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TOMOMI SAITO[1,*], MASANORI KURITA[1], HITOSHI OKAMOTO[1], ITARU UCHIDA[1,4], DENISE PARKER[2], AND GEORGE BALAZS[3]

[1]*Port of Nagoya Public Aquarium, 1-3 Minato-machi, Minato-ku, Nagoya 455-0033, Japan [m-kurita@nagoyaminato.or.jp; h-nakamura@nagoyaminato.or.jp];*
[2]*Joint Institute for Marine and Atmospheric Research, 2032 SE Oregon State University Drive, Newport, Oregon 97365 USA [Denise.Parker@noaa.gov];*
[3]*Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 1845 WASP Boulevard, Honolulu, Hawaii 96818 USA [itsahonuworldinhawaii@hotmail.com];*
[4]*Present address: Nango, Chigasaki, Kanagawa 253-0061, Japan*
**Present address of corresponding author: Usa Marine Biological Institute, Kochi University, Usa, Tosa, Kochi 781-1164, Japan [t-saito@kochi-u.ac.jp]*

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Tracking Male Loggerhead Turtle Migrations Around Southwestern Japan Using Satellite Telemetry

Tomomi Saito[1,*], Masanori Kurita[1], Hitoshi Okamoto[1], Itaru Uchida[1,4], Denise Parker[2], and George Balazs[3]

[1]*Port of Nagoya Public Aquarium, 1-3 Minato-machi, Minato-ku, Nagoya 455-0033, Japan [m-kurita@nagoyaminato.or.jp; h-nakamura@nagoyaminato.or.jp];*
[2]*Joint Institute for Marine and Atmospheric Research, 2032 SE Oregon State University Drive, Newport, Oregon 97365 USA [Denise.Parker@noaa.gov];*
[3]*Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 1845 WASP Boulevard, Honolulu, Hawaii 96818 USA [itsahonuworldinhawaii@hotmail.com];*
[4]*Present address: Nango, Chigasaki, Kanagawa 253-0061, Japan*
**Present address of corresponding author: Usa Marine Biological Institute, Kochi University, Usa, Tosa, Kochi 781-1164, Japan [t-saito@kochi-u.ac.jp]*

Abstract. – Three satellite-tagged male loggerhead turtles (*Caretta caretta*) were released from the coastal waters of Satsuma Peninsula, Kyusyu, southwestern Japan (lat 31°42′N, long 130°18′E), and their movements were tracked for up to 449 d. Total distance traveled by the turtles ranged from 1540 to 5519 km. The turtles remained mainly along the coast and islands of the East China Sea and the Sea of Japan, except for spending a brief period of time (1–30 d) in the open ocean. The long-distance movement followed a seasonal pattern, evidently triggered by fluctuations in sea surface temperature.

Key Words. – Reptilia; Testudines: Cheloniidae; *Caretta caretta*; male; migration; sea surface temperature

Loggerhead turtles (*Caretta caretta*) are found worldwide in temperate to tropical seas and are listed as endangered on the International Union for Conservation of Nature (IUCN) Red List (IUCN 2014). The Japanese archipelago is the only reproductive area for the North Pacific population of loggerheads. Data on the migratory pattern of the species are essential in order to devise effective conservation strategies.

The migration of loggerheads has been monitored mainly among adult females that come ashore to nest, during which time flipper tags and satellite transmitters are attached (Godley et al. 2008). Iwamoto et al. (1985) reported that Japanese female loggerhead turtles forage primarily on the continental shelf of the East China Sea after they nest on the beaches of Miyazaki Prefecture, Kyusyu. Nishimura and Nakahigashi (1992) performed a survey of fishermen and research institutes running research vessels around the East China Sea which revealed that 40 adult loggerhead turtles were caught incidentally in trawl nets in the East China Sea from 1987 to 1990. Sato et al. (1997) and Kamezaki et al. (1997) recognized similar movement of the Japanese female loggerheads by the mark-and-recapture method from 16 nesting sites along the Japanese coastline, including parts of Miyazaki and Wakayama prefectures. These past studies led to the characterization of the East China Sea as an important adult resident foraging habitat for Japanese female loggerheads (Nishimura and Nakahigashi 1990; Kamezaki et al. 1997).

