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Movements of Loggerhead Turtles (*Caretta caretta*) in East Asia Waters

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Abstract. – Four loggerhead turtles (*Caretta caretta*) with 81.0–85.3 cm curved carapace length were satellite tracked off Fujian and Guangdong provinces, southern China, in 2017 and 2022, and 2 movement patterns were revealed: resident and long-distanced seasonal migration. Identified hotspots include the eastern waters of Leizhou Peninsula, southern Taiwan Strait, central East China Sea, and the area between the southern Yellow Sea and the northern East China Sea. This study contributes foundational data for the North Pacific Regional Management Unit and highlights the need for cooperation among countries in East Asia.

Key Words. – Hotspots; Seasonal Migrations; East China Sea; Regional Management Unit; Satellite Tracking

Chinese abstract. – 于2017年和2022年在中国南部的福建省和广东省共对四只曲线背甲长在81.0-85.3 cm 之间的红海龟进行了卫星定位追踪, 揭示了两种活动特征, 即定居型和长距离的季节性洄游型。识别的热点活动区域包括雷州半岛东部海域、台湾海峡南部海域、东海中部海域以及黄海南部至东海北部之间海域。本研究为北太平洋的区域管理单元提供了基础数据, 并强调了东亚国家之间合作的重要性。

关键词. – 活动热点; 季节性迁徙; 东海; 区域管理单元; 卫星定位追踪

Loggerhead sea turtles (*Caretta caretta*) in the North Pacific Ocean begin their migration as hatchlings from nesting beaches in Japan moving offshore to the central or eastern North Pacific for growth. During their journey, they exhibit a mixture of both passive movement, driven by oceanic currents, and positive orientation to food productive areas to feed and optimize growth while avoiding thermal stressors (Briscoe et al. 2016). Most loggerheads eventually return to the neritic habitats of the northwest Pacific, such as the coastal waters around Japan and the East China Sea, when reaching carapace lengths of 50–70 cm (Kobayashi et al. 2011; Narazaki et al. 2015; Ng et al. 2024). Some, however, stay in the eastern North Pacific around Baja California, Mexico, to forage or remain in oceanic waters until sexual maturity (Peckham et al. 2007). Upon approaching or reaching sexual maturity, they return to nesting grounds in southern Japan (Resendiz et al. 1998; Nichols et al. 2000).

In the northwest Pacific, the East China Sea is a critical habitat for loggerhead turtles because of its abundant food resources, such as benthic cephalopods and crustaceans (Nishimura and Nakahigashi 1992; Hatase et al. 2002; NOAA Fisheries and U.S. Fish and Wildlife Service 2020). An estimated 70% of postnesting loggerhead females in Japan choose the East China Sea for residential foraging (Okuyama et al. 2022). The habitat uses and movement routes of loggerheads were also observed to respond to sea surface temperature (SST) changes. For example, loggerheads traveled from the coastal waters of Japan and the Sea of Japan to the East China Sea as temperatures dropped (Kamezaki et al. 1997; Oki et al. 2019). Such seasonal movement is also typical for green turtles (*Chelonia mydas*) living in this region (Jang et al. 2018).

The loggerhead population size in East Asia waters has declined since the 1980s (Zheng 1985; Chan et al. 2007; Mou et al. 2013; Kim et al. 2024). The species was upgraded to Category I of the National Key Protected Wild Animals List in 2021 in China (National List of Key Protected Wild Animals 2021). A significant satellite

Table 1. Summary of satellite tracking data for 4 loggerheads released in mainland China.

