MIGRATIONAL MOVEMENTS AND SEASONAL HOME RANGES OF GREATER CRESTED TERNS *THALASSEUS BERGII* BREEDING IN THE SOUTH CHINA SEA

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ABSTRACT

YU, X., GUO, X., JI, Y., TANG, S., JIA, C. & LEI, F. 2022. Migrational movements and seasonal home ranges of Greater Crested Terns *Thalasseus bergii* breeding in the South China Sea. *Marine Ornithology* 50: 245–251.

The migratory pathways of Greater Crested Terns *Thalasseus bergii* in the East Asian-Australasian Flyway are poorly known. We tracked three birds by deploying GPS/GSM transmitters in September 2018, one for 23 months, one for 16 months, and one for 1.5 months. These tracks included complete fall migration routes for all three individuals and partial spring migration routes for two individuals between a breeding area in the Xisha Archipelago (South China Sea) and two wintering areas, one in the western Philippine Archipelago and the other in the western Celebes Sea. We observed that the two fully tracked terns had large seasonal home ranges and strong fidelity to wintering grounds and stopover sites during spring migration.

Key words: fidelity, GPS/GSM tracking, Greater Crested Tern, home range, migration, *Thalasseus bergii*

INTRODUCTION

The Greater Crested Tern *Thalasseus bergii* is a colonial-breeding seabird that is widely distributed from the southeastern Atlantic Ocean eastwards to the western and central Pacific (Payo-Payo *et al.* 2018, Gochfeld *et al.* 2020). Although the Greater Crested Tern is considered a species of Least Concern on the IUCN Red List (BirdLife International 2018b), it is vulnerable to fluctuations in fish populations (Crawford *et al.* 2014), and the species was upgraded from Least Concern to Grade II conservation in China in 2021 (www.forestry.gov.cn/html/main/main_5461/20210205122418860831352/file/20210205151950336764982.pdf). Research on the Greater Crested Tern thus far has mainly focused on local population sizes and reproductive ecology (Tayefeh *et al.* 2015, Payo-Payo *et al.* 2018). As the presence of Greater Crested Terns is used to attract critically endangered Chinese Crested Terns *T. bernsteini* to available breeding locations (BirdLife International 2018a, Lu *et al.* 2020), tracking Greater Crested Terns throughout their annual cycle is critical for understanding the reasons behind declines in the local population of the Chinese Crested Terns. Any movement data will assist in the management and re-establishment of their breeding colonies. Most of the Greater Crested Terns found in southeastern China are summer visitors. For example, it has been shown that Greater Crested Terns breeding in the Matsu Islands overwintered in Vietnam, Cambodia, Thailand, Myanmar, and the Philippines (Chang *et al.* 2018). However, movement patterns of the breeding population in the South China Sea are not well known, and the birds are considered local residents (Yan *et al.* 2006).

In this study, we deployed loggers that use Global Positioning System satellites or the Global System for Mobile Communications (GPS/GSM) on Greater Crested Terns in the Xisha Archipelago, South China Sea, to identify annual temporal-spatial movement patterns. We were especially interested in the non-breeding period, as well as the location of potentially important migration stopovers. Though our sample size was small, we calculated home range size during the summering and wintering periods for the tracked individuals. We found that the two fully tracked terns had large seasonal home ranges and returned to the same wintering grounds and stopover sites used previously.

METHODS

Capture and GPS/GSM deployment

Our study was conducted on the QiLianyu Islands in the northern part of the Xisha Archipelago in the South China Sea (16°55′–17°01′N and 112°12′–112°21′E). The total land area of the QiLianyu Islands is 1.32 km^2. We captured three Greater Crested Terns (labeled G01, G02, and G03) using mist nets in September 2018 and attached solar-powered GPS/GSM data loggers (Hunan Global Messenger Technology Co., Ltd.) using leg-loop harnesses made of Teflon. The mass of logger and tape was 6 g, ~1.9% of adult body mass. This work complied with the requirements of Fair *et al.* (2010). GPS/GSM location, instantaneous ground speed, altitude above mean sea level, and instantaneous heading were collected by the loggers. Locations that were accurate within 5–100 m were used to analyze the movements of the terns. The maximal and minimal temporal resolutions achieved by the loggers were 3 hours and 24 hours, respectively.

