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Sea turtles: University of Florida – University of the Azores connection 1984 - present. A review

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The loggerhead (*Caretta caretta*) is the most common sea turtle in the Azores. Since they do not nest in the area, a tagging program was started in the 1980's to try to discover their origin. The result based on size distribution, suggested that they mainly are coming from beaches in SE United States. A collaboration between University of Florida and the University of the Azores began in 1984 in order to proceed with further research.

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INTRODUCTION

That sea turtles are common in the Azores has been known for a long time. The Dutch sea captain Van Linschoten (1595) wrote in his sailing directions: "…when you pass from 36º to 39º 1/3 degrees you will come to see the island of Flores with many turtles floating in the water". In the 18th and 19th centuries biologists started to ask about the origin of the turtles in the eastern Atlantic suggesting they came with the currents from warmer seas. Prince Albert Ist of Monaco published several observations on turtles in the eastern Atlantic and around the Azores archipelago from his oceanographic campaigns on the yachts "Hirondelle" and "Princess Alice". Not knowing of any nesting beaches in the area and being very knowledgeable about currents, he wrote that turtles in the Azores must have come from "Antilles ou Floride" transported by the Gulf Stream (Albert Ier, Prince de Monaco 1898). The Dutch zoologist Brongersma (1972), in his monumental work on European Atlantic sea turtles, suggested that the turtles found in European waters might be derived from western Atlantic nesting beaches. However, there were more options. Later, Brongersma (1982) wrote:" The population in Macaronesian waters consist of turtles that stay in the area for a part of their life; turtles do not breed in the area, but they do get there when they are young, moving away again when they became adult. The question arises: "whence do these turtles come, and where do they go?" He discussed the possibility that they might come from the Mediterranean or the west coast of Morocco. He stated:" To solve these problems, it is necessary to start tagging programs".

Some tagging of loggerheads (*Caretta caretta*) in the Azores had already been done by Dalberto Pombo on the island of Santa Maria (Pombo 1978). At first he used "home-made" tags but later he received tags from the University of Florida. It was with these tags, offered by Pombo, that the first turtles were tagged in 1982 at the Department of Oceanography and Fisheries (DOP) of the University of the Azores in Horta. The contact with University of Florida was made! The cooperation between the two Universities has lasted continuously to this day.

Thirty eight papers in several fields of sea turtle biology have been published by collaborating scientists from both sides of the Atlantic:
http://accstr.ufl.edu/files/accstr_azores_publications.pdf

The Lost Year

While Europeans were wondering where the sea turtles came from, the Americans were discussing "the mystery of the lost year" (Carr 1982). The hatchlings of loggerhead sea turtles (*Caretta caretta*) leave the beaches of south-eastern United States with the size of 5 cm carapace length, disappear into the sea and when they are observed again in benthic foraging areas in the Western Atlantic, they have grown into juveniles of about 50 cm. It is this "missing" life stage that was called the "lost year".

Archie Carr (1909-1987) of the University of Florida, one of the world's foremost authorities on sea turtles, had been inquisitive about the problem for many years, especially in regard to green turtles in Tortuguero, Costa Rica (Carr 1967). For the loggerhead turtles, a breakthrough came in 1984 when Carr received from Helen Martins of the Department of Oceanography and Fisheries (DOP) at the University of Azores, the carapace lengths of 40 turtles tagged in Azores. The size frequency distribution of the Azorean turtles complemented the "missing" size classes in the eastern United States waters (Fig. 1). Carr would conclude that they were part of the US population that reproduces in the southeastern United States (Carr 1986). He suggested that