Satellite telemetry has made it possible to monitor the movements of turtles over large areas. Moreover, although the sex of the turtles was not identified, Kobayashi et al. (2011) characterized a region of high occupancy for nonreproductive loggerhead turtles in the East China Sea, covering 433,549 km^2 of coastal and pelagic areas next to Taiwan, China, Japan, and South Korea.

There were no original papers that clarified the seasonal migration of Japanese male loggerheads based on the mark-and-recapture method, although 2 satellite tracks on the seasonal migration of males were known (Sakamoto et al. 1997; Hatase et al. 2002a). Sakamoto et al. (1997) tracked a small-sized male loggerhead turtle that had been incidentally caught in a pound net in the southernmost region of the Kii Peninsula, Wakayama Prefecture, in western Japan, in January 1996. This turtle migrated southeast along the Kuroshio Current and stayed in the south of the current in the pelagic Pacific throughout the winter (Sakamoto et al. 1997). Hatase et al. (2002a) also examined another small-sized male loggerhead caught in the same location as the previous study. As these males were relatively small, it was suggested that they possibly differed in foraging habitat by body size, as females do (Hatase et al. 2002b, 2007; Hawkes et al. 2006). However, little remains known about the migratory habits of adult males.

Several researchers cite sea surface temperature (SST) as one of the factors promoting the seasonal migration of loggerhead turtles. Bentivegna (2002) stated that SST stimulated the seasonal migration of the male

and female loggerheads in the Mediterranean Sea. In the western Atlantic, Hawkes et al. (2007) suggested that SST promoted the north–south migration of the female loggerheads. Mansfield et al. (2009) also observed that neritic loggerhead turtles began migrating south of Cape Hatteras, North Carolina, when the SST dropped below 20°C. Furthermore, Polovina et al. (2000, 2004, 2006) identified that juvenile, subadult, and adult loggerhead turtles in the North Pacific occupied specific areas of the pelagic environment, possibly related to SST and/or the mechanisms of ocean productivity and retention of zooplankton prey.

Using satellite telemetry we tracked 3 male loggerhead turtles in the East China Sea and southwestern Japanese waters. The aims of this study are to 1) ascertain the seasonal migratory route of Japanese male loggerhead turtles in this area, 2) ascertain how they utilize the coastal areas of the East China Sea and the Sea of Japan, and 3) describe how SST influences migration in this area.

METHODS

Three male loggerhead turtles were captured alive in a pound net located 0.4 km offshore of Kasasa-cho, Satsuma Peninsula, Kagoshima Prefecture, Kyusyu, southwestern Japan (lat 31°42′N, long 130°18′E), from 31 March to 10 May 2005 (Table 1). We measured the straight carapace length (SCL) and straight carapace width of the turtles to the nearest 0.1 cm. Male turtles were identified based on external morphology (i.e., tail length or presence of claws on front flippers) (Kamezaki 2003; Limpus and Limpus 2003). After the measurements were taken, they were kept in 8 × 8-m cages placed inside the Kataura fishing port on Kasasa-cho until their release dates. The capture site was located near the southern end of the Fukiagehama beach, which is one of the most prominent loggerhead rookeries in mainland Kyusyu (Kamezaki et al. 2003). The size of nesting females at the Fukiagehama beach from 1999 to 2007 ranged from 72.0 to 95.3 cm in SCL (84.2 ± 5.2 cm) (Sea Turtle Association of Japan 2007).

Telonics, Inc. (Mesa, AZ) ST-20 platform terminal transmitters (PTTs) were attached to each turtle's carapace with epoxy resin and fiberglass cloth after the carapace had been carefully cleansed of grease and debris (Balazs et al. 1996). Duty cycles of tags were 6 hrs on, 48 hrs off for PTT IDs 53752 and 53749, and 12 hrs on, 48 hrs off for PTT ID 53755. After the epoxy had completely dried, the turtles were transported by fishing boat and released from the capture sites: 1 male (ID 53752) on 28 May 2005, and 2 males (IDs 53749 and 53755) on 24 June 2005. The turtles' locations were obtained through the Argos satellite system that classified 6 location classes (LC) of decreasing accuracy (LC 3: <150 m, LC 2: 150–350 m, LC 1: 350–1000 m, LC 0: >1000 m, LC A and B no accuracy given) plus LC Z, which constitutes invalid, reject locations. We used only

Table 1. Summary of metadata for 3 male loggerhead turtles satellite-tagged in southwestern Japan including straight carapace length (SCL), straight carapace width (SCW), sea surface temperature (SST), and days and distance traveled.