Defining stages of the annual cycle

We used the GPS/GSM locations to characterize migration routes, non-breeding range, and breeding range. The onset of autumn migration was defined as the last day the bird was present at the breeding colony. The end of autumn migration was defined as the first day that the bird arrived at its first wintering site (G01 used two separate wintering sites, see Results). Spring migration was defined in an equivalent way: the onset of migration was the last day the bird was present at (one of) the wintering site(s), and the end of migration was the first day the bird was back at the breeding colony. A stopover day was defined by the bird using the same night roost as the previous night during migration. The wintering stage was defined as the time after arrival at the wintering area and before spring migration.

Data analysis

We quantified migration using three metrics: daily migration rate, total migration distance, and migration schedule. We calculated the daily migration rate (km/d) for each individual using the great-circle distance (km) between GPS/GSM locations. The presence of many invalid data points for G02 in 2020 did not permit us to determine departure and arrival dates from breeding and non-breeding home ranges. The total migration distance was defined as the sum of the distances on travel days, excluding movements during stopover days and during winter. Migration routes were mapped using ArcGIS 10.7. The breeding and wintering home ranges were calculated using the dynamic Brownian bridge movement model (Kranstauber *et al.* 2012). Interpolated positions were also used to generate utilization distributions (UDs) separately for each individual using the R package "adehabitatHR" (Calenge 2006). The values of the 50% (core area) and 95% (home range) UDs were calculated to make comparisons among individuals.

RESULTS

Two of the three terns were successfully tracked to wintering sites during two consecutive years. The logger for G01 was active from 05 September 2018 to 16 December 2019 and recorded a total of 1991 reliable positions. The logger for G02 was active from 05 September 2018 to 31 July 2020 and recorded a total of 1606 reliable positions. The logger for G03 was active from 05 September to 19 October 2018 and recorded a total of 100 reliable positions.

General temporal–spatial distribution

From the GPS/GSM distribution analysis during fall migration, birds were found to travel generally southeast through the South China Sea. Migration details are summarized in Table 1. G01 left the QiLianyu Islands on 13 September 2018 and arrived in the western Philippine Archipelago after 4 days, having migrated at an average speed of 326 km/d. Within the western Philippine Archipelago, G01 initially remained at northwestern Burias Island for 16 days, then continued to overwinter among islands to the south of San Jose until 13 May 2019. It then started its northward