Loggerhead	Satellite transmitter ID No.	Tag model	Body size[a] CCL (cm)	CCW (cm)	BW (kg)	Tracking duration (d/mo/yr)	Tracking days	Movement distance (km)
A	153333	K2G-576A	82.0	78.0	76.9	7 Apr 2017–21 Jan 2018	291	6539.6
B	153331	K2G-576A	82.0	77.5	66.9	3 Dec 2017–2 Aug 2018	242	2704.5
C	229533	SPOT-287C	85.3	75.0	67.8	11 Jun 2022–13 Nov 2022	170	1152.5
D	234199	SPOT-287C	81.0	73.3	64.9	11 Jun 2022–11 Jan 2023	214	5069.6

[a] CCL: curved carapace length; CCW: curved carapace width; BW: body weight.

tracking effort was conducted in 2002–2008 in northern Taiwan with 34 loggerheads of 69–95 cm curved carapace length (CCL) taken as bycatch. Their hotspots were identified in the central East China Sea and the northern waters of Taiwan (Kobayashi et al. 2011). No satellite tracking studies have been conducted on loggerheads in other Chinese waters. Insufficient data on habitat uses and movement routes of loggerheads in China impedes the ability to identify key foraging areas for the species and to allocate the monitoring and research resources, and limits the effectiveness of conservation efforts.

In this study, 4 loggerheads caught as fisheries bycatch in the waters of Fujian and Guangdong provinces of China were satellite tracked after release, 2 in 2017 and 2 in 2022. Their movement patterns were described and analyzed to initiate satellite tracking research effort for loggerheads from the coast of mainland China. This study lays the groundwork for future studies and contributes to a broader understanding within the Regional Management Unit (RMU) of the North Pacific (Wallace et al. 2010, 2023).

Methods. — Four loggerheads were tracked after accidental capture in bottom trawler nets. They were held either in floating cages of a mariculture zone or in an outdoor pool of a government rescue center and released shortly after 1 to several weeks. All 4 loggerheads were energetic and capable of self-feeding without any visible external injuries before released. They were released in their capture regions; 2 loggerheads (A and B) were released in April (spring) and December (winter) 2017 in Zhangzhou (117.3871°E, 23.7046°N), Fujian Province, and the other 2 (C and D) in June (summer) 2022 in Zhanjiang (110.3786°E, 21.2233°N), Guangdong Province (Table 1, Fig. 1). Curved carapace lengths (CCLs) ranged from 81.0 to 85.3 cm. None showed signs of lengthened tail growth indicative of being a male. However, this secondary sex feature can occur at larger sizes, so the gender identification of the 4 turtles was not possible. Two types of satellite transmitters, SPOT-287C (Wildlife Computers Company, USA) and K2G-576A (Sirtrack Company, New Zealand), were attached; the transmitter weights were less than 1% of the turtle body weights (Table 1). The transmitter weights were not expected to adversely influence the turtles' movements (Watson and Granger 1998). Transmitter attachment followed the protocol describing in Balazs et al. (1996).

The transmitter duty cycles of loggerheads A and B were the same: 3 hrs on, 3 hrs off. For loggerheads C and D, Argos Uplink Masks were added during 2 periods (0500–0800 hrs, 1600–1900 hrs, Greenwich Mean Time) in any days without satellites passing. Location data were downloaded from Argos (https://argos-system.claamerica.com/) and classified as 7 location accuracy classes (LC) (CLS 2016). Three types of geolocations were discarded: (1) LC Z points (invalid points), (2) on-land points, and (3) swimming speed exceed 5 km/hr (Luschi et al. 1998). To eliminate differences caused by the varying numbers of geolocations obtained each day, the highest precision coordinate was selected to represent the day's position. If there were multiple coordinates with the same precision on a given day, the one closest to the midday (1200 hrs) was selected (Zbinden et al. 2008). The total movement distance of each loggerhead was calculated as the sum of the distances between adjacent points in the filtered dataset. The average daily transit speed was determined by dividing the distance between adjacent points by the time interval between them. Daily locations for each individual turtle were plotted using the Maptool (http://www.seaturtle.org/maptool/#).

ArcMap 10.8.1 was used to make a fishnet density map for visualizing spatial distribution patterns, helping to identify high- and low-density areas within a dataset; the value of each cell was obtained based on the number of occurrences. The map was used to show the activity ranges and hotspots of the 4 turtles, and the grid size of each polygon unit is 50×50 km (Pikesley et al. 2013).