Turtle ID	SCL (cm)	SCW (cm)	Date caught	Date deployed	Start position	SST at release (°C)	SST at beginning of southwestward migration (°C)	Mean SST ± SD (range) (°C)	Date terminated	End position	Days tracked	Integrated distance (km)	Endpoint distance (km)
53752	81.7	65.1	31 Mar 2005	28 May 2005	Lat 31.28°N, long 130.09°E	22	N/A	27.2 ± 1.9 (24–29)	12 Sep 2005	Lat 31.38°N, long 127.58°E	101	1540	208
53749	73.7	57.3	4 Apr 2005	24 Jun 2005	Lat 31.28°N, long 130.09	24	N/A	26.6 ± 1.7 (23–29)	3 Nov 2005	Lat 33.48°N, long 129.04°E	133	2227	280
53755	88.7	69.6	10 Apr 2005	24 Jun 2005	Lat 31.28°N, long 130.09°E	24	20	21.1 ± 4.3 (16–29)	10 Sep 2006	Lat 33.38°N, long 127.10°E	449	5519	371

LC 1, 2, and 3 as well as LC 0, A and B fixes that provided reliable information about the migration path. When more than one location was obtained within a day, the most accurate LC was selected according to the CLS/Argos hierarchy. Geolocations requiring a travel speed of more than 5 km/hr were eliminated (Luschi et al. 1998). The total distances covered by the males were defined as the sum of the shortest distances between successive locations. The minimum average travel speeds for each segment of track were calculated using the distance traveled by the time between filtered locations.

We divided migration into oceanic (waters deeper than 200 m) and neritic (waters less than 200 m deep) phases. Possible days in oceanic or neritic waters were calculated using location and time data. Bathymetric data were sampled from the Japan Oceanographic Data Center (http://www.jodc.go.jp) for filtered locations. The SST of Japanese waters during the study calculated as daily mean temperature and sorted with the resolution of 1°C were obtained from the Japan Meteorological Agency (http://www.jma.go.jp). Temperatures for daily positions for each turtle were then determined from these data.

RESULTS

The first male (ID 53752, 81.7 cm SCL) was released from the capture site on 28 May 2005 and tracked until 12 September 2005 (Fig. 1A). The SST upon release was 22°C. The turtle traveled 1540 km in 101 d (Table 1), spending 2–7 d in the open ocean of the East China Sea. It first moved northwest and remained mainly around 200 km west-northwest of the release site. The last signal was sent from approximately 290 km west of the release site.

The second male (ID 53749, 73.7 cm SCL) was released on 24 June 2005 and the SST upon release was 24°C. The last signal was sent from 30 km southwest of the Tsushima Islands on 3 November 2005 (Fig. 1B). It traveled 2227 km in 133 d of tracking. The turtle spent 17–30 d on the open ocean of the East China Sea. First, it moved westward and remained around 120 km west-northwest of the release site until mid-July 2005. It subsequently moved and remained for a month around 150 km northwest of the Goto Islands, Nagasaki Prefecture. After the beginning of September 2005, the turtle traveled to the area between the Goto Islands and Tsushima Island. The tag then stopped when the turtle was 30 km off Karatsu, Saga Prefecture, on 28 September 2005; however, this turtle did not enter the Sea of Japan.

The third male (ID 53755, 88.7 cm SCL) was released with the second male on 24 June 2005. It undertook the longest migration: 5519 km over 449 d until the last signal was sent on 10 September 2006 from 120 km south of Jeju Island, South Korea (Fig. 1C). The turtle remained mainly in the neritic phase along the coasts and islands of the East China Sea and the Sea of Japan, except for an oceanic phase for a brief period of