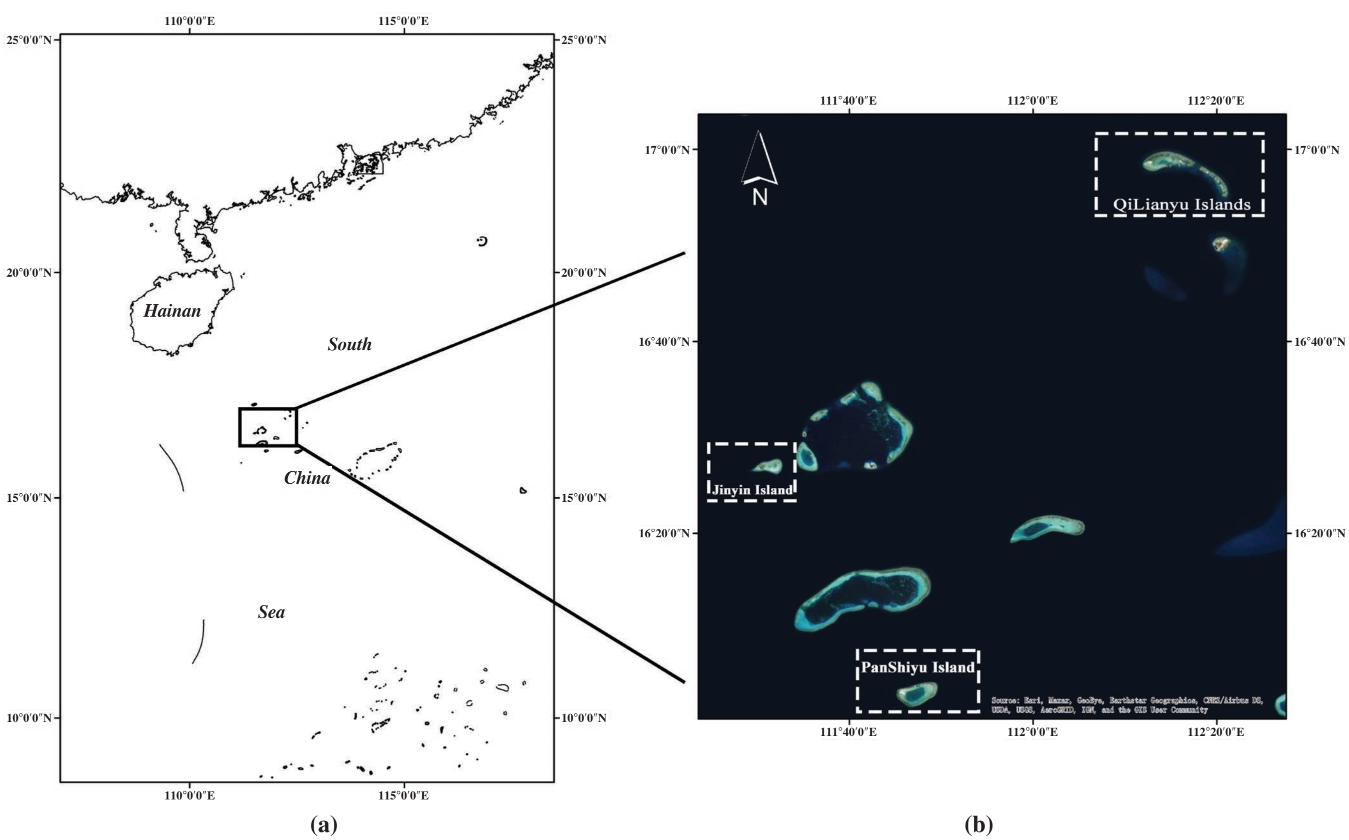

Fig. 1. Map of the study area where Greater Crested Terns *Thalasseus bergii* were tagged after the nesting season: (a) the South China Sea and (b) location of QiLianyu Islands, Jinyin Island, and PanShiyu Island in the Xisha Archipelago.

TABLE 1
Migration details for three Greater Crested Terns *Thalasseus bergii* investigated during 2018–2020

Bird	Period	Migration distance (km)	Daily migration rate (km/d)	Travel days
G01	13–17 Sep 2018	1303.83	325.96	4
	6–11 Sep 2019	1193.52	238.70	5
	13–15 May 2019	1037.02	518.51	2
G02	15–21 Sep 2018	2013.08	335.51	6
	08 Mar–07 Apr 2019	1838.84	262.69	7 (plus 23 days at migratory stopover)
G03[a]	13 Sep 2018–?	ND	ND	ND

[a] ND not determined

migration. G01 took just 2 days to migrate to Jinyin Island, Xisha Archipelago, arriving on 15 May 2019, having migrated at an average speed of 519 km/d. Position data revealed that G01 mainly bred on and foraged near Jinyin Island and the QiLianyu Islands and surrounding waters within Xisha Archipelago (Fig. 1). During the fall migration of 2019, G01 left the QiLianyu Islands on 06 September and arrived at the same wintering site as the previous year after 5 days, having migrated at an average speed of 239 km/d. This individual remained in the same general area until the signal was lost on 16 December 2019.

