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Seasonal residency of loggerhead turtles *Caretta caretta* tracked from the Gulf of Manfredonia, South Adriatic

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Abstract

A detailed knowledge of sea turtle distribution in relation to anthropogenic threats is key to inform conservation measures. We satellite tracked five loggerhead turtles incidentally caught in the Gulf of Manfredonia, where a high turtle occurrence and high by-catch levels have been recently reported. Turtles were tracked for a period ranging from 27 to 367 days, with a minimum travel distance ranging from 151 to 4,300 km. With the caution due to the small sample size, results suggest that: (i) the area may host residential loggerhead turtles at least in summer, while they probably move elsewhere in winter due to the low temperatures occurring in shallow waters; (ii) turtles may have very small home ranges in the area; (iii) turtle occurrence may be higher in shallow waters along the coast. Moreover (iv) one turtle showed remarkable fidelity to the same spot after seasonal migration and constant migration paths. If confirmed and further detailed, such movement patterns may guide effective conservation strategies to reduce the impact of bycatch in the area.

Keywords: Satellite tracking, home range, seasonal migration, temperature, by-catch.

Introduction

Marine vertebrates are usually wide-ranging, with different anthropogenic threats occurring across their distributional range. Detailed knowledge of their distribution and movement patterns in relation to these threats is key to generating effective conservation approaches (Gerber & Heppel, 2004; Hamann *et al.,* 2010).

Loggerhead sea turtles (*Caretta caretta*) can frequent very distant areas during different life stages (Bolten, 2003; Nichols *et al.,* 2000), feeding on epipelagic or benthic prey in oceanic or neritic zones, respectively (Bjorndal, 1997; Bolten, 2003; Nichols *et al.,* 2000). This species uses trophic resources opportunistically and exhibits a highly plastic life history, according to the local oceanographic and ecological features, but in general juveniles tend to frequent more neritic habitats as they grow (Bolten, 2003; Casale *et al.,* 2008a; Musick & Limpus, 1997; Schroeder *et al.,* 2003), with exceptions (Hatase *et al.,* 2002; Hawkes *et al.,* 2006; Rees *et al.,* 2010). There are indications from tagging studies on multiple populations that neritic juveniles remain in or at least revisit specific areas (Avens *et al.,* 2003; Cardona *et al.,* 2009; Carman *et al.,* 2016; Casale *et al.,* 2007; Mansfield *et al.,* 2009; Musick & Limpus, 1997). Adults also show fidelity to their neritic feeding grounds (Broderick *et al.,* 2007; Hawkes *et al.,* 2006; Hawkes *et al.,* 2011; Schofield *et al.,* 2010; Schroeder *et al.,* 2003; Zbinden *et al.,* 2011), which may be the same ones they recruited to as juveniles (Casale *et al.,* 2007; Limpus & Limpus, 2001).

Loggerhead turtles represent the most abundant turtle species in the Mediterranean Sea, with reproductive habitats concentrated in the eastern basin and dispersing widely in the other areas, including the western part, both as juveniles and as adults (Casale & Margaritoulis, 2010). Within the Mediterranean, the Adriatic Sea has been identified as an important foraging area for loggerhead turtles of all life stages, as shown by a variety of information. First, over 11,000 incidental captures have been estimated to occur annually in the Adriatic, mostly by bottom trawlers (Casale, 2011). Second, tag recoveries and satellite tracking of adults tagged while breeding in Zakynthos (Greece) showed that the Adriatic is one of the few foraging grounds for adult loggerhead turtles from this rookery (Hays *et al.,* 2010b; Lazar *et al.,* 2004; Margaritoulis *et al.,* 2003; Schofield *et al.,* 2010; Zbinden *et al.,* 2008; Zbinden *et al.,* 2011). Third, medium to long-term permanence of juvenile loggerhead turtles in the area has been shown by tag returns (Casale *et al.,* 2007) and satellite tracking (Casale *et al.,* 2012a). Finally, the Adriatic, and its southern part in particular, hosts an important developmental area for turtles in the first years

of life (Casale *et al.,* 2010), probably hatched in Greece, as suggested by dispersal models based on sea currents (Casale & Mariani, 2014; Hays *et al.,* 2010a) and genetic markers from larger juveniles (Clusa *et al.,* 2014). While the Mediterranean is frequented by loggerhead turtles belonging to two regional management units (Wallace *et al.,* 2010), the Mediterranean and the Atlantic (Carreras *et al.,* 2006; Casale *et al.,* 2008b), the Adriatic seems to be a foraging ground for Mediterranean loggerhead turtles only (Clusa *et al.,* 2014; Giovannotti *et al.,* 2010).

