

New nesting site for the expanding green, olive ridley and hawksbill turtle populations in Cabo Verde

Samir Martins^{a,*}, Juan Patino-Martinez^b, Kirsten Fairweather^c, María Medina^d, Ana Liria-Loza^d, Airton Jesus^e, Jairson da Veiga^b, Albert Taxonera^c, Ivone Monteiro^f, Adolfo Marco^{a,g}

^a BIOS.CV - Conservation of the Environment and Sustainable Development, Santa Isabel 5211 Sal Rei, Boa Vista Island, Cabo Verde

^b Maio Biodiversity Foundation, Porto Inglês, Maio Island, Cabo Verde

^c Associação Projeto Biodiversidade, Mercado Municipal 26, Santa Maria 4111, Sal Island, Cabo Verde

^d NGO Cabo Verde Natura 2000, Sal Rei 5110 Boa Vista Island, Cabo Verde

^e Fundação Tartaruga, Riba d'Olte, N° 172, Sal Rei, Boa Vista Island, Cabo Verde

^f Delegation of the Ministry of Agriculture and Environment, Sal Rei, Boa Vista Island, Cabo Verde

^g Department of Conservation of Biodiversity, Estación Biológica de Doñana, CSIC, C/ Américo Vespucio/s/n, 41092 Sevilla, Spain

ARTICLE INFO

Keywords:

Sporadic nesting
Range expansion
Green turtle
Chelonia mydas
Olive ridley
Lepidochelys olivacea
hawksbill
Eretmochelys imbricata
Cabo Verde

ABSTRACT

Currently, some sea turtle populations are expanding their home range distribution toward higher latitudes at an unprecedented rate. These expansions are associated to factors such as climate change or and increased conservation efforts. Already home to one of the largest loggerhead turtle (*Caretta caretta*) rookeries in the world, the islands of Cabo Verde Archipelago have recorded sporadic nesting of green (*Chelonia mydas*), olive ridley (*Lepidochelys olivacea*) and hawksbill (*Eretmochelys imbricata*) turtles in recent years. Here, we present the compiled information on these sporadic nesting events that occurred between 2013 and 2022 and discuss possible causes for their occurrence. Throughout the study period, the green turtle was documented on 20 occasions, the olive ridley on 25 occasions and the hawksbill on three occasions. All nesting females were found untagged and were subsequently tagged. Nesting activities occurred on the islands of Santo Antão, Sal, Boa Vista and Maio, most of them within the Sea Turtle Natural Reserve in Boa Vista Island. We suggest introducing new conservation strategies targeting the green, olive ridley, and hawksbill turtles nesting in Cabo Verde. We further suggest the use of genetic studies to determine the population origins of these three species.

1. Introduction

Climate change is considered as the main driver of current altitudinal and latitudinal expands of species and population ranges [1]. The observation of new species in previously unknown latitudes is increasingly frequent [2–4] and includes different taxa such as birds [1,5], terrestrial mammals, fish, zooplankton and even plant species [1,6].

In addition to climate change, other factors are also associated with range expansion, such as changes in land use, food resource availability, dispersal ability and intraspecific competition [7–9]. Experimental studies have showed that when is a decline in predation, due for instance to fishing pressure, prey have displayed changes in migration patterns or

expansion of habitats [10,11].

Nevertheless, home range expansion may also be related to heightened public awareness and advances in communication technologies, facilitating citizens to report more frequently on species occurrence in unreported habitats or those with previously sporadic events [2–4]. Citizen science projects that engage volunteers to gather data to address scientific questions have been particularly useful in improving knowledge on the dynamics of species distributions [12,13] and documenting potential home range expansion for numerous taxa across the world [1]. Generally, when a species is particularly charismatic, larger, or endangered, it will receive more attention [14–16].

The increase in conservation efforts is driving the recovery of some

Abbreviations: CCL, Curved Carapace Length; CCW, Curved Carapace Width; IUCN, International Union for Conservation of Nature; PIT, Passive Integrated Transponder; STNR, Sea Turtle Natural Reserve.

* Corresponding author at: BIOS.CV, Sal Rei, C.P. 5211 Boa Vista Island, Cabo Verde.

E-mail addresses: ilheuraso@gmail.com, samirmartins@bioscabo Verde.com (S. Martins).

<https://doi.org/10.1016/j.ecoec.2023.100082>

Received 24 April 2023; Received in revised form 20 December 2023; Accepted 22 December 2023

Available online 27 December 2023

2666-9005/© 2023 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

species, for example the humpback whales (*Megaptera novaeangliae*), which then leads to an increase in reported sightings [19]. New areas of sea turtle occurrence and nesting in the Mediterranean region [3,4,17,18], and on the west African coast [19–25], have been recorded due to an increase in conservation efforts, increasing monitored areas and improving staff training.

The West coast of Africa hosts five species of sea turtle both breeding and foraging, namely the leatherback (*Dermochelys coriacea*), green (*C. mydas*), olive ridley (*Lepidochelys olivacea*), hawksbill (*Eretmochelys imbricata*) and loggerhead (*Caretta caretta*) [26]. All are listed under the International Union for Conservation of Nature (IUCN) Red List threatened categories [27]. Specifically, the olive ridley, loggerhead and leatherback turtles are categorized as vulnerable, the green turtle as endangered and the hawksbill turtle as critically endangered [27]. In this region, the most important nesting ground for green turtles is located in Guinea Bissau, with more than 30,000 nests annually [24] and for loggerhead turtles is in Cabo Verde with more than 100,000 nests annually [25].

In the Cabo Verde Archipelago, the first research efforts on sea turtle occurrence started in the late 1990s, with preliminary results revealing that the coast of these islands holds important habitats for these five species [28]. Since then, research on the nesting beaches around all islands has been conducted, and the results suggest that, during this time, nesting activity was mostly of loggerhead turtles [29,30], more than 50 % of which was located on the island of Boa Vista [25]. Nonetheless, there was one occurrence of a nesting green turtle on the island of Sal in the summer of 2002 [31].

Interestingly, in the last 10 years, several sporadic nesting events of green, olive ridley and hawksbill turtles have been recorded in Cabo Verde, mainly on the islands of Boa Vista, Sal and Maio during the loggerhead turtle nesting season which occurs from June to November [32,33]. Therefore, this manuscript aims to compile the information of sporadic nesting occurrences of these species within the archipelago of Cabo Verde and discuss possible causes of its increased occurrence.

2. Materials and methods

2.1. Study sites

The Cabo Verde Archipelago, located approximately 500 km off the

west coast of Africa, is comprised of ten islands plus one uninhabited island and various islets (Fig. 1). The study sites include the islands of Santo Antão, Sal, Boa Vista and Maio, where nesting of the concerned species has occurred (Fig. 1, 2).

Sal, Boa Vista and Maio are the easternmost and flattest islands of Cabo Verde (Fig. 1) and those with highest loggerhead turtle nesting activities, hosting more than 90 % of all loggerhead nesting in the archipelago [23,25,32,34]. Santo Antão (Fig. 1) is the most mountainous island with black sandy beaches, contributing approximately 1 % of nesting in the archipelago [25].

