The reduction on mean BM throughout the season was much lower than expected. Body condition was similar across years and with no influence in the reproductive output within a given season. It would very interesting evaluating the relation between BCI and the survival and remigration of adult females. We also emphasize in the need of better indexes to determine the health status of turtle populations, as these are often unrelated to the clinical status of individuals (e.g. Flint *et al.*, 2010).

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