There is growing evidence of several anthropogenic threats in the Adriatic affecting loggerhead turtles: the aforementioned incidental catch and also collision with boats, debris ingestion and pollutants (Affronte & Scaravelli, 2001; Casale *et al.,* 2010; Franzellitti *et al.,* 2004; Lazar & Gračan, 2011; Lazar *et al.,* 2011). However, the current knowledge about the distribution of these animals in the Adriatic is still not adequate to understand the real overlapping of their key foraging areas with these main anthropogenic threats.

Recently, a new important neritic foraging ground has been discovered in the Gulf of Manfredonia, in the South Adriatic, where incidental catch levels are very high (Casale *et al.,* 2012c) and represent the most likely cause for the observed low annual survival probability in the area (Casale *et al.,* 2015). The limited number of loggerhead turtles tracked from or to the Adriatic so far, frequented the north-central parts and no information is available about the movement patterns of turtles foraging in the Gulf of Manfredonia. This study aims to provide first indications about the use of this area by loggerhead turtles and specifically (i) whether it is a residential area for a limited number of turtles or a migratory pathway without a permanent group of animals; (ii) whether turtles use the whole Gulf or only a part of it; (iii) if the Gulf is frequented all year round or just seasonally.

Materials and Methods

The loggerhead turtles included in this study were incidentally captured by bottom trawlers in the neritic waters of the Gulf of Manfredonia, Italy, in the period 25 June – 3 July 2012.All turtles were healthy when captured and were brought to the port of Manfredonia, where their curved carapace length notch-to-tip (CCL) (Bolten, 1999) was measured and platform terminal transmitters (PTTs) were attached to them. Then the turtles were brought c. 1 mile offshore and released. The entire operation, from capture to release, was kept as short as possible, and the turtles spent only a few hours in tanks on the fishing boats. Argos-linked PTTs (sirtrack F4H 471A, equipped with Fastloc GPS)were attached to the second vertebral carapace scute using a two-part epoxy resin (Power Fasteners, Netherlands).

The PTTs were programmed with a duty cycle (for transmissions to Argos) of 10 hrs on and 38 off. PTT data were collected by Argos (www.argossystem.org), automatically downloaded by the Satellite Tracking and Analysis Tool (STAT) (Coyne & Godley, 2005), and processed by the Sirtrak FastLoc Admin Tool program to obtain position data. In order to study the general movement patterns and preferred areas of the turtles, and to avoid potential biases due to redundancy, we selected only one position fix per day. For days with more than one fix, the one closest to midday was chosen. Locations were plotted and analysed in ArcGIS 10.0. For each turtle the area of the minimum convex polygon (MCP) was calculated (excluding any overlapping terrestrial parts). High-use areas were identified using Kernel density estimates (KDE) with 50% utilization distribution (UD). Minimum travel distance was calculated as the sum of linear distances among consecutive fixes, for two sets of fixes: all and daily. Monthly sea surface temperatures in the South Adriatic during the study period were obtained through the Maptool program (SEATURTLE.ORG, www.seaturtle.org).

Reults

Five loggerhead turtles were tracked, ranging from 47.8 to 74 cm CCL. Two of them (B and E) were above the minimum size of nesting females in the Mediterranean (Margaritoulis *et al.,* 2003), and so it cannot be excluded that they were adults. The largest turtle was identified as a male from the typical long tail of males (Casale *et al.,* 2005). Turtles were tracked for a period ranging from 27 to 367 days, providing a total of 1,985 fixes of which 380 were day-fixes (Table 1). Their minimum travel distance ranged from 151 to 4,300 km. Four turtles (A, B, D, E) remained in the area of the Gulf of Manfredonia (Fig. 1). Of these, turtles A, B and D remained in a small area for most of the monitored period, while turtle E moved between different areas, mostly at the border of the Gulf (Fig. 1). The fifth turtle (C) immediately moved out of the Gulf, and settled in a northern coastal area until November, then made two counterclockwise rounds in the South Adriatic and returned to the same coastal spot at the beginning of May, where it remained until the end of transmissions (Fig.2). While in this coastal zone, in both periods this turtle spent most of the time in the same small area (Fig.2), comparable in size to the other turtles in the Gulf. During the summer, all turtles frequented waters < 50 m deep, four of them < 20 m and two of them < 10 m (Figs. 1 and 2).In the coastal areas frequented by the tracked turtles in summer, sea surface temperatures dropped below 15°C in the period December 2012-April 2013 (Supplemental Fig. S1).