In Sal, although a green turtle was identified in 2002 [31], the turtle monitoring program started in 2008 with the most important nesting beaches in the south of the island [34,35]. Since 2008 all nesting beaches have been regularly monitored [34].

In Boa Vista, the turtle monitoring program started in 1998 with daily monitoring of the most important nesting beaches, within the Sea Turtle Natural Reserve (STNR; Fig. 1) [28,33]. From 2008, the conservation program expanded the area of implementation, monitoring more than 85 % of nesting activities [32]. Since 2018, all nesting beaches have been monitored daily during the loggerhead nesting season. In Santo Antão, the turtle monitoring program started in 2007 led by locals and with technical support from the National Institute for Fisheries Development and the Municipal Council [36].

In Maio, the turtle monitoring program started in 1999 with several monthly censuses. From 2006 until 2009, the conservation program was limited to basic beach patrols by local guards, however, since 2011, the program expanded to include nesting female and nest monitoring most important nesting beaches all around the island [37,38].

2.2. Beach and nesting female monitoring

On all islands, beach monitoring was generally conducted from 20:00 to 07:00 nightly across all study years, from mid-June to the end of October. In general, the fieldwork was carried out by an experienced supervisor supported by 2 to 4 volunteers or local guards per beach. When encountering a nesting female, the team remained behind the turtle until it commenced digging the egg chamber to minimize stress. Tagging was only conducted after the female finished laying eggs to prevent disturbing her. Female identity was checked by reading existing metal tags or using scanners (AVID mini-tracker or Power tracker) to

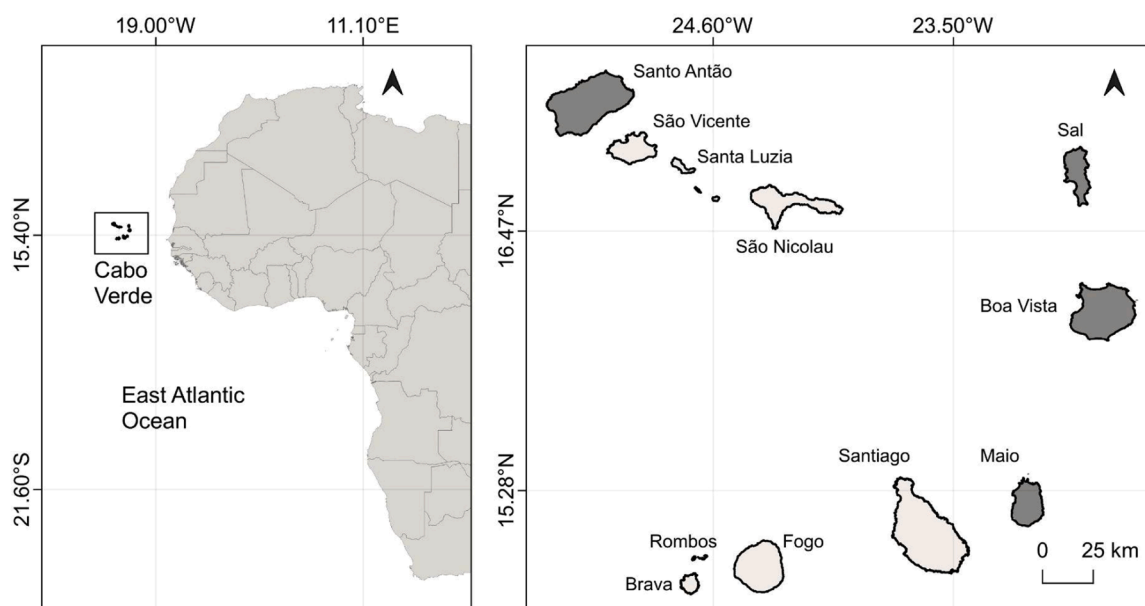


Fig. 1. Map of the Archipelago of Cabo Verde and its location in the West African Region. The islands with recordings of the study species are presented in dark grey; Santo Antão, Sal, Boa Vista and Maio.