Results. — Loggerheads B and C stayed close to their release sites in southeastern Zhangzhou (the southern Taiwan Strait) and eastern Zhanjiang (the eastern waters of Leizhou Peninsula), with their activity ranges confined within areas of about 50,000 km^2 and 4000 km^2, respectively (Fig. 1). They transmitted for 242 days and 170 days, respectively (Table 1). The average speeds were 0.33 km/hr for loggerhead C and 0.50 km/hr for loggerhead B based on the filtered datasets, both lower than 1 km/hr, the threshold to distinguish traveling from foraging behavior (Schofield et al. 2010). The days with less than 1 km/hr speeds observed accounted for 89% and 96% of the total tracking durations for loggerheads B and C, respectively. For loggerhead B, the location points were initially clustered in the northern South China Sea in

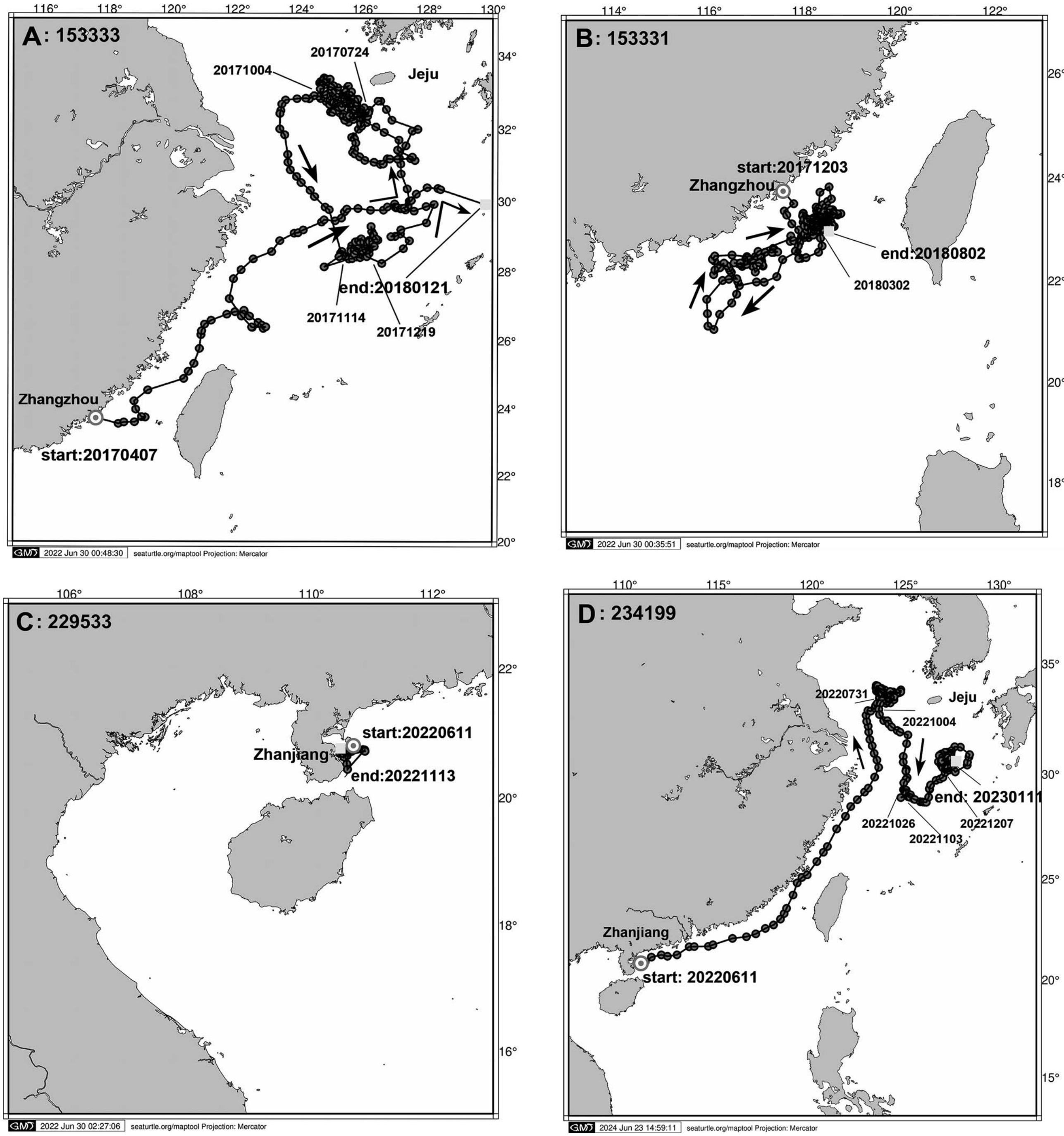

Figure 1. Migratory routes of the 4 loggerheads released in Zhangzhou, Fujian Province (A and B), and Zhanjiang, Guangdong Province (C and D), China. The black arrows show the directions of their movements, the red concentric circles show the release sites, and the blue squares show the end points. A–D refer to loggerheads A–D in Table 1.

winter from December 2017 to mid-February 2018; it moved slightly northeast, and the geolocations became more concentrated for 5 mo in March–July 2018 in the southern Taiwan Strait. Loggerhead C also stayed within a concentrated area from June to November 2022, over a 5-mo tracking period.

Loggerheads A and D transmitted for 291 days and 214 days, respectively (Table 1). In contrast with loggerheads B and C, the destinations of loggerheads A and D were relatively far from their release sites, about 1400 km and 2200 km, and the activity ranges were about 45,000 km^2 and 22,000 km^2, respectively (Fig. 1). Both loggerheads showed a similar seasonal migratory pattern. First, irrespective of release time, either April 2017 or June 2022, loggerheads A and D traveled considerably northward after release along the coastline of mainland China and passed through the Taiwan Strait with a fast average traveling speed of 1.15 km/hr for loggerhead A and 1.68 km/hr for loggerhead D. Then they both reached the area between the southern Yellow Sea and the northern