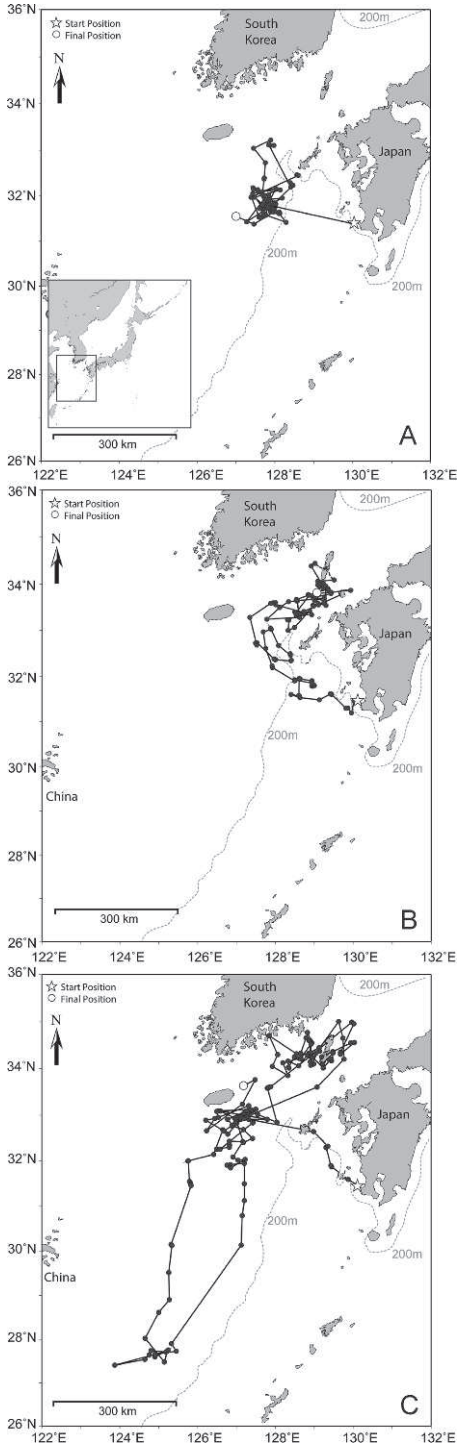

Figure 1. Migration route maps. ☆: start position; ○: final position. A: Male loggerhead turtle ID 53752 after the release off Satsuma Peninsula, southwestern Japan, on 28 May 2005. B: Male loggerhead turtle ID 53749 after the release off Satsuma Peninsula, southwestern Japan, on 24 June 2005. C: Male loggerhead turtle ID 53755 after the release off Satsuma Peninsula, southwestern Japan, on 24 June 2005.

time (1–12 d) in the open ocean. First, it moved northwest from the release site and stayed 80 km south of Jeju Island. It then moved around Tsushima Island and the southern coast of South Korea in August 2005. It reached 25 km east of Tsushima Island on 30 November 2005,