G02 left the QiLianyu Islands on 15 September 2018 and arrived in the western Celebes Sea after 6 days, having migrated at an average speed of 336 km/d. G02 moved as far south as the northern Makassar Strait during the winter and remained mainly in the western Celebes Sea until 08 March 2019. It then started its northward migration and flew to the southeast of Banggi Island, in the western Sulu Sea on 10 March 2019, remaining there for 23 days. On 03 April, G02 resumed its spring migration and arrived at Jinyin Island in the Xisha Archipelago on 07 April, having migrated at an average speed of 263 km/d. Position data revealed that G02 mainly bred on and foraged near the QiLianyu and PanShiyu islands and their surrounding waters within Xisha Archipelago. During the period of movement following the 2019 breeding season, departure and arrival dates from breeding and non-breeding areas for this bird could not be determined due to invalid

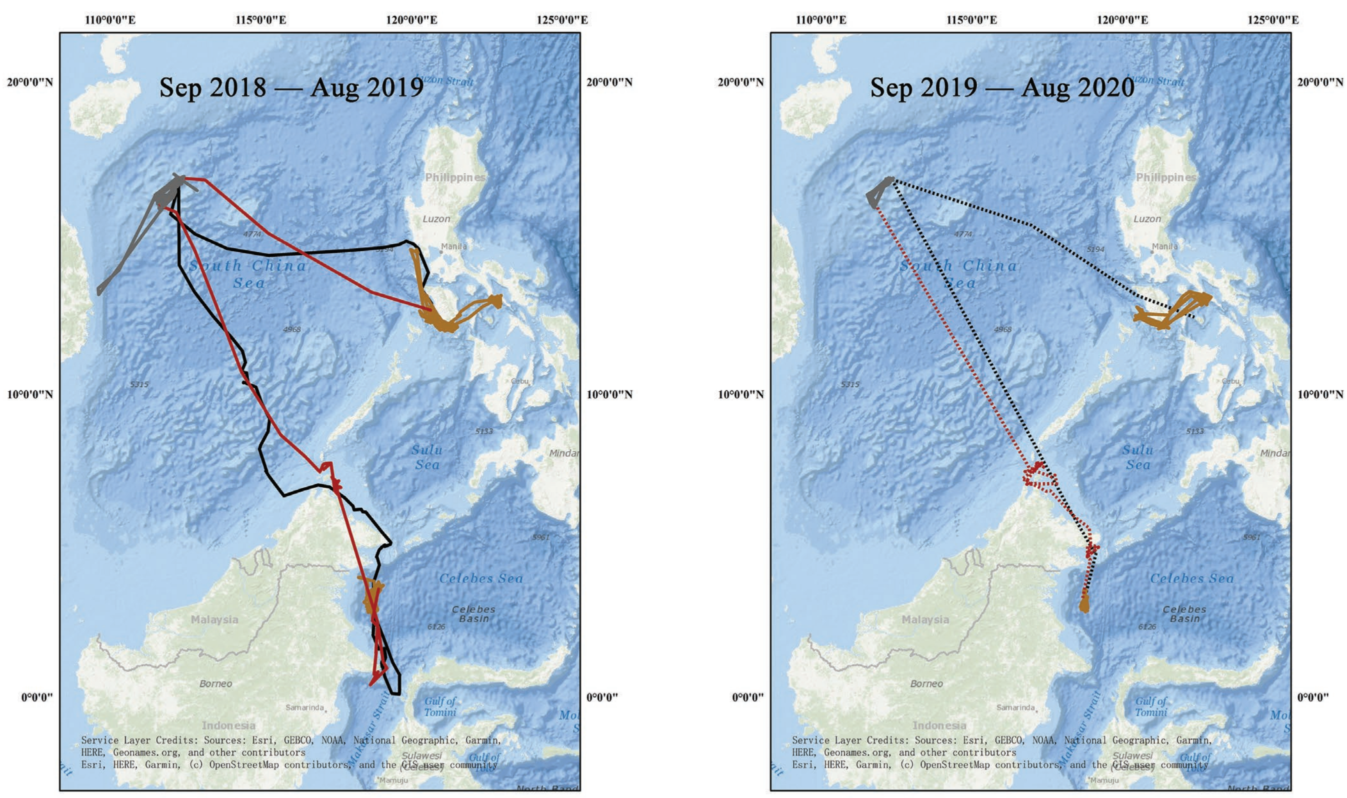

Fig. 2. Annual movement patterns of two Greater Crested Terns *Thalasseus bergii* tracked from breeding colonies in the QiLianyu Islands over two years, September 2018–August 2019 (left) and September 2019–August 2020 (right). Black = autumn migration (post-breeding, September), dark orange = winter range (October–April), red = spring migration (return, May), and grey = breeding range (June–August). Dotted lines represent uncertain routes because of GPS/GSM data loss during migration.

GPS/GSM data from September 2019 to July 2020, possibly due to a broken antenna. However, many data points at both a stopover site during the 2020 spring migration and the 2019/20 wintering locations for G02 indicated that the spring migration route and wintering area were similar to those used in the previous year (see Fig. 2). In two consecutive years, G01 and G02 returned to the same wintering grounds used previously, an indication of site fidelity.