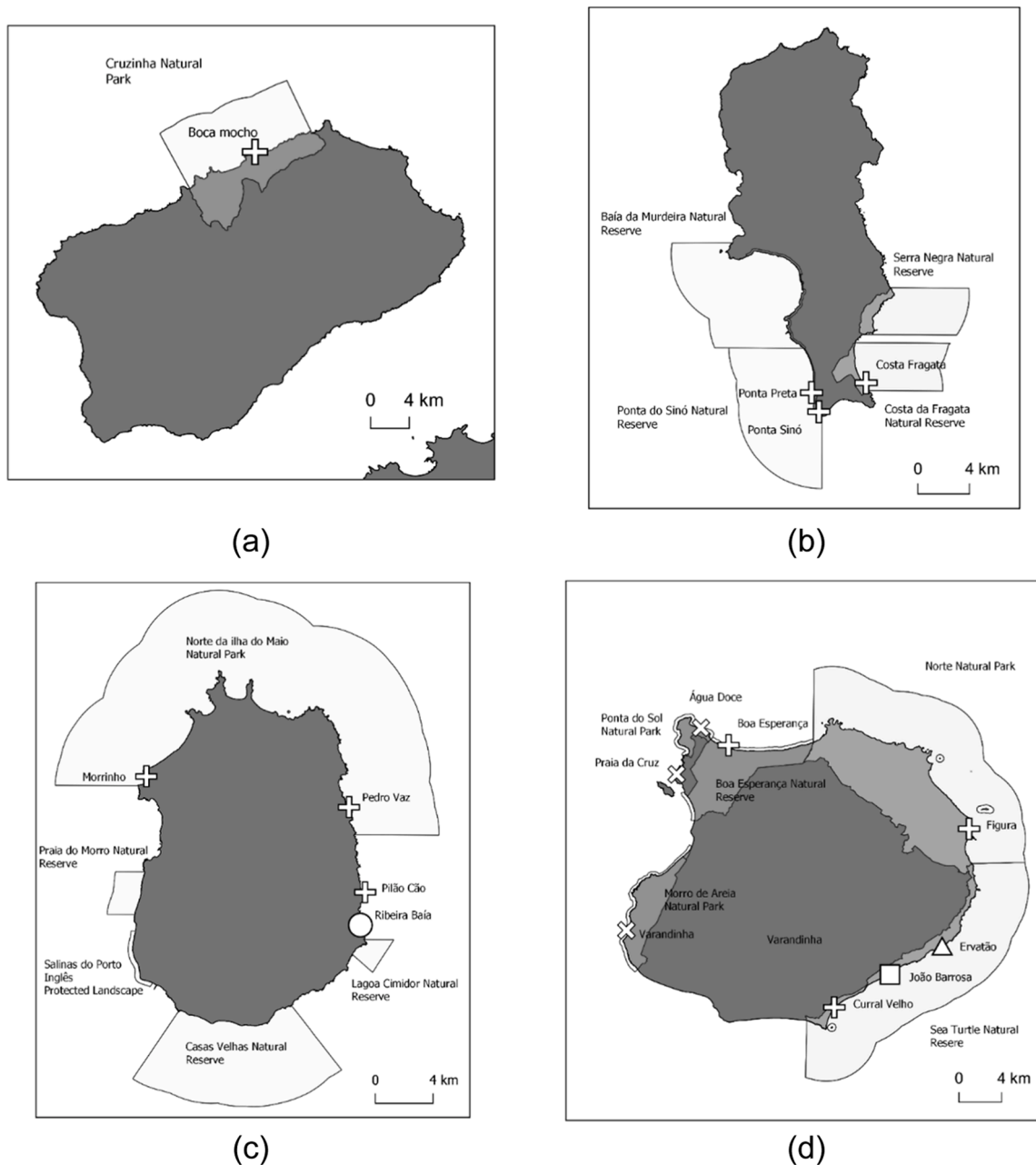


Fig. 2. Map of the Cabo Verdean islands of Santo Antão (a), Sal (b), Maio (c) and Boa Vista (d), where nesting of green, olive ridley and hawksbill turtles has been observed. Symbols indicate nesting occurrence of green turtles only, “+”, olive ridley only, “x” and hawksbill only, “o”. The triangle indicates where both green and olive ridleys have been sighted and the square where sightings of all three species have occurred. Protected areas of each island are shown in light grey.

read passive integrated transponder (PIT) tags when egg laying finished, or the turtle started to return to the sea after a failed nesting attempt. Untagged females were tagged with an AVID FriendChip or Datamars PIT tag in the right flipper, and/or Inconel metal tags fitted on the trailing edge of the foreflippers between the proximal second and third scales, in accordance with the Cabo Verde tagging protocol [39]. The minimum curved carapace length (CCL) from the anterior point at midline (nuchal scute) to the posterior notch at midline between the supracaudals and curved carapace width (CCW) at the widest point, were measured to an accuracy of 2 mm using a flexible measuring tape [40]. Species identification was based on the external morphological features described by Pritchard and Mortimer [41].

Due to the low probability of survival of clutches facing beach flooding, ghost crab predation, light pollution and dog predation [25,42, 43], affected clutches were relocated to hatcheries where possible. In

zones without hatcheries, the clutches were left in their original place, after recorded the clutches size, and fenced with plastic mesh to avoid ghost crab predation or disturbance by other animals or people, or they were relocated to a safer place within that beach.

Morning nest surveys were conducted by patrolling at sunrise and those nests from species other than loggerhead turtles were relocated to a hatchery. All nests were monitored daily during incubation. Three days after hatchling emergence the nests were excavated to count the number of hatched eggs [42,44]. Hatch success (%) was calculated as the total number of hatched eggs over the total number of eggs in each nest [45].

3. Results

3.1. Nesting occurrence

The first occurrence of a nesting green turtle was recorded in 2013, the nesting olive ridley in 2014 and the nesting hawksbill in 2021 (Fig. 3). All these observations were made during the nesting season between July and October. For instance, the green turtle was recorded 20 times, of which 17 were successful nests. Of the females that successfully nested we were able to identify and tag 10 females. The olive ridley was the most recorded species, with 25 females observed and tagged (Fig. 3), and successful nesting occurring on all but one occasion. Regarding the hawksbill turtle, 3 females were identified and tagged, all during successful nesting events.

Most sightings were recorded on Boa Vista with a total of 24 olive ridley, 11 green and two hawksbill sightings, followed by Maio with four green, one olive ridley and one hawksbill sighting (Fig. 2b, c, d). Three green turtle nests were recorded on Sal Island and one green turtle nest on the island of Santo Antão (Fig. 2a, b, c). All nests were recorded between the months of July and September over differing years (Fig. 4).

The nesting beach with highest occurrence was João Barrosa, in the south-east of Boa Vista (STNR), where all the three species were sighted (Fig. 2d). For this beach alone, a total of 21 olive ridley, five green and four hawksbill sightings have occurred. Other beaches where sightings occurred were Ervatão (two green and three olive ridley sightings) and Curral Velho (two green sightings) (Fig. 2d) both in Boa Vista, and Morrinho (two green and one olive ridley sighting) in Maio (Fig. 2c). Occurrences were recorded within a marine protected area (Fig. 2) mainly on the STNR, with the exception being those in Praia da Cruz beach, in Boa Vista (Fig. 2d) and the beaches of Pilão Cão and Ribeira de Baía in Maio (Fig. 2c).

3.2. Remigration

On first encounter, all nesting green, olive ridley and hawksbill turtles were found untagged and were therefore tagged by the field team. Of these, one green turtle was initially captured and tagged in Maio (Pedro Vaz beach) on August 26th, 2018 during an unsuccessful nesting attempt, and was subsequently recorded successfully nesting in Boa Vista (Figura beach) five days later.

One olive ridley female was recaptured on two occasions in Boa Vista. After being tagged on August 16th, 2018 the female was recaptured on September 9th that same year, and again in June of 2022, with all sightings occurring on João Barrosa beach, during the nesting

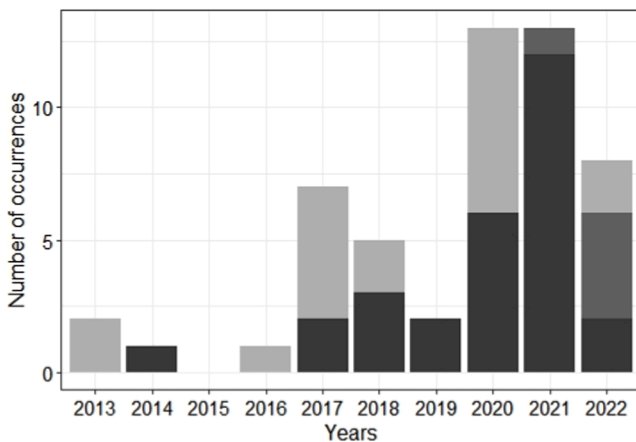


Fig. 3. Occurrence of sea turtle species in Cabo Verde from 2013 to 2022. The green turtle (*Chelonia mydas*) is represented in dark grey, the olive ridley (*Lepidochelys olivacea*) in light grey and the hawksbill (*Eretmochelys imbricata*) in intermediate grey.

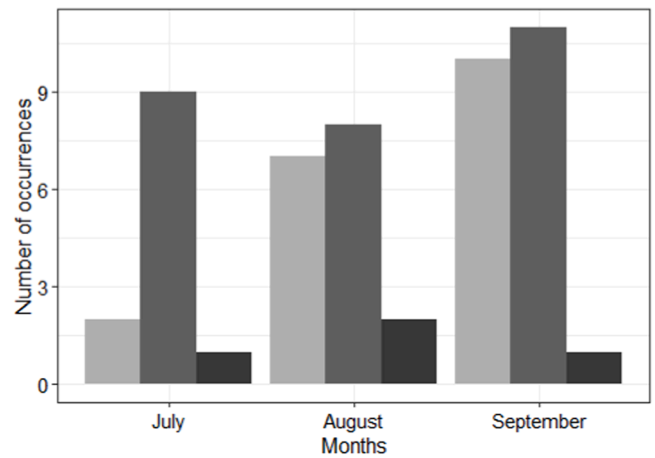


Fig. 4. Seasonality in nesting occurrence of green (*Chelonia mydas*; light grey), olive ridley (*Lepidochelys olivacea*; intermediate grey) and hawksbill (*Eretmochelys imbricata*; dark grey) turtles in Santo Antão, Sal, Boa Vista and Maio Islands in Cabo Verde, 2012–2022.

process.