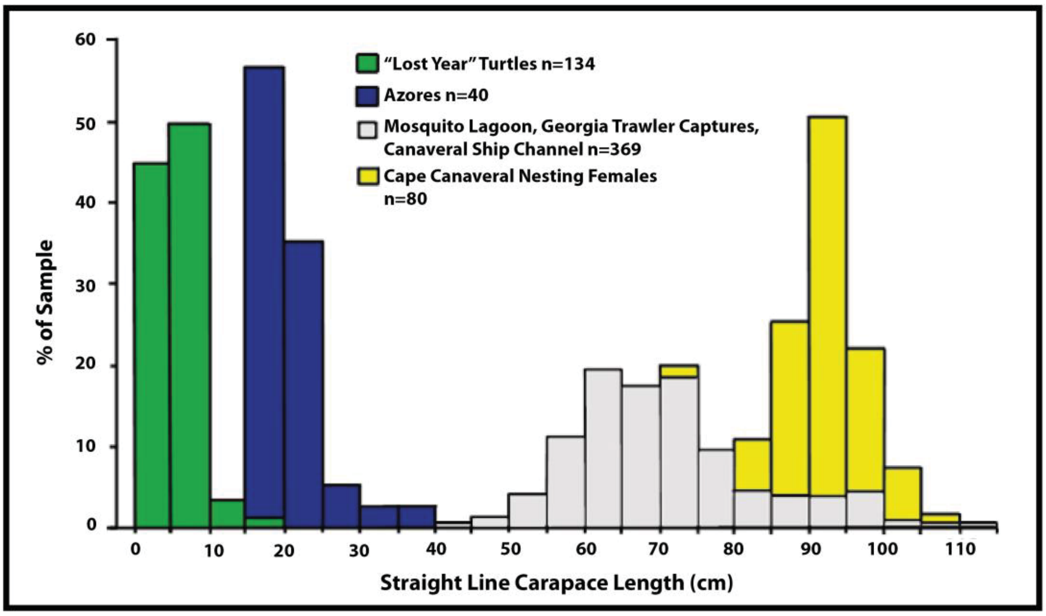

Fig. 1. Shell-length distribution in three groups of American loggerheads and one group from eastern Atlantic (Azores) (Carr 1986).

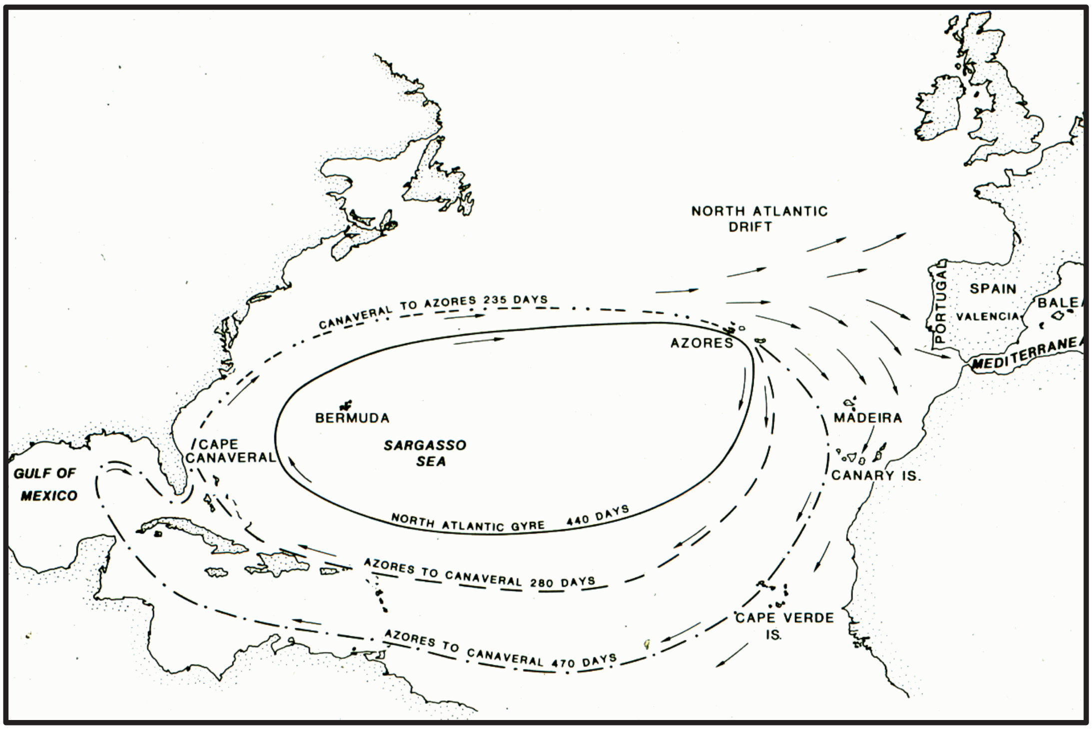

Fig. 2. Three transatlantic routes that turtles (or drift bottles) might follow in the main Atlantic currents, with calculated travel times (Carr 1986).

loggerhead hatchlings from the sotheastern USA rookeries become assimilated into the Gulf Stream Current and from there, some were taken by the eastern part of the Gulf Stream turning south, into the "Azorean" Current, that carried them past Azores, Madeira and Canary Islands and back again to the western Atlantic (Fig. 2).