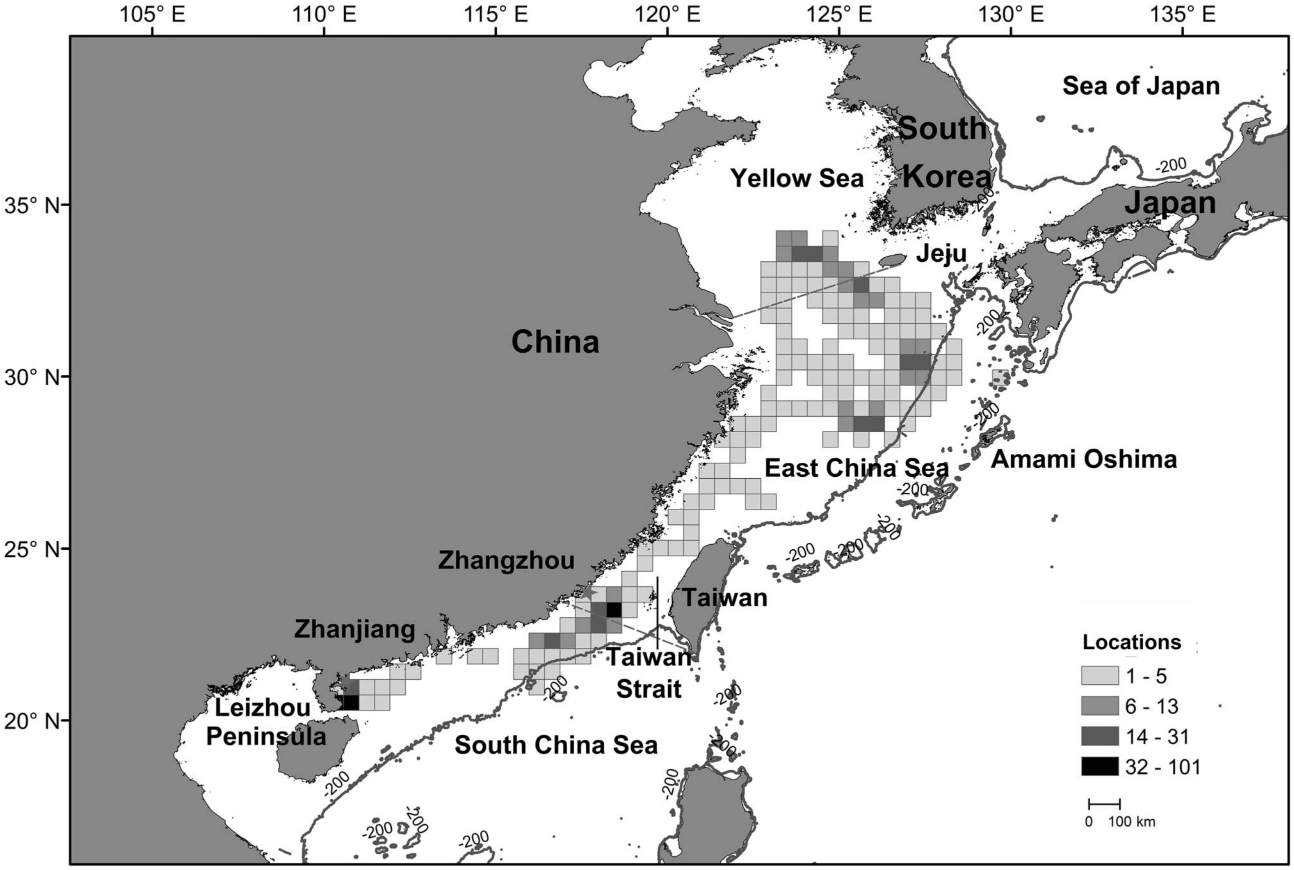

Figure 2. Density map of all filtered locations from the 4 loggerheads during their tracking periods. The grid size is 50 × 50 km, and the 200 m isobath is shown. Stars: the release sites in Zhangzhou and Zhanjiang, southern China. Dashed lines: the boundaries among the Yellow Sea, East China Sea, and South China Sea.

East China Sea in July, and presumably foraged there until early October. Last, they left the main foraging grounds and moved southward to the central East China Sea in October and November. From October until their signals ceased in January, loggerheads A and D overall trajectories displayed a "U" shape. They first moved south to around 28°N and 125°E, where they stayed for more than 1 mo for loggerhead A and about 1 wk for loggerhead D, and then moved north again but did not reach the latitude of their main foraging grounds. The movement route of loggerhead D was more associated with the coastline than loggerhead A. During presumed foraging, movement speeds were slow (0.77 km/hr for loggerhead A, and 0.59 km/hr for loggerhead D), and activity areas were more concentrated.

The fishnet density mapping approach revealed that the hotspots from the 4 loggerheads included the eastern waters of Leizhou Peninsula, the southern Taiwan Strait, the central East China Sea, and the area between the southern Yellow Sea and the northern East China Sea (Fig. 2). The buffer zones around hotspots were relatively wide, especially in the East China Sea. The travel corridor for the 2 loggerheads (A and D) was along the Taiwan Strait. All 4 loggerheads mainly inhabited water depths of less than 200 m (Fig. 2).