One hawksbill female, tagged on August 18th, 2018, was subsequently recorded on August 29th and again on September 12th of that same year, while nesting, with all sightings occurring on João Barrosa beach in Boa Vista.

3.3. Reproductive parameters

The nesting and biometric parameters of all three species are provided in Table 1. For the green turtle a mean CCL of 104.8 cm (SD = 7.0, $n = 11$) and CCW of 93.3 cm (SD = 4.3, $n = 11$) were recorded, with a mean of 128 eggs laid (SD = 50.7, $n = 17$) and a hatching success of 59.8 % (SD = 18.2 %, $n = 17$). For the olive ridley, a mean CCL of 71.2 cm (SD = 3.2, $n = 25$) and CCW of 70.9 cm (SD = 2.5, $n = 25$) were recorded, with a mean of 119 eggs laid (SD = 30.7, $n = 21$) and a success of 40.4 % (SD = 24.5 %, $n = 21$). For the hawksbill, a mean CCL of 83.9 cm (SD = 3.1, $n = 3$) and CCW of 75.4 cm (SD = 4.8, $n = 3$) was recorded with a mean of 97 eggs laid (SD = 52.6, $n = 3$) and a success of 57.9 % (SD = 20.1 %, $n = 3$).

4. Discussion

The Cabo Verde Archipelago is home to one of the largest nesting populations of loggerhead turtles in the world, a fact that is well

Table 1

Biometric and nesting data of green (*Chelonia mydas*), olive ridley (*Lepidochelys olivacea*) and hawksbill turtles (*Eretmochelys imbricata*) on the islands of Cabo Verde.

Parameters	Green turtle		Olive ridley turtle		Hawksbill turtles	
	mean (SD)	min – max (n)	mean (SD)	min – max (n)	mean (SD)	min – max (n)
Curved carapace length (cm)	104.8 (7.0)	98.0 – 121.0 (11)	71.2 (3.2)	65.0 – 77.1 (25)	83.9 (3.1)	75.4 – 100.0 (3)
Curved carapace width (cm)	93.3 (4.3)	88.8 – 81.1 (11)	70.9 (2.5)	65.5 – 76.3 (25)	75.4 (4.8)	70.9 – 81.1 (3)
Clutch size	127.9 (50.7)	24 – 202 (17)	119.1 (30.7)	56 – 163 (21)	97.3 (52.6)	43 – 148 (3)
Hatching success (%)	59.8 (18.2)	18.0 – 80.0 (17)	40.4 (24.5)	1.0 – 75.0 (21)	57.9 (20.1)	43.7 – 72.1 (3)

documented [22,23,31,34]. This study shows that, for the first time, green, olive ridley and hawksbill turtles are also nesting in Cabo Verde.

Occurrence of green turtles has been referenced in the Portuguese navigator's logbooks since the 15th century, specifically on the islands of São Vicente, São Nicolau, Sal and Boa Vista [46,47]. Hawksbill turtles have also been reported nesting in Cabo Verde. However, it is suggested that this could be due to misidentification or incorrect assumptions [48]. Both adults and subadults of olive ridley turtles have been found stranded on the archipelago's shore, usually emaciated and debilitated [48].

The repeated nesting found over these years (2013 – 2022), and the subsequent return of some females, indicates the possibility that Cabo Verde is beginning to host a small, new growing population of green, olive ridley and hawksbill turtles, especially in Boa Vista, where most of the sightings occurred. These recurrent nesting events, at least in the last ten years, could be caused by either a natural expansion of their nesting range, a higher monitoring effort or a combination of both. Nesting range expansion among sea turtles is currently occurring. For example, several reports on the expansion of the nesting range of loggerhead turtles in the Mediterranean region [2–4,17] are accredited to the ongoing occupation from distant nesting beaches and not remnants of a past population [2]. The kemp's ridley sea turtle (*Lepidochelys kempii*) has expanded its range to include coastal areas in Florida, USA where nesting now occurs annually, more than 1500 km from their historical nesting range in Mexico [49]. In some regions of the Atlantic coast, leatherback turtles are also expanding their nesting grounds, with new nesting areas documented in southern Brazil [50,51] and Florida [52], with nest numbers increasing each year. A similar phenomenon could also be happening in Cabo Verde with green, olive ridley and hawksbill turtles searching for new breeding areas.

Although an increase in nesting activity has been attributed to growing monitoring efforts in many rookeries [3,4,17,50,52] this seems an unlikely reason in the case of Cabo Verde. At least where most nesting activities were recorded, the monitoring and census of nesting beaches has been consistent since 1998 by trained staff capable of identifying the different sea turtle species. The same has been observed on other islands, where for the last ten years, trained staff have been regularly monitoring the nesting beaches and records of new species have not increased. Therefore, it is unlikely that these sightings or tracks (in the case of green turtle whose tracks differ from the *Caretatinae* subfamily) would not be detected on the nesting beaches. Indeed, green turtles crawl leaving symmetrical diagonal markings made by the forelimbs, while the loggerhead, hawksbill and olive ridley sea turtles crawl leaving alternating (asymmetrical) diagonal marks made by the forelimbs [44]. Secondly, all sightings occurred within the same season as the loggerhead turtle nesting season, from July until October, when every local sea turtle NGO is monitoring all nesting beaches. Nests that were laid outside this season have been monitored until emergence and were all identified as loggerhead turtle nests. Considering that a PIT tag is a reliable tagging system, as the chances of losing it is very low [53], all the recorded females (green, olive ridley and hawksbill) were recorded as new females. Since none was found with a PIT tag. Which excludes the possibility that they were previously tagged as loggerhead turtles by mistake. Most records were successful nests and it is possible that false crawls were missed suggesting the numbers reported here might be underestimated.