The tagging of turtles continued in Azores throughout the 1980's with materials (tags and pliers) and funds from Archie Carr to pay artisanal fishermen for catching loggerheads with dipnets.

THE TUNA YEARS - Collaboration with the Azorean Tuna Fleet

After Carr passed away in 1987, and the Center for Sea Turtle Research named after him (ACCSTR), continued with Karen Bjorndal as director. Alan Bolten from the ACCSTR visited the Azores and made plans for further research together with a team from DOP. In order to study the biology of these juvenile Oceanic-stage loggerheads (then called pelagic stage; see Bolten 2003), a collaborative tagging project was established in 1990 with the commercial tuna fleet based in Horta, on Faial island. The tunas in Azores are caught using the pole and line method. When the fishermen were not busy with their fishing activities, they would catch turtles that were found floating on the surface with a dip net. Each boat was supplied with a databook (Fig. 3) in which the fishermen recorded date, tag numbers, latitude, longitude, and curved carapace length (CCL).

We also got the opportunity to get data from Madeira. A tagging program was established with S/Y "Song of the Whale" (from International Fund for Animal Welfare - IFAW) that was working in the area at the time.

Turtles were observed by the crew while looking out for whales, and they would catch turtles using dip nets.

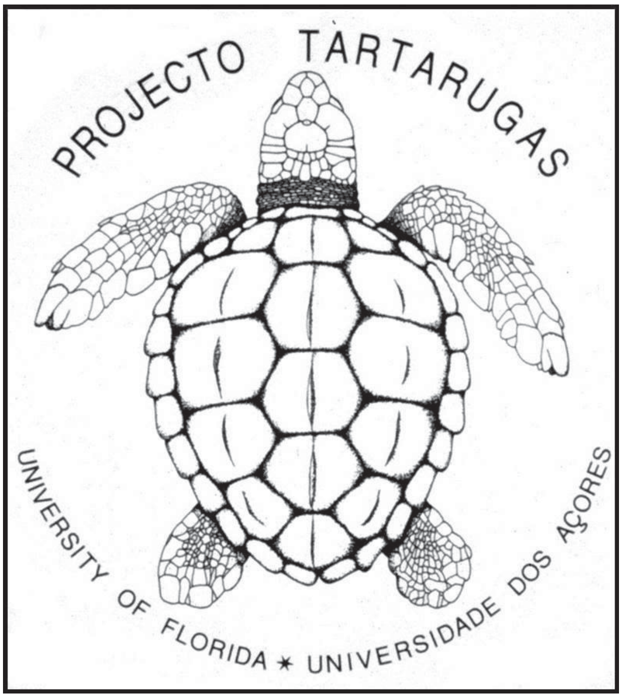

Fig. 3. Data book for the tuna boats.

The response from the tuna fishing fleet was very positive. During the fishing season (late April to October) of the 3 years (1990-1992), the crews tagged and measured 731 loggerhead turtles. On S/Y "Song of the Whale" 45 turtles were tagged during May and June 1990, in the waters around Madeira. Turtles varied in size from 10.0 to 82.0 cm (CCL) with a mean of 33.6 cm. The first results of length frequency distribution from Azores for the three years (1990-1992) and the year 1990 from Madeira were published by Bolten et al. (1993).

Location of the tag recoveries resulting from this program are shown in Figure 4.

The mean size of the Madeiran turtles was significantly greater than that of the 1990 Azorean sample, but the dispersion of the size distribution was not significantly different. The greater mean size of Madeiran loggerheads in 1990 was proposed to support the theory that turtles move from the Azores to Madeira (Carr 1986). The size range from this study was shown to fill completely the size range of turtles never seen in western Atlantic (Bolten et al. 1993, Figs. 5 and 6). The project with the tuna boats continued until 1996.

Migration – Molecular Markers

The major line of evidence that the turtles in the eastern Atlantic emerge from the beaches in the western Atlantic had been that the size distribution complemented each other (Carr 1986; Bolten et al. 1993). Sightings and tag recoveries also supported the hypothesized travel of the loggerhead turtles (Eckert & Martins 1989; Bolten et al. 1992a, Bolten et al. 1992b).

In the beginning of the 1990's genetic markers started to be used for elucidating distribution of migrating marine animals. In most species of sea turtles, females return to nest in the vicinity of their natal beach (Bowen 1995). However, the populations may become mixed on feeding grounds (Carr 1975; Bowen 1995 b) and with important management implications.