Discussion. — This study documented dichotomous movement patterns for the 4 tracked loggerheads: resident versus long-distance migration. For the residential loggerheads B and C, they remained in the area of their release: the southern Taiwan Strait and the eastern waters of Leizhou Peninsula, respectively. These 2 locations are proposed as potentially important foraging grounds for loggerheads, aligning with previous observations for green sea turtles (Ye et al. 2021; Song 2022). The 2 locations showed a preference of the 2 loggerheads for warm waters and abundant food supplies. Loggerhead B remained near the 20°C isotherm during the winter months (December to February) (Ocean Color: https://oceancolor.gsfc.nasa.gov/), while loggerhead C displayed a similar hotspot within a 4000 km^2 area over 5 mo around the tropical waters, where the mean annual temperature stays above 20°C (Zheng and Lei 1999). The southern Taiwan Strait and the eastern waters of Leizhou Peninsula, well known, respectively, as the Minnan and Yuexi Fishing Grounds, are likely attractive due to the stable food availability, such as swimming crabs like *Monomia haanii*, and warmer temperatures, both of which may support their need for consistent body temperatures and provide ample foraging opportunities (Zeng et al. 2019; Lin et al. 2021). For loggerheads A and D showing long-distance movement behavior, their patterns were very similar, irrespective of release sites and times. They moved northward to the southern Yellow Sea and the northern East China Sea (western Jeju Island, South Korea) and stayed there from July to September (summer to autumn), then migrated southward to the central East China Sea in October (autumn). The diets of loggerheads can change with the seasons, but mainly focus on crabs, jellyfish, and bivalve mollusks in nearshore waters of West Pacific (Kim et al. 2021). The southern Yellow Sea and the northern East China Sea are known for the abundant fisheries resources above, likely to attract carnivorous loggerheads traveling for foraging (Frick et al. 2009; Cho et al. 2014; Kim et al. 2024).