G03 left the QiLianyu Islands on 13 September 2018 and flew to the southeast of Banggi Island in the western Sulu Sea over 6 days. It used the same stopover site as G02 and remained there until 15 October 2018. G03 then continued to migrate southward, and the signal was lost after 4 days.

Breeding and wintering home ranges

We calculated the home ranges of two of the three terns in their summering and wintering areas from September 2018 to July 2020 (Table 2). The core areas and home ranges differed substantially among individuals. G01 had the larger seasonal range of movements, with a home range of 12 788 km^2 in summer and 11 260 km^2 in winter. G02 had the smaller seasonal range of movements, with a home range of 3597 km^2 in summer and 2140 km^2 in winter. Based on the 95% home range map, the summer range size, which had multiple core areas, was slightly larger than the winter range. (Fig. 3).

DISCUSSION

Based on GPS/GSM tracking of two individuals, we found that Greater Crested Tern home ranges and core areas during the summer and winter ranged from 2140 to 12 788 km^2 and from 530 to 1318 km^2, respectively. The two fully tracked terns had large breeding home ranges compared to other tern species such as Sandwich Tern *T. sandvicencis*, which has a maximum individual home range of 1980 km^2 (Fijn *et al.* 2017), and Forster's Tern *Sterna forsteri*, which has a home range of 5775 ± 1184 ha (57.75 ± 11.84 km^2; Bluso-Demers *et al.* 2008). Compared to G02, G01 was observed to have a much larger wintering home range, with multiple core areas during the winter of 2018/19, although tracking information was not available for three months after it arrived in the wintering ground.

TABLE 2
Estimates of home range size of Greater Crested Terns *Thalasseus bergii* based on the dynamic Brownian bridge movement model

Period	ID-year[a]	95% Home range (km^2)	50% Core area (km^2)
Summer	G01-2019	12 788.1	1291.7
	G02-2019	4115.5	575.5
	G02-2020	3596.6	529.7
	Mean ± SD	6833.4 ± 4216.0	799.0 ± 348.9
Winter	G01-2018	7003.0	834.0
	G01-2019	11 260.0	1317.7
	G02-2018	6627.4	774.3
	G02-2019	2140.1	614.6
	Mean ± SD	6757.7 ± 3227.7	885.2 ± 262.3