To study the status of the loggerhead turtles in Azores and Madeira waters, we analysed mtDNA

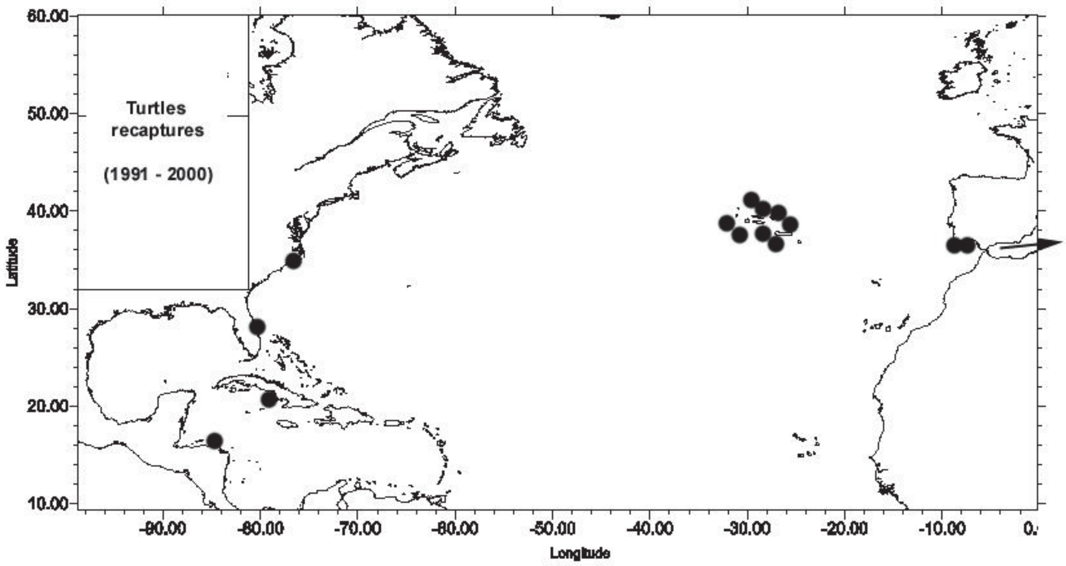

Fig.4. Tag recoveries of loggerheads tagged in the Azores (Bolten 2003).

sequences for 131 juvenile loggerheads, 79 from Azores and 52 from Madeira, caught by dipnet (Bolten et al.1998). Blood samples were collected for analyses of haplotype sequences. Nesting beach haplotype sequences were established for comparing with foraging ground mixed stocks (Bolten et al.1998).

Haplotypes frequencies in the Azores and Madeira samples were not significantly different. Maximum likelihood (ML) analyses were used to estimate contributions from potential source rookeries. The result showed that estimates of relative numbers of turtles in the Azores are: 88% from south Florida nests, 8% from northeast Florida to North Carolina nests, 3% from Mexico nests, and 1% from northwest Florida nests.

LONGLINE FISHERIES – BYCATCH

Loggerhead turtles are protected by the International Union for the Conservation of Nature (IUCN) and by the Bern convention of 1979. Until the first part of 1980's the main conservation problem in our region was turtles caught for food and their shells for the tourist trade, more so in Madeira than in the Azores (Brongersma 1982). The big impact, however, came with the swordfish (*Xiphias gladius*) longline fishery which started as a separate fishery in 1987. The problem of sea turtles in the Azores being incidentally caught by this fishery was first raised by Bolten et al. (1994) who gave a report on 28 loggerheads caught by longline fishing boats targeting swordfish. The hooks in this fishery are primarily baited with squid and mackerel. The lines are generally set at depths of 5 – 50 m. Both loggerheads and leatherbacks (*Dermochelys coriacea*) are captured on the baited hooks although the leatherbacks are more usually entangled in the lines. Turtles are usually released alive by the fishermen. In general, the line is cut as close to the mouth as possible and the hook is left inside.

To better understand this impact and manage turtle populations affected by this fishery, a Longline Observer Program in cooperation between ACCSTR and DOP started in 1998 with the objective to place observers on the longline boats targeting swordfish (Prieto et al. 2000). The sampling method was designed to provide information about the fishery and associated bycatch as catch per unit effort and biological data on the turtles and other species caught incidentally, especially blue sharks. Turtles caught on baited hooks were measured and tagged. Hooks were removed when possible, and hook position, physical condition and behaviour were noted before release. Biologists worked as observers on three boats (Altair, Mar da Prata and Pérola do Corvo). The crews were also trained in this procedure. The program was funded by the National Marine Fisheries Service, USA, through University of Florida.