Table 1. Loggerhead turtles (Caretta caretta) tracked from the Gulf of Manfredonia, Italy. CCL: Curved carapace length; MCP: Minimum Convex Polygon; KDE 50%: Kernel density estimation with 50% utilization distribution. *only summer residential area.

Turtle	CCL (cm)	Deploy date	Last fix date	N days	N fixes	N day-fixes	Total travel (km) All fixes (day-fixes)	Area MCP (km²)	Area KDE 50% (km²)
A	52	25/06/2012	22/07/2012	27	122	21	151 (88)	164	18
B	74	27/06/2012	12/09/2012	77	118	45	169 (106)	34	22
C	56.4	28/06/2012	30/06/2013	367	1358	215	4300 (3838)	106430 (1760)*	1927 (69)*
D	47.8	28/06/2012	06/08/2012	39	166	30	331 (204)	489	47
E	69.8	03/07/2012	29/11/2012	149	221	69	698 (523)	2,186	267

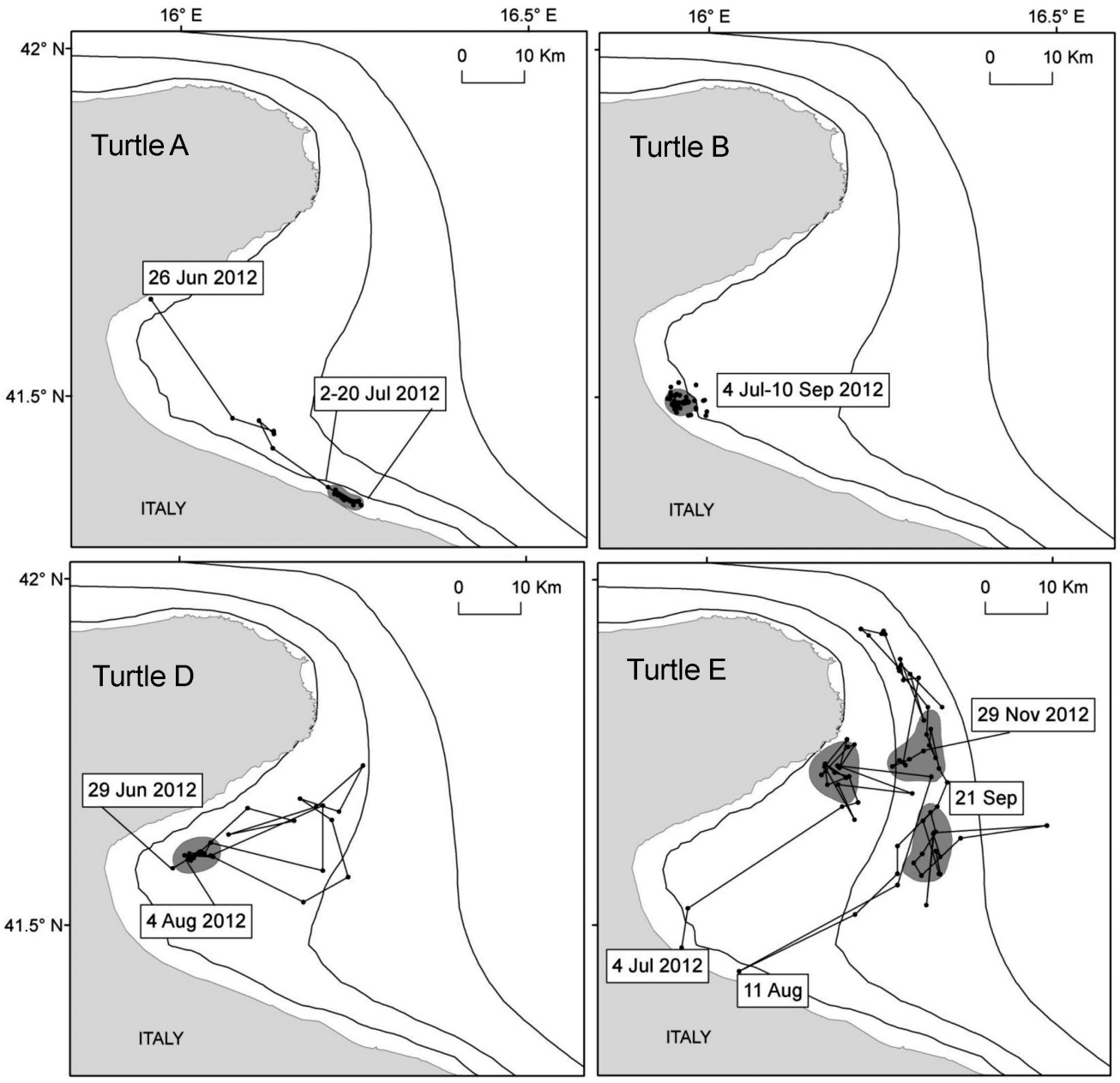

Fig. 1: Positions and paths of four loggerhead turtles (A, B, D, E) which remained in the Gulf of Manfredonia during the monitored period. The grey areas represent KDE 50%. Isobaths are shown (10, 20, 50 m).