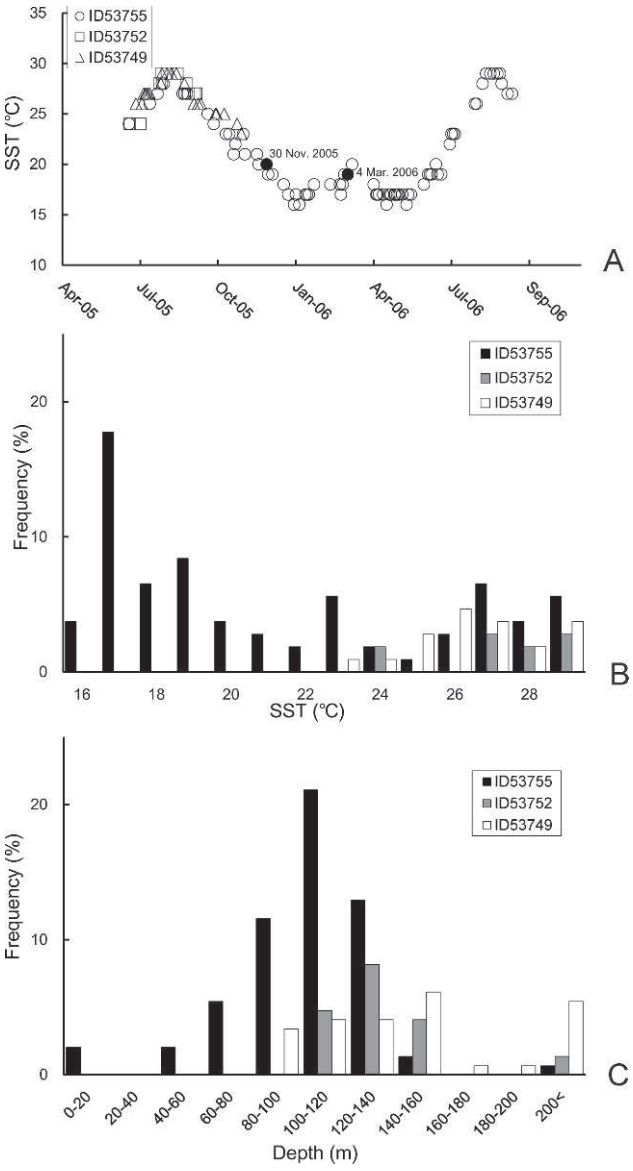

Figure 2. Sea surface temperature (SST) and bathymetry of habitat. A: SST at each location of the male loggerhead turtles from June 2005 to September 2006. ● indicates SSTs at the northernmost turtle position on 30 November 2005 and the southernmost turtle position on 4 March 2006. B: Frequency distribution of SSTs collected for all turtle locations for the entire tracking period. C: Frequency distribution of bathymetry collected for all turtle locations for entire tracking period.

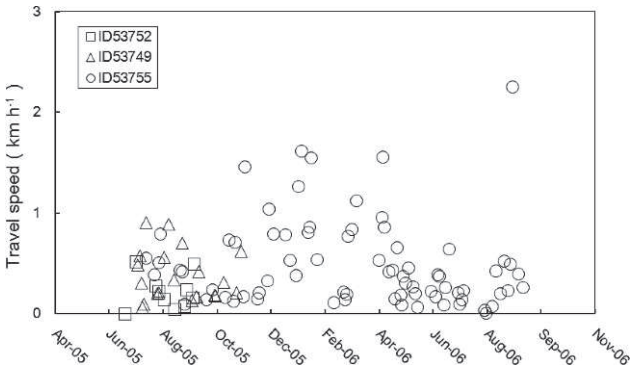

Figure 3. Seasonal change of travel speed (km/hr) for the 3 male turtles satellite-tracked during this study.

when the SST was 20°C. Then, the turtle returned to the southwest without entering farther into the Sea of Japan on the 2 December 2005 (SST: 19°–20°C). The SST of this location decreased from 20°C to 16°C in the month after the turtle moved to the southwest. It later travelled to 400 km west of the release site in early January 2006 (SST: 18°–19°C). Furthermore, it moved southward to 350 km northwest of Okinawa Island on 18 January 2006 (SST: 17°–18°C) and remained there until the end of March 2006 (SST: 19°–21°C). From the end of March 2006 (SST: 20°C) the turtle went northward again, passing 270 km to the west of the release site on 7 April 2006 (SST: 17°–18°C). The turtle remained within 200 km of Jeju Island from the middle of April 2006 until the last location data was received on 10 September 2006.

The SST at which the 3 males traveled ranged from 16°C to 29°C, from winter to summer, respectively (Fig. 2A). The third male (ID 53755) showed a remarkable year-round migration pattern depending on the fall and rise of SST in the Sea of Japan and the East China Sea. Figure 2B shows the frequency distribution of SSTs collected for all turtle locations for the entire tracking period. Mean SSTs at filtered locations were 27°C, 27°C, and 21°C for locations received from turtles with PTT IDs 53752, 53749, and 53755, respectively. Figure 2C shows the frequency distribution of bathymetry collected for all locations over the entire tracking period. Mean ocean depth at filtered locations was 159 m, 225 m, and 102 m for locations received from turtles with PTT IDs 53752, 53749, and 53755, respectively.

The turtles traveled at a mean speed of 0.52 km/hr in early November to early April, but they traveled at mean 0.20 km/hr in the other periods (Fig. 3). The faster movements (> 1 km/hr) of the male with PTT ID 53755 were often observed during the period from early November 2005 to early April 2006.