Most nesting activity of all three species, occurred on the coast of Boa Vista, within the STNR (Fig. 1). This cannot be considered a result of a higher monitoring effort compared to other nesting beaches, as identical efforts are also applied on beaches outside the STNR and in other islands. Instead, it could represent the females' preference of this nesting habitat. In fact, this coastal region is the most preferred habitat for loggerhead turtles in Cabo Verde, supporting approximately 50 % of the nesting activities of Cabo Verde [32]. Therefore, if the sea turtles reported here are not due to an increased monitoring effort, where have they come from? Juveniles of green and hawksbill turtles from both

sides of the Atlantic have been recorded in coastal waters of the sheltered, easternmost islands of Cabo Verde (Fig. 1). Nonetheless, the observed green and hawksbill females were all large adult females, therefore it is unlikely that large adult nesting females reported here are from Cabo Verde feeding grounds. For instance, there are no records of adults in the area [54,55]. In addition, juveniles of olive ridleys have also never been reported in the region [48]. The closest established green turtle nesting ground to Cabo Verde is 950 km away in the Bijagos archipelago of Guinea Bissau, one of the largest green turtle populations in the world [24,56]. The nearest olive ridley population is approximately 750 km away, in The Gambia, although with lower nesting activities [19]. The largest aggregation of hawksbill turtles is in the Gulf of Guinea, mainly in São Tomé and Príncipe respectively, approximately 4000 km from Cape Verde [57]. The parameters recorded in Cabo Verde, such as CCL, CCW, clutch size or hatching success, are within the ranges reported for these neighboring populations in Guinea Bissau, The Gambia or São Tomé and Príncipe [19,56,57]. However, genetic studies are needed to determine the origins of these nesting adults, because they could originate from a more distant population, even as far as the other side of the Atlantic.

We cannot exclude a possible hybridisation scenario of these three species with the loggerhead turtle in the East Atlantic region, given the size of this population having more than 100,000 nests in recent years [25]. In fact, the hybridisation process has frequently occurred in the past among the Cheloniidae family [58], and some of the reasons given is that species with temporal overlapping in nesting seasons or populations in decline (presenting a low chance to find a mate of the same species) often hybridize [59]. Fertile hybrid combination, at least in the first generation, has been found between five turtle species (olive ridleys, Kemp's ridleys, loggerheads, hawksbills and green turtles) in different parts of the world [58–60]. Cases of hybridisation have also been reported in Western Africa [61]. A study using genetic markers should be performed to identify potential occurrences of hybridisation among these individuals and its consequences for sea turtle conservation in the west African region.

4.1. Conservation concern

Although the underlying causes of these sporadic nesting events in Cabo Verde remain unclear, these species are nesting with success in the Archipelago. Conservation projects in Cabo Verde should start to include these three species of sea turtle (green, olive ridley and hawksbill) within the loggerhead conservation plan or initiate new conservation strategies for these species, such as the one implemented for the loggerhead turtle. This collation of sporadic nesting events could be helpful as a reference for beaches that are beginning to receive new nesting turtle species.

There is also a need to initiate the collection of thermal data from nests and their surrounding area to better understand the incubation temperature, sex and fitness of hatchlings, as previously practiced with loggerheads in Cabo Verde [62–64]. This would aid in developing an effective, climate change resilient conservation strategy and perhaps an increased understanding of the potential dispersal capacity of such species.

The main factors driving these nesting events remain unknown, however, they could be a response to global warming phenomena. Therefore, it seems important that the local ONGs start to develop a monitoring plan, with homogeneous protocols, to improve the knowledge on the nesting activity of these species in Cabo Verde and to focus on the ecological and thermal conditions of these nesting beaches.

Funding

This work was supported by a Marine Turtle Conservation Fund (MTCF) - US Fisheries and Wildlife Service/NOAA [Grant number F12AS00404]; Foundation Rufford [Grant number 36,399-1]; STM (Sea

Turtle Survival) project from PRCM (The Regional Partnership for the Conservation of the Coastal and Marine Zone) and the Mava Foundation for Nature [Grant number AO1 – 17,105].

CRediT authorship contribution statement

Samir Martins: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Supervision, Visualization, Project administration, Funding acquisition, Writing – original draft, Writing – review & editing. **Juan Patino-Martinez:** Conceptualization, Data curation, Methodology, Investigation, Validation, Resources, Writing – original draft, Writing – review & editing. **Kirsten Fairweather:** Validation, Investigation, Resources, Writing – original draft, Writing – review & editing. **María Medina:** Methodology, Validation, Resources, Data curation, Writing – original draft, Project administration, Funding acquisition. **Ana Liria-Loza:** Conceptualization, Data curation, Funding acquisition. **Airton Jesus:** Methodology, Validation, Resources, Project administration, Funding acquisition. **Jairson da Veiga:** Methodology, Resources, Project administration, Funding acquisition. **Albert Taxonera:** Methodology, Resources, Project administration, Funding acquisition. **Ivone Monteiro:** Methodology, Resources, Project administration, Funding acquisition. **Adolfo Marco:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Resources, Project administration, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

Authors have no conflicts of interest to declare.

Data availability

Data will be made available on request.

Acknowledgments

Special thanks to the staff of all sea turtle camps for their support in the field. Thanks to the National Directorate of the Environment for authorizing this study. The authors would also like to thank the National Directorate of the Environment for authorizing this study, and the Marine Turtle Conservation Fund (MTCF) - US Fisheries and Wildlife Service/NOAA, Foundation Rufford, PRCM (The Regional Partnership for the Conservation of the Coastal and Marine Zone) and Mava Foundation for Nature for their funding support. The proposal to conduct this study was evaluated and approved by the National Directorate of the Environment of Cabo Verde (Authorization N° 058/DNA/2022). We would like to thank all turtle conservation NGOs that contributed with their data, which allows us to have a robust database to conduct this study.