[a] SD standard deviation

The large wintering home range of G01 can be explained in part by the strong flight capability of the species. This has also been documented in other tern species, such as the Arctic Tern *S. paradisaea* (Egevang *et al.* 2010) and the Sooty Tern *Onychoprion fuscatus* (Jaeger *et al.* 2017). The movement and home range patterns of terns can be affected by food availability (Newton 2002). For example, Elegant Terns *T. elegans* migrate northward as food availability fluctuates due to changes in upwelling (Velarde *et al.* 2015). Cold-water upwellings also apparently provide vital foraging resources in the migratory staging of Roseate Terns *S. dougallii* (Redfern *et al.* 2021). In regard to other studies of Greater Crested Terns, two individuals that nested in the Xisha Archipelago took different migration routes, one wintering in the western Philippine Archipelago and the other in the western Celebes Sea. There are productive marine ecosystems in the two wintering areas that apparently provide suitable foraging habitat (Peterson *et al.* 2000, Oliveros *et al.* 2012, Tunnicliffe *et al.* 2016). The same waters attract over-wintering Bridled Terns *O. anaethetus* (Surman *et al.* 2018) and Greater Crested Tern from the Matsu Islands (Chang *et al.* 2018).

For our study, the reasons why the two birds from the same nesting site utilized different wintering grounds and how they learned their respective migration routes is not clear, but it likely would be if we had had a larger sample size. Banggi Island was identified as an important stopover site used by G02 and G03 during spring and fall migration, respectively, and we speculate that it is a preferred site to roost and replenish energy reserves due to Banggi's abundant reef fish resources (Teh *et al.* 2007). We suggest that the two birds migrated more quickly in spring than in autumn because of competition for nest sites, which is influenced by arrival order at the breeding grounds. Environmental factors such as increasing daylight may also have been involved (Nilsson *et al.* 2013). The daily travel speeds of these terns were slower than those of other terns (Table 3), and this discrepancy is most likely explained by the fact that Greater Crested Terns engage in a fly-and-forage strategy during their migratory movement, as employed by other seabird species (Amélineau *et al.* 2021).

Our results indicate the likelihood of fidelity to wintering grounds and stopover sites during spring migration, with two individuals returning to previously used wintering grounds and stopover sites. This phenomenon has also been reported in the Gull-billed Tern *Gelochelidon nilotica* (Goodenough & Patton 2019) and is probably associated with philopatry to particularly productive breeding and wintering regions (Feng *et al.* 2019, Pyle *et al.* 2001, Hoover 2003). It's uncertain whether Greater Crested Terns are faithful to the breeding grounds based on our study. We could not determine this because the three terns tracked were captured in September, the post-breeding period. Previous studies have indicated that Greater Crested Terns can be attracted to new breeding sites by using social attraction techniques, which suggests relaxed philopatry (Lu *et al.* 2020).

Though our sample size was small, our study revealed the migration routes and home range sizes of Greater Crested Terns in the South China Sea on both the breeding and wintering grounds. Further studies with larger sample sizes focusing on population dynamics, habitat selection, and migratory connectivity of Greater Crested