The observed seasonal movements in this study are common for loggerheads in East Asia (Saito et al. 2015; Kim et al. 2024). Postnesting and bycatch tracking studies in Japan, South Korea, and Taiwan of China frequently reported that loggerheads moved to the East China Sea for foraging (Kobayashi et al. 2011; Saito et al. 2015; Oki et al. 2019; Kim et al. 2024). This study further corroborates these findings, providing additional evidence of the seasonal migratory patterns, and reinforces the notion that the area between the southern Yellow Sea and the northern East China Sea serves as critical foraging grounds for loggerheads. The consistency of loggerhead movements across different release sites and times also underscores the ecological importance of the East China Sea for loggerheads.

Most studies, including ours, attributed the seasonal migration of loggerheads to a change of water temperature. Although sea turtle thermal biology has been extensively studied in some regions (Spotila et al. 1997; Hochscheid et al. 2002), information on the specific SST preferences and thresholds for loggerheads in the East China Sea and the Yellow Sea is limited. The SST in the southern Yellow Sea and the northern East China Sea can drop below 10°C in winter (Ocean Color: https://oceancolor.gsfc.nasa.gov/), which is a lethal temperature for sea turtles (Niemuth et al. 2020), and also influences the overwintering behavior of fishery resources (Li et al. 2009; Liu and Cheng 2019). Loggerheads A and D began migrating southward from the southern Yellow Sea and the northern East China Sea in October, when the average monthly water temperature was still above 20°C (Ocean Color: https://oceancolor.gsfc.nasa.gov/). This observation contributes to filling a critical gap in our understanding of loggerhead thermal preferences and migratory behavior triggers specific to the southern Yellow Sea and the northern East China Sea region. Our findings suggest that loggerheads in this region may initiate migratory behavior at higher temperatures than previously assumed, possibly as a preemptive response to anticipated winter cooling.

The complexity of movement patterns poses challenges for developing precise conservation strategies for loggerheads in the East Asian region. From a small sample size (only 4 loggerheads tracked) in this study, 2 dichotomous but common movement patterns and several important foraging hotspots were revealed. These results enhance our understanding of loggerhead ecology in East Asia waters and contribute valuable data to the North Pacific RMU, where loggerhead nesting grounds are confirmed only in Japan (Wallace et al. 2010, 2023; Ng et al. 2024). To further improve our knowledge and conservation efforts in the East China Sea, South China Sea, and Yellow Sea, tracking sample size should be increased. Behavioral research and environmental monitoring in hotspots and foraging grounds can also be helpful to better understand what influences their seasonal movement strategies. Additionally, cooperation among East Asian countries is important to develop comprehensive, cross-border conservation plans that address the complex movement patterns observed. Implementing an observer program to assess the interaction between fishery practices and sea turtles in the seas or developing predictive models similar to NOAA Fisheries' TurtleWatch in Hawaii (Howell et al. 2008) could help mitigate sea turtle bycatch risks and inform conservation strategies. Furthermore, satellite tracking combined with oceanographic in situ data analysis can enhance our understanding of habitat preferences and migration corridors, guiding the establishment of dynamic marine protected areas. By continuing to build on this study, we can refine our approach to loggerhead conservation in the East Asian region and contribute to the global efforts to protect this important species.

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