References

- [1] C. Parmesan, G. Yohe, A globally coherent fingerprint of climate change impacts across natural systems, *Nature* 421 (2003) 37–42, <https://doi.org/10.1038/nature01286>.
- [2] C. Carreras, M. Pascual, J. Tomás, A. Marco, S. Hochscheid, J.J. Castillo, P. Gozalbes, M. Parga, S. Piovano, L. Cardona, Sporadic nesting reveals long distance colonisation in the philopatric loggerhead sea turtle (*Caretta caretta*), *Sci. Rep.* 8 (2018) 1435, <https://doi.org/10.1038/s41598-018-19887-w>.
- [3] S. Hochscheid, F. Maffucci, E. Abella, M.N. Bradai, A. Camedda, C. Carreras, F. Claro, G.A. de Lucia, I. Jribi, C. Mancusi, A. Marco, N. Marrone, L. Papetti, O. Revuelta, S. Urso, J. Tomás, Nesting range expansion of loggerhead turtles in the Mediterranean: phenology, spatial distribution, and conservation implications, *Glob. Ecol. Conserv.* (2022) e02194, <https://doi.org/10.1016/J.GECCO.2022.E02194>.
- [4] O.O. Prato, V. Paduano, G. Baldi, S. Bonsignore, G. Callea, C. Camera, G. Culmone, S. D'angelo, D. Fiorentino, G. Galia, S. Coriglione, L. Genco, G. Mazzotta, N. Napolitano, F.P. Palazzo, G. Palilla, S.D. Pelletti, T. Mingozi, L. Agresti, P. Casale, Minor sea turtle nesting areas may remain unnoticed without specific monitoring: the case of the largest mediterranean Island (Sicily, Italy), *Animals* 12 (2022) 1221, <https://doi.org/10.3390/ANI12091221>.
- [5] A.T. Hitch, P.L. Leberg, Breeding distributions of North American bird species moving North as a result of climate change, *Conser. Biol.* 21 (2007) 534–539, <https://doi.org/10.1111/j.1523-1739.2006.00609.x>.
- [6] B. Worm, H.K. Lotze, Marine biodiversity and climate change. *Climate Change: Observed Impacts On Planet Earth*: Second Edition, Elsevier Inc., 2016, pp. 195–212, <https://doi.org/10.1016/B978-0-444-63524-2.00013-0>.
- [7] J. Balbontín, J.J. Negro, J.H. Sarasola, J.J. Ferrero, D. Rivera, Land-use changes may explain the recent range expansion of the Black-shouldered Kite *Elanus caeruleus* in southern Europe, *Ibis* 150 (2008) 707–716, <https://doi.org/10.1111/j.1474-919X.2008.00845.x>.
- [8] T.M. Newsome, G.A. Ballard, C.R. Dickman, P.J.S. Fleming, R. Van De Ven, Home range, activity and sociality of a top predator, the dingo: a test of the Resource Dispersion Hypothesis, *Ecography* 36 (2013) 914–925, <https://doi.org/10.1111/J.1600-0587.2013.00056.X>.
- [9] C. Schradin, G. Schmohl, H.G. Rödel, I. Schoepf, S.M. Treffler, J. Brenner, M. Bleeker, M. Schubert, B. König, N. Pillay, Female home range size is regulated by resource distribution and intraspecific competition: a long-term field study, *Anim. Behav.* 79 (2010) 195–203, <https://doi.org/10.1016/J.ANBEHAV.2009.10.027>.
- [10] F. Ferretti, B. Worm, G.L. Britten, M.R. Heithaus, H.K. Lotze, Patterns and ecosystem consequences of shark declines in the ocean, *Ecol. Lett.* 13 (2010) 1055–1071, <https://doi.org/10.1111/J.1461-0248.2010.01489.X>.
- [11] M.D. McMahan, D.C. Brady, D.F. Cowan, J.H. Grabowski, G.D. Sherwood, Using acoustic telemetry to observe the effects of a groundfish predator (Atlantic cod, *Gadus morhua*) on movement of the American lobster (*Homarus americanus*), *Can. J. Fish. Aquat. Sci.* 70 (2013) 1625–1634, <https://doi.org/10.1139/CJFAS-2013-0065>.
- [12] G.T. Pecl, J. Stuart-Smith, P. Walsh, D.J. Bray, M. Kusetic, M. Burgess, S.D. Frusher, D.C. Gledhill, O. George, G. Jackson, J. Keane, V.Y. Martin, M. Nursey-Bray, A. Pender, L.M. Robinson, K. Rowling, M. Sheaves, N. Moltschaniwskyj, Redmap Australia, Challenges and successes with a large-scale citizen science-based approach to ecological monitoring and community engagement on climate change, *Front. Mar. Sci.* 6 (2019) 349, <https://doi.org/10.3389/FMARS.2019.00349/BIBTEX>.
- [13] B.L. Sullivan, J.L. Aycrigg, J.H. Barry, R.E. Bonney, N. Bruns, C.B. Cooper, T. Damoulas, A.A. Dhondt, T. Dietterich, A. Farnsworth, D. Fink, J.W. Fitzpatrick, T. Fredericks, J. Gerbracht, C. Gomes, W.M. Hochachka, M.J. Iliff, C. Lagoze, F. A. La Sorte, M. Merrifield, W. Morris, T.B. Phillips, M. Reynolds, A.D. Rodewald, K. V. Rosenberg, N.M. Trautmann, A. Wiggins, D.W. Winkler, W.K. Wong, C.L. Wood, J. Yu, S. Kelling, The eBird enterprise: an integrated approach to development and application of citizen science, *Biol. Conserv.* 169 (2014) 31–40, <https://doi.org/10.1016/J.BIOCON.2013.11.003>.
- [14] E. Berti, S. Monsarrat, M. Munk, S. Jarvie, J.C. Svenning, Body size is a good proxy for vertebrate charisma, *Biol. Conserv.* 251 (2020), 108790, <https://doi.org/10.1016/J.BIOCON.2020.108790>.
- [15] L.R. Kidd, E.A. Gregg, S.A. Bekessy, J.A. Robinson, G.E. Garrard, Tweeting for their lives: visibility of threatened species on twitter, *J. Nat. Conserv.* 46 (2018) 106–109, <https://doi.org/10.1016/J.JNC.2018.10.001>.
- [16] E.A. Macdonald, D. Burnham, A.E. Hinks, A.J. Dickman, Y. Malhi, D. W. Macdonald, Conservation inequality and the charismatic cat: felis felis, *Glob. Ecol. Conserv.* 3 (2015) 851–866, <https://doi.org/10.1016/J.GECCO.2015.04.006>.
- [17] C. Mancino, D. Canestrelli, L. Maiorano, Going west: range expansion for loggerhead sea turtles in the Mediterranean Sea under climate change, *Glob. Ecol. Conserv.* 38 (2022) e02264, <https://doi.org/10.1016/J.GECCO.2022.E02264>.
- [18] T. Mingozi, G. Masciari, G. Paolillo, B. Pisani, M. Russo, A. Massolo, Discovery of a regular nesting area of loggerhead turtle *Caretta caretta* in southern Italy: a new perspective for national conservation, *Biodivers. Conserv.* 16 (2007) 3519–3541, <https://doi.org/10.1007/S10531-006-9098-6/TABLES/3>.
- [19] A. Agyekumhene, P. Yankson, L. Stemle, P. Allman, Sea turtle nesting activity in Ghana, West Africa, *Chelon. Conser. Biol.* 20 (2021) 273–280, <https://doi.org/10.2744/CCB-1487.1>.
- [20] L.K. Barnett, C. Emms, A. Jallow, A.M. Cham, J.A. Mortimer, The distribution and conservation status of marine turtles in The Gambia, West Africa: a first assessment, *Oryx* 38 (2004) 203–208, <https://doi.org/10.1017/S0030605304000353>.
- [21] F.L. Hama, C. Dyc, A.S.O. Bilal, M.M. Wagne, W. Mullie, Z.E.A.O. Sidaty, J. Fretey, *Chelonia mydas* and *Caretta caretta* nesting activity along the Mauritanian coast, *Salamandra* 54 (2018) 45–55.
- [22] A. Marco, S. Martins, E. Abella, J. Patiño-Martinez, Potential causes for an important and hopeful increase in sea turtle nesting in Cabo Verde in 2018, *Afr. Sea Turtle Newslett.* 10 (2018) 4–8.
- [23] J. Patiño-Martinez, L. Dos Passos, I.O. Afonso, A. Teixidor, M. Tiwari, T. Székely, R. Moreno, Globally important refuge for the loggerhead sea turtle: maio Island, Cabo Verde, *Oryx* (2021) 1–9, <https://doi.org/10.1017/S0030605320001180>.
- [24] A.R. Patrício, C. Barbosa, P. Catry, A. Regalla, Ecology and conservation of green turtles in Guinea-Bissau, *Testudo* 9 (2021) 102–114.
- [25] A.A. Taxonera, K. Fairweather, A. Jesus, A. Gonzalves, A. Queiruga, A. Lima, A. Varella-da-Veiga, C. Oujo, C. Lopes, J.H. Cruz, J.P. Lomba, J. Patiño-Martinez, M. E.S. Medina, N.R. Brás, P. Rendall, S. Correia, S. Roque, V. Rodrigues, C. Eizaguirre, A. Marco, Z. Radwan, M. Tiwari, Sea Turtles, In *Abundance, USA*, 2022.
- [26] J. Fretey, Biogeography and conservation of marine turtles of the Atlantic coast of Africa, 2001.