The largest size classes of loggerheads present in the area are impacted by this fishery (Bolten 1994; Ferreira et al. 2001). They are significantly larger than those caught by dipnet (see Bolten 2003).

Based on a stage-based population model for loggerhead turtles from the southeastern United States, Crouse et al. (1987) concluded that these large size classes are important for the survival of loggerhead sea turtles in the Atlantic. Ferreira et al. (2001) estimated, based on the catch rate of our data, that during the swordfish season (May to December) of 1998, the turtles caught by the entire fleet amounted to 4190.

In order to find a way to decrease this impact, a workshop to discuss the problem was held in Horta in 1998 (Bolten et al. 2000). A Longline Experiment was carried out during the years (2000-2004) to evaluate the effects of gear modification (hook type and size) on rates of sea turtle bycatch in the swordfish longline fishery in the Azores (Bolten et al. 2004). The size ranges of turtles caught during the experiments (mean=52.2 cm CCL) were the size/age classes that recruit to the neritic foraging grounds of the western Atlantic (Ferreira et al. 2001). High mortality in these age classes will result in reduced recruitment to the nesting beaches and may have an important impact on the population status. It was confirmed that the use of circle hooks significantly decreased the rate of throat hooking in loggerhead turtles and thus may reduce sea turtle mortality (Bolten et al. 2004). The hour of day of longline retrieval had a significant effect on the rate of loggerhead turtles caught. Therefore, retrieval of the longline earlier in the day would reduce the interaction with loggerhead turtles (Bolten et al. 2004).

The turtles might be caught with the hook in the mouth which is most common, or they may have swallowed the hook (in oesophagus or gut), and are rarely hooked externally, e.g. in a flipper. When the hook is in the lower jaw it is easier to remove and causes less injury.

To get an indication of what happens to turtles released with swallowed hooks, Brian Riewald (Ph.D. student of University of Florida) conducted an experiment at DOP (Riewald et al. 1999, 2001). He used 6 turtles that were deeply hooked in oesophagus and 12 unhooked control individuals. These were equipped with satellite-linked time depth recorders (SLTDR) and released in the summer of 2000. The end result showed that the hooked turtles made shallower and longer dives than the control turtles and tended to move more linearly to the east. The control turtles, however, tended to move nonlinearly and remain in closer proximity to the mid-Atlantic ridge. Diving profiles of the two groups were also shown to be different, the hooked turtles would dive shallower but with longer duration of each dive. (Riewald et al. 2001). It was not possible from this experiment to know if transmitter failure was due to mortality or mechanical causes. The behaviour of 1 of the 6 hooked turtles suggested that it was recovering.

GROWTH - DURATION OF THE OCEANIC STAGE

"The mystery of the lost year" received a lot of attention in the past. Carr (1986) wrote: "We know enough now to stop speaking of 'the lost year'…" and he suggests: "… the lost year of the Atlantic loggerhead is more like four or five years…" To estimate the duration of the oceanic stage, we must know the size at which the turtles leave the oceanic habitat and recruit to neritic habitats and the somatic growth rates of the turtles. Loggerheads begin to leave oceanic habitats at approximately 46 cm CCL, and almost all of them have left the oceanic habitat by 64 cm CCL (Fig. 6). Preliminary estimates of the duration of the oceanic stage of 10-12 years were given by Bolten et al. (1994, 1995) based on growth rates calculated from recaptures of tagged turtles.

Fig. 5. Helen Martins with a first year class loggerhead stranded in Porto Pim Bay, Faial island, Azores (photo: Alan Bolten, 1989)

In addition to recapture of tagged turtles we could estimate growth rates of very small turtles. Following a storm, 6 turtles with CCL from 9.1 to 10.8 cm were found alive or recently dead at Porto Pim beach on Faial island on 7/8 February 1990, and one more on 25 January 1993 measuring 10.4 cm (Fig. 5). These individuals were almost certainly young-of-the-year with an average hatching date of 1 September the previous year. Hatchlings have a mean CCL of 4.65 cm, so the mean growth rate was 1 cm CCL per month (Bjorndal et al. 2000).