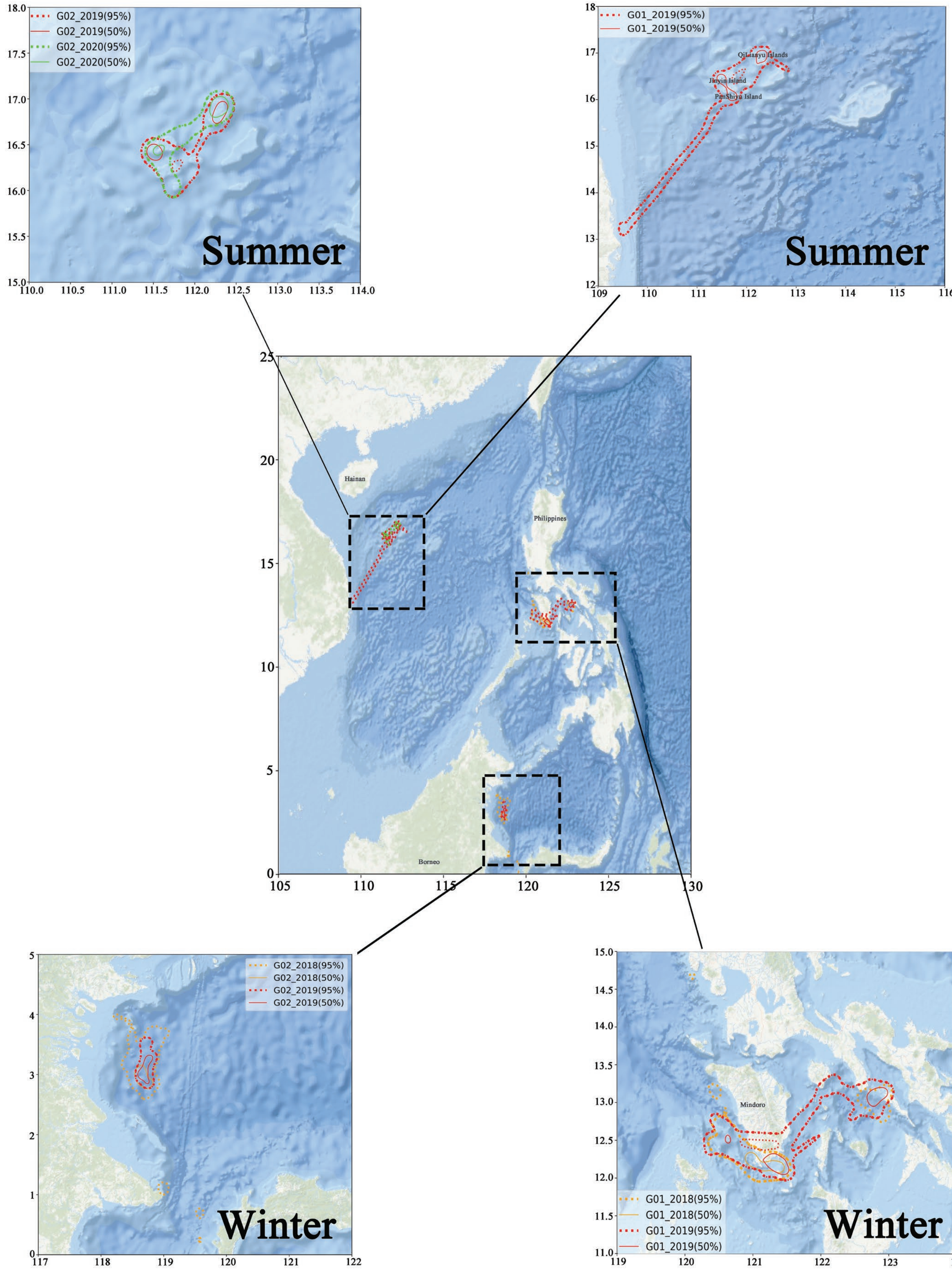

Fig. 3. Home ranges and core areas of two Greater Crested Terns *Thalasseus bergii* during the summer and winter. Yellow, red, and green lines in the four subgraphs indicate movement of terns in 2018, 2019, and 2020, respectively.

TABLE 3
Travel and migration rates for a selection of terns, for autumn migration (away from the breeding area) and spring migration (towards the breeding area)

Species	Daily travel speed (km/d)		Overall migration speed (km/d)		Reference
	Autumn	Spring	Autumn	Spring	
Greater Crested Tern *Thalasseus bergii*	300	390	300	289	This study
Caspian Terns *Hydroprogne caspia*	490	565	92	246	Rueda-Uribe *et al.* 2021
Arctic Terns *Sterna paradisaea*	-	-	330	520	Egevang *et al.* 2010
Bridled Terns *Onychoprion anaethetus*	225	225	180	225	XY unpubl. data

Tern populations across their range will enhance our understanding of this species' annual life cycle and will improve monitoring of their abundance. Such information is critical for identifying the causes of population declines in Chinese Crested Terns (*T. bernsteini*), a closely related endangered species, and establishing relevant reserves.

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