- [27] IUCN, The IUCN Red List of threatened species. Version 2019-2, (2023). <https://www.iucnredlist.org> (accessed March 3, 2020).
- [28] L.F. López-Jurado, I. Cabrera, D. Cejudo, C. Évora, P. Alfama, Distribution of marine turtles in the archipelago of Cape Verde, West Africa, in: H.J. Kalb, T. Wibbels (Eds.), Proceedings of the Nineteenth Annual Symposium on Sea Turtle Biology and Conservation, NOAA Technical Memorandum NMFS-SEFSC-443, South Padre Island, Texas, 2000, pp. 245–247.
- [29] A. Marco, E. Abella-Pérez, C. Monzón-argüello, S. Martins, S. Araújo, L.F. López Jurado, The international importance of the archipelago of Cape Verde for marine turtles, in particular the loggerhead turtle *Caretta caretta*, Zool. Caboverd 2 (2011) 1–11.
- [30] L.F. Lopez-Jurado, P. Sanz, E. Abella, Loggerhead nesting on Boa Vista, República de Cabo Verde, SWOT report—state of the World's Sea Turtles. (2007).
- [31] A. Liria-Loza, M. Medina-Suárez, S. Martins, A. Marco, J. Nicolau, T. Reischig, A. Taxonera, B. Renom, L. Dos Passos, J. Patiño-Martínez, M. N'Deye-Pereira, A. Sônia, Unusual green and olive ridley nest events in Cape Verde in the last 15 years, in: Proceedings of the Thirty-Eighth Annual Symposium on Sea Turtle Conservation and Biology, Kobe, Japan, 2018.
- [32] A. Marco, E. Abella, A. Liria-Loza, S. Martins, O. López, S. Jiménez-Bordón, M. Medina, C. Oujó, P. Gaona, B.J. Godley, L.F. López-Jurado, Abundance and exploitation of loggerhead turtles nesting in Boa Vista island, Cape Verde: the only substantial rookery in the eastern Atlantic, Anim. Conserv 15 (2012) 351–360, <https://doi.org/10.1111/j.1469-1795.2012.00547.x>.
- [33] N. Varo-Cruz, Biología Reproductora De La Tortuga Boba (*Caretta caretta* Linneo, 1758) En La Isla De Boavista, Archipiélago de Cabo Verde, Universidad de Las Palmas, 2010.
- [34] J.-O.O. Laloë, J. Cozens, B. Renom, A. Taxonera, G.C. Hays, Conservation importance of previously undescribed abundance trends: increase in loggerhead turtle numbers nesting on an Atlantic island, Oryx 54 (2019) 1–8, <https://doi.org/10.1017/S0030605318001497>.
- [35] S.P.P. Lino, E. Gonçalves, J. Cozens, The loggerhead sea turtle (*Caretta caretta*) on Sal Island, Cape Verde: nesting activity and beach surveillance in, Life Marine Sci 27 (27) (2010).
- [36] S.E. Merino, S. Correia, I. Cruz, M.A. Correia, O Arquipélago de Cabo Verde e a conservação das tartarugas marinhas, AmbientalMENTEsustentable 4 (2007) 117–123.
- [37] S. Martins, F. Soares, E. Ribeiro, E. Abella, F. Koenen, A. Marco, et al., Importance of the island of Maio (Cape Verde) for current and future loggerhead conservation in the Eastern Atlantic, in: T. Tucker, L. Belskis, A. Panagopoulou, A. Rees, M. Frick, K. Williams, et al. (Eds.), Proceedings of the Thirty-Third Annual Symposium on Sea Turtle Biology and Conservation, NOAA Technical Memorandum, Baltimore, USA, 2013, p. 106.
- [38] J. Patiño-Martínez, L. Dos Passos, R. Amador, A. Teixeira, S. Cardoso, A. Marco, F. Koenen, A. Dutra, C. Eizaguirre, E.G. Dierickx, M. Tiwari, T. Székely, R. Moreno, Strategic nest site selection in one of the world's largest loggerhead turtle nesting colonies, on Maio Island, Cabo Verde, Oryx (2022) 1–8, <https://doi.org/10.1017/S0030605321001496>.
- [39] A. Marco, E. Abella-Pérez, A. Liria-Loza, S. Martins, N. de S. Loureiro, L.F. López-Jurado, Manual for the monitoring of sea turtles in the Cape Verde Islands, Zool. Caboverd 3 (2012) 1–23. www.scvz.org.
- [40] A.B. Bolten, Techniques for measuring sea turtles, in: K.L. Eckert, K.A. Bjørndal, F.A. Abreu-Grobois, M. Donnelly (Eds.), Research and Management Techniques For the Conservation of Sea Turtles, IUCN/SSC Marine Turtle Specialist Group Publication, Washington DC, 1999, pp. 110–114.
- [41] P.C.H. Pritchard, J.A. Mortimer, Taxonomy, external morphology and species identification, in: K.L. Eckert, K.A. Bjørndal, F.A. Abreu-Grobois, M. Donnelly (Eds.), Research and Management Techniques For the Conservation of Sea Turtles, IUCN/SSC Marine Turtle Specialist Group, Washington DC, 1999, pp. 21–40.
- [42] S. Martins, N. Ferreira-Veiga, Z. Rodrigues, A. Querido, N. de Santos Loureiro, K. Freire, E. Abella, C. Oujó, A. Marco, Hatchery efficiency as a conservation tool in threatened sea turtle rookeries with high embryonic mortality, Ocean Coast Manag 212 (2021), 105807, <https://doi.org/10.1016/j.ocecoaman.2021.105807>.
- [43] S. Martins, J. Patiño-Martínez, E. Abella, N. de Santos Loureiro, L.J. Clarke, A. Marco, Potential impacts of sea level rise and beach flooding on reproduction of sea turtles, Clim. Change Ecol 3 (2022), 100053, <https://doi.org/10.1016/j.ecoche.2022.100053>.
- [44] E. Abella, A. Marco, L.F. López-Jurado, Success of delayed translocation of loggerhead turtle nests, J. Wildlife Manag 71 (2007) 2290, <https://doi.org/10.2193/2006-512>.
- [45] J.D. Miller, Success, determining clutch size and hatching, in: K.L. Eckert, K.A. Bjørndal, F.A. Abreu-Grobois, M. Donnelly (Eds.), Research and Management Techniques For the Conservation of Sea Turtles, 4th ed., IUCN/SSC Marine Turtle Specialist Group, 1999, pp. 134–139, <https://doi.org/10.1037/h0033590>.