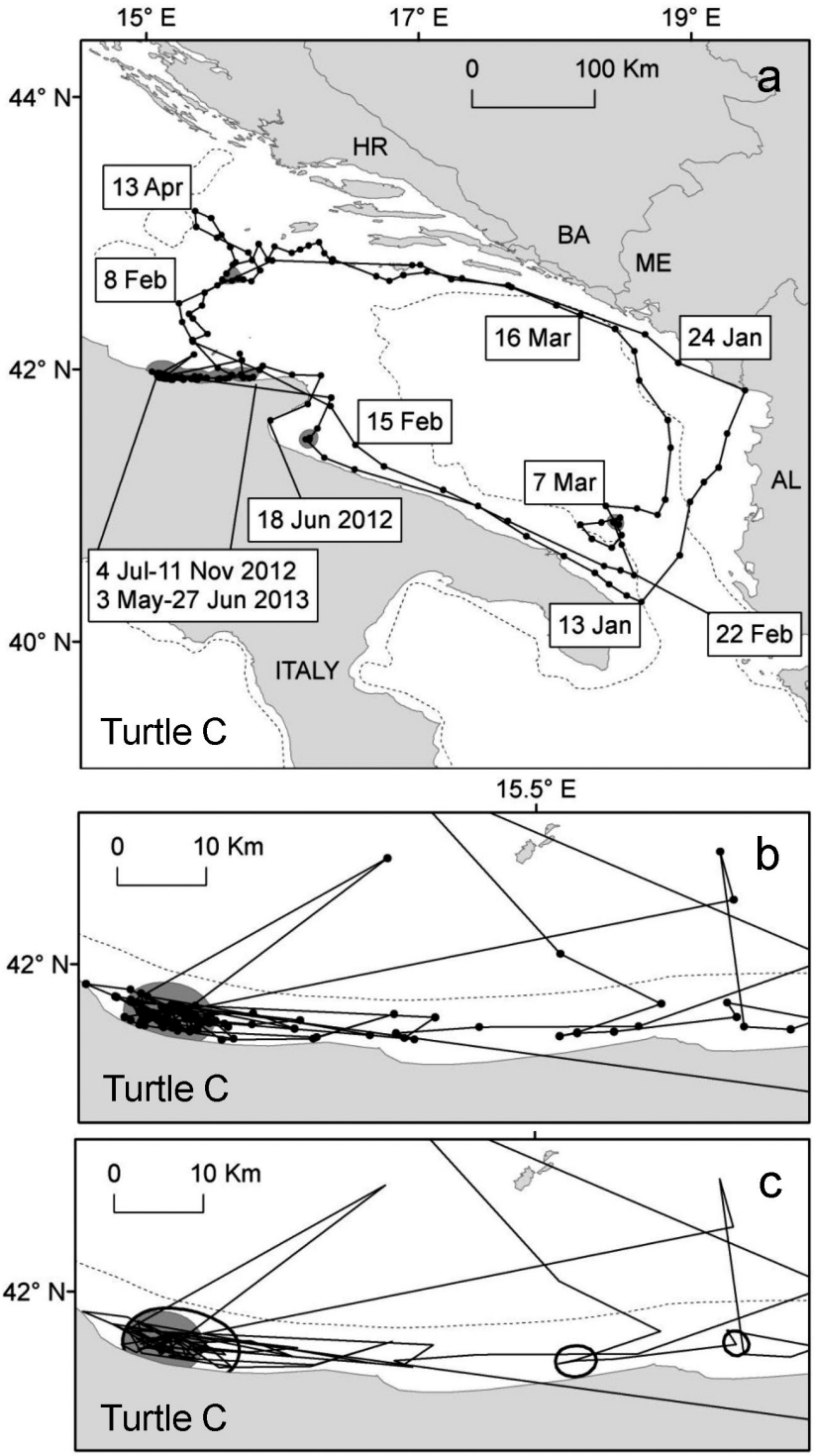

Fig. 2: Turtle C. (a) entire path.(b) coastal subarea of the periods 4 Jul-11 Nov 2012 and 3 May-27 Jun 2013, where the grey area represents KDE 50% for aggregated data. (c)the same subarea with separate KDE 50% for the period 2012 (grey area) and 2013 (ellipse). AL: Albania; BA: Bosnia and Herzegovina; HR: Croatia; ME: Montenegro. Isobaths 200m (a) and 20 m (b and c) are shown.

Discussion

This study contributes to the current knowledge of loggerhead sea turtle movements in the Adriatic, with the first individuals tracked from the southern zone. Although limited in sample size and monitored period, a usual problem in sea turtle tracking studies, results provide clues about conservation aspects and indicate next research steps.

All turtles were tracked for some time during the summer season and a strong resident behaviour was observed in four of them. Their home ranges were much smaller than juveniles in the western Mediterranean (Cardona *et al.,* 2009; Revelles *et al.,* 2007a; Revelles *et al.,* 2007b), juveniles in the Adriatic Sea (Casale *et al.,* 2012a), and juveniles and adult males in the central Mediterranean (Casale *et al.*, 2012b; Casale *et al.,* 2013), while they were

comparable to those observed in adult males in the North Adriatic and Ionian (Rees *et al.,* 2013; Schofield *et al.,* 2010) and in juveniles in the neritic waters of the Ebro Delta, Spain (Cardona *et al.,* 2009). Although there is a general tendency of a progressive reduction of home ranges with a gradual shift from a pelagic-vagile to a benthic-sedentary lifestyle (Casale *et al.,* 2012b), the very small home ranges observed in this and other studies seems to be associated to local conditions, such as very shallow coastal waters with probable availability of benthic prey. In all the five turtles a general pattern can be observed with smaller home ranges occurring close to the shore and in shallow waters (<20 or even < 10 m) and larger home ranges or wandering movements occurring offshore. The four turtles that remained in the Gulf on Manfredonia during the tracking period settled in different areas. This suggests that optimal environmental conditions occur in a wide part of the Gulf and a much larger sample would be needed to identify possible subareas where turtle concentrate. Present results suggest that turtle occurrence may be higher in shallow waters along the coast, and further investigation may inform conservation actions aimed at reducing the impact of fishing (Casale *et al.,* 2012c).