DISCUSSION

The 3 males captured in the coastal waters of Satsuma Peninsula, Kyusyu, southwestern Japan, made excursions around the East China Sea and the Sea of Japan. Importantly, we were able to follow the signal that came from one of them over the course of a full year. The dispersal of our male loggerheads was similar to the postbreeding patterns reported for adult females in this region (Kamezaki et al. 1997). This is also consistent with the results by Nishimura and Nakahigashi (1990, 1992) and Kobayashi et al. (2011), in that there is a region of high occupancy for nonreproductive female and male loggerheads in the East China Sea. In this study, the males were at higher latitudes of the East China Sea and the Sea of Japan in the summer before migrating south to the warm temperate wintering grounds in the autumn. This

pattern is clearly illustrated by the movement of the turtle with PTT ID 53755, which was tracked for 449 d.

The autumn/winter movements of the loggerhead turtles in the East China Sea and the Sea of Japan may be regulated by SST. The SST at which males traveled ranged from 16°C to 29°C, from winter to summer respectively. At the entrance to the channel of Charleston Harbor, South Carolina, densities of loggerhead turtles varied seasonally (Van Dolah and Maier 1993), with the highest density observed during the summer months and lower densities during the spring and fall. Densities were positively correlated with water temperature and no turtles were captured during the winter months when the water temperature was below 16°C.

Matured female loggerheads of the western Atlantic moved south upon sensing the drastic water temperature decrease between seasons while foraging (Hawkes et al. 2007). The previous knowledge about the seasonal migration of loggerhead turtles also suggests they migrate in response to a drop in SST (Polovina et al. 2006; Kobayashi et al. 2008; Mansfield et al. 2009; Arendt et al. 2012). It is possible that the drop in SST was the signal for the male turtles to migrate southward from the Sea of Japan to the East China Sea. Loggerhead turtles rarely breed in the Sea of Japan, which is the northern limit of the reproductive migration of many tropical–subtropical species (Nishimura 1967). Nishimura (1969) stated that the most significant factors controlling the animal distribution in the Sea of Japan are the strong influx of the Tsushima Warm Current from the south in the summer to autumn and the winter thermohaline convection and southward drift current induced by the cold and dry northwest monsoon. The movements of the males observed in this study may be interpreted by the characteristic hydrographic conditions of these regions (Nishimura 1969).

Using stable isotope analysis and satellite tracking, Hatase et al. (2002b, 2007) confirmed consistent differences in utilization of foraging areas by body size in Japanese female loggerhead turtles. After laying eggs, the females either swam out in the open ocean or stayed in the neritic zone. It was found that the ones that headed for the open ocean showed signs through stable isotope analyses that they had fed on plankton from the open ocean and the others that stayed in the neritic had fed on neritic benthos. Hawkes et al. (2006) recognized a similar foraging habitat in female loggerheads in Cape Verde, in the eastern Atlantic Ocean. In the present study, we could confirm that the 3 males remained mainly along the coasts or islands of the East China Sea and the Sea of Japan, except for spending a brief period of time (1–30 d) in the open ocean (Fig. 1A–C).

The present male loggerheads traveled at different speeds depending on the season (Fig. 3). Especially, the faster movements (> 1 km/hr) of the male with PTT ID 53755 were often observed during the period from early November 2005 to early April 2006. Schofield et al. (2010) used 1 km/hr as a threshold to distinguish the onset and the end of the ''migration'' and ''foraging'' segments of tracks. Thus, the period from early November to early April is defined as the migration period and the other times as foraging periods in this study. Our data indicated that males tend to search and move frequently to warmer waters in winter, but tend to remain in one location in other seasons.

Conservation efforts for sea turtles around Japanese coastal waters have so far been limited to nesting areas. However, to be effective, a conservation strategy should include protection measures that take diverse stages of an animal's life cycle into account. Given the increased coastal degradation, pollution, and fishing pressure, data about seasonal migrations and migratory pathways are essential to safeguard this endangered species. We found that loggerhead turtles enter into the Sea of Japan during the foraging period and travel back to the East China Sea during the migration period through the straits of South Korea and Kyushu. This area is characterized by intense fishing and marine traffic (Hada 2011) and seasonal low SST. More tracking data are needed, as estimates for home range sizes of the North Pacific loggerhead population are lacking. This information on the seasonal migration of Japanese loggerhead turtles could be applied to the conservation and management of the species in order to mitigate the impact of fishing through specific measures, such as shorter fishing seasons and stricter regulations for fishing and marine traffic during the migration period for loggerhead turtles.

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