- [46] L.F. López-Jurado, Historical review of the archipelagos of Macaronesia and the marine turtles, in: L.F. López-Jurado, A. Liria-Loza (Eds.), Marine Turtles – Recovery of Extinct Populations, Monografía Instituto Canario de Ciencias Marinas, Las Palmas, 2007, pp. 53–76.
- [47] N. de S. Loureiro, M.M.F. Torrao, Homens e tartarugas marinhas. seis séculos de história e histórias nas ilhas de Cabo Verde, Anais. Hist. Alem. Mar. IX (2008) 37–78.
- [48] N. Varo-Cruz, J. Cozens, A. Liria-loza, J. Fretey, New records of the olive ridley sea turtle *Lepidochelys olivacea* (Eschscholtz, 1829) from the Cape Verde Islands, Zool. Caboverdiana 2 (2011) 53–61.
- [49] D.A. Pike, Forecasting range expansion into ecological traps: climate-mediated shifts in sea turtle nesting beaches and human development, Glob. Chang. Biol 19 (2013) 3082–3092, <https://doi.org/10.1111/GCB.12282>.
- [50] L.P. Colman, J.C.A. Thomé, A. de P. Almeida, C. Baptistotte, P.C. Paulo, A. C. Broderick, F.A. Ribeiro, L. Vila-Verde, B.J. Godley, Thirty years of leatherback turtle *Dermochelys coriacea* nesting in Espírito Santo, Brazil, 1988–2017: reproductive biology and conservation, Endanger. Spec. Res 39 (2019) 147–158, <https://doi.org/10.3354/ESR00961>.
- [51] J.C.A. Thomé, C. Baptistotte, L.M.P. Moreira, J.T. Scalfoni, A.P. Almeida, D. B. Rieth, P.C.R. Barata, Nesting biology and conservation of the leatherback sea turtle (*Dermochelys coriacea*) in the state of Espírito Santo, Brazil, 1988–1989 to 2003–2004, Chelon. Conser. Biol 6 (2007) 15–27.
- [52] K. Stewart, M. Sims, A. Meylan, B. Witherington, B. Brost, L.B. Crowder, Leatherback nests increasing significantly in Florida, USA; trends assessed over 30 years using multilevel modeling, Ecol. Appl 21 (2011) 263–273, <https://doi.org/10.1890/09-1838.1>.
- [53] J.B. Pfaller, K.L. Williams, M.G. Frick, B.M. Shamblin, C.J. Nairn, M. Giron dot, Genetic determination of tag loss dynamics in nesting loggerhead turtles: a new chapter in “the tag loss problem, Mar. Biol 166 (2019) 97, <https://doi.org/10.1007/s00227-019-3545-x>.
- [54] C. Monzón-Argüello, L.F. López-Jurado, C. Rico, A. Marco, Pedro López, G.C. Hays, P.L.M.M. Lee, P. López, G.C. Hays, P.L.M.M. Lee, Evidence from genetic and Lagrangian drifter data for transatlantic transport of small juvenile green turtles, J. Biogeogr 37 (2010) 1752–1766, <https://doi.org/10.1111/j.1365-2699.2010.02326.x>.
- [55] C. Monzón-Argüello, N. de S. Loureiro, C. Delgado, A. Marco, J.M.M. Lopes, M.G. G. Gomes, F.A. Abreu-Grobois, Principe island hawksbills: genetic isolation of an eastern Atlantic stock, J. Exp. Mar. Biol. Ecol 407 (2011) 345–354, <https://doi.org/10.1016/j.jembe.2011.07.017>.
- [56] P. Catry, C. Barbosa, B. Paris, B. Indjai, A. Almeida, B. Limoges, C. Silva, H. Pereira, Status, ecology, and conservation of sea turtles in Guinea-Bissau, Chelon. Conser. Biol 8 (2009) 150–160, <https://doi.org/10.2744/CCB-0772.1>.
- [57] R.L. Ferreira, F.R. Ceia, T.C. Borges, J.A. Ramos, A.B. Bolten, Foraging niche segregation between juvenile and adult hawksbill turtles (*Eretmochelys imbricata*) at Príncipe island, West Africa, J. Exp. Mar. Biol. Ecol 498 (2018) 1–7, <https://doi.org/10.1016/j.jembe.2017.10.005>.
- [58] S.T. Vilaça, R. Piccinno, O. Rota-Stabelli, M. Gabrielli, A. Benazzo, M. Matschner, L.S. Soares, A.B. Bolten, K.A. Bjørndal, G. Bertorelle, Divergence and hybridization in sea turtles: inferences from genome data show evidence of ancient gene flow between species, Mol. Ecol (2021), <https://doi.org/10.1111/MEC.16113>.
- [59] L.S. Soares, K.A. Bjørndal, A.B. Bolten, M.L. Wayne, J.C. Castilhos, M.I. Weber, M. López-Mendilaharsu, M.A. Marcovaldi, S.T. Vilaça, E. Naro-Maciel, Reproductive output, foraging destinations, and isotopic niche of olive ridley and loggerhead sea turtles, and their hybrids, in Brazil, Endanger. Spec. Res 44 (2021) 237–251, <https://doi.org/10.3354/ESR01095>.
- [60] C. Brito, S.T. Vilaça, A.L. Lacerda, R. Maggioni, M.A. Marcovaldi, G. Vélez-Rubio, M.C. Proietti, Combined use of mitochondrial and nuclear genetic markers further reveal immature marine turtle hybrids along the South Western Atlantic, Genet. Mol. Biol 43 (2020) 1–11, <https://doi.org/10.1590/1678-4685-GMB-2019-0098>.
- [61] J. Fretey, Première description de l'hybridation entre la Tortue imbriquée (*Eretmochelys imbricata*) et la Tortue verte (*Chelonia mydas*) en Afrique de l'Ouest, Afr. Sea Turtle Newslett 1 (2014) 33–36.
- [62] E. Abella, A. Marco, S. Martins, L.A. Hawkes, E. Abella, A. Marco, S. Martins, L. A. Hawkes, Is this what a climate change-resilient population of marine turtles looks like? Biol. Conserv 193 (2016) 124–132, <https://doi.org/10.1016/j.biocon.2015.11.023>.
- [63] S. Martins, E. Silva, E. Abella, N. de Santos Loureiro, A. Marco, Warmer incubation temperature influences sea turtle survival and nullifies the benefit of a female-biased sex ratio, Clim. Change 163 (2020) 689–704, <https://doi.org/10.1007/s10584-020-02933-w>.
- [64] C. Tanner, A. Marco, S. Martins, E. Abella-Pérez, L.A. Hawkes, Highly feminised sex ratio estimations for the world's third-largest nesting aggregation of the loggerhead sea turtle, Mar. Ecol. Prog. Ser 621 (2019) 209–219, <https://doi.org/10.3354/meps12963>.