The only turtle tracked all year round (Turtle C) showed different movement patterns between the seasons, being resident in a coastal neritic area in summer and moving over a wide offshore area during winter. Given the different depths of sea floor in the two areas, this was likely associated with feeding on benthic and pelagic prey, respectively. Seasonal migrations seem uncommon in the Mediterranean (Luschi & Casale, 2014), with the few directly observed cases reported from the Adriatic (Casale *et al.,* 2012a; Zbinden *et al.,* 2008). However, the seasonal change showed by turtle C was more in terms of movement pattern (resident vs. wandering) than of a proper latitudinal migration. We hypothesize that this change was driven by the temperature regimes in the area, on the basis of two observations. First, turtle C left and came back to the residential area in two months (November and May) with the same surface temperature. Second, during the winter months the sea temperature at the residential area (shallow waters) dropped to very low values (c. 10°C). Although loggerhead turtles can maintain some level of activity at cold temperatures (min 11.8°C; Hochscheid *et al.,* 2007), seasonal movements have been interpreted as an avoidance of such low temperatures, for instance in the Atlantic (Hawkes *et al.,* 2011; Musick & Limpus, 1997) and in the Mediterranean (Cardona *et al.,* 2009; Casale *et al.,* 2012a; Lazar *et al.,* 2003; Zbinden *et al.,* 2008; Zbinden *et al.,* 2011). In the shallow waters (< 20 m) frequented in summer by most of the tracked turtles, sea surface temperatures in winter dropped at lower levels than offshore waters. We hypothesize that the behaviour of turtle C is not an exception and that in winter loggerhead turtles leave those shallow waters of the Gulf of Manfredonia and nearby, either remaining in the Adriatic - but in offshore waters like turtle C - or moving outside the Adriatic. Such a seasonal