Another analysis of the duration of the oceanic stage was carried out with length frequency models using the length distribution data from the collaboration with the Azorean Tuna Fleet described above, and data from young-of-the-year loggerheads (Bjorndal et al. 2000). This study

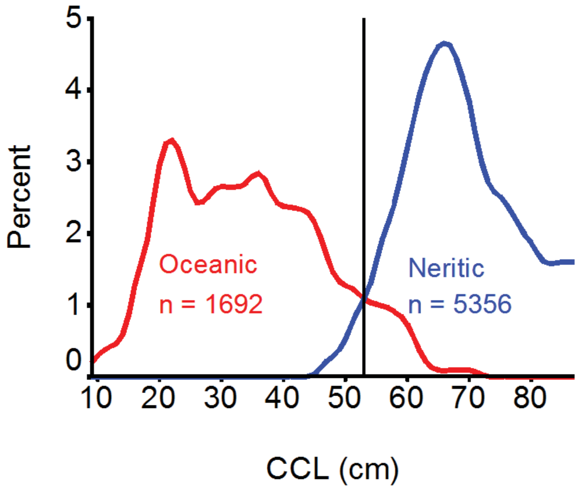

Fig. 6. Red curve shows size distribution of oceanic loggerheads captured in waters around the Azores (n=1692) and blue curve, neritic loggerheads stranded in southeastern USA (n= 1803). Adapted from Bjorndal et al. (2000).

generated duration estimates of 6.5 to 11.5 years at 46 to 64 cm CCL, respectively (Bjorndal et al. 2000). These estimates were consistent with growth rates calculated from recaptures of tagged turtles. Incorporating the oceanic stage duration in population models would have a major effect on estimates of population growth.

However, for this study (Bjorndal et al. 2000), we did not yet take into consideration compensatory growth (CG) which is a very important concept. CG may occur when an organism that has grown at a reduced rate due to environmental condition, is exposed to better conditions. During the first years of life the North Atlantic loggerheads inhabit extremely stochastic environments. The duration and path of the journey undertaken by loggerhead hatchlings from western Atlantic nesting beaches to eastern Atlantic foraging areas are determined largely by chance (Bolten 2003). They encounter habitats that vary greatly in temperature, wind and current conditions. And, because oceanic-stage loggerheads feed mainly on epipelagic invertebrates with patchy distribution, this lifestage experiences alternating periods of food abundance and limitation (Bjorndal 1997). This environmental variation results in variable growth rates. Skeletochronology was used to estimate ages and annual growth rates in loggerheads around Azores and Madeira (Bjorndal et al. 2003a). Somatic growth rates were based on three different analytical approaches. We showed that variation in size-at-age in juvenile loggerheads is substantially reduced by compensatory growth and thus, size is a better predictor of age than expected. Compensatory growth decreases with age, apparently as the turtles get greater control of their movements.

Survival Probabilities

We used catch-curve analyses to generate initial estimates of mortality rates of the oceanic-stage juvenile loggerheads in the waters around the Azores (Bjorndal et al. 2003b). Two age distributions were evaluated: a total sample of 1600 turtles captured by a variety of methods between 1984 and 1995 and a subset of 733 turtles captured by collaboration with the Azorean tuna fleet from 1990 to 1992. Because loggerhead sea turtles begin to emigrate from oceanic to neritic habitats at age 7, the best estimates of instantaneous mortality rate (0.094) and annual survival probability (0.911) not confounded with permanent emigration were generated for age classes 2 through 6. These estimates must be interpreted with caution because of the assumptions upon which catch-curve analyses are based.

Consolidating Sea Turtle Conservation in the Azores (COSTA)

Since 2015, DOP and the ACCSTR are collaborating under a broad conservation program called the COSTA project, which aims to fortify research capacity and conservation practices for the benefit of loggerhead sea turtles. The program consists of a longline fishery observer program for the Portuguese fleet that operates in the eastern North Atlantic for estimating and monitoring the impact of this activity on oceanic-stage juvenile loggerheads, but also to promote best practices on board in order to minimize adverse impacts. The program relies on two full time observers that operate from the Portuguese mainland as well as from the archipelago and can count on the collaboration of large part of the fishing fleet.

Interactions with floating marine debris are a second important threat for juvenile loggerheads. Based on the analysis of gastrointestinal tracts of stranded and bycaught individuals, 83% of the loggerhead sea turtles were shown to have ingested debris composed exclusively of plastics (Pham et al. 2017). Stranding events and interactions at sea such as entanglements are therefore closely monitored.

The program further maintains the collaborative tagging program with the participation from local whale watching companies, and invests strongly in training and outreach to marine users, children and by extension the general public to promote awareness and involvement concerning conservation issues of sea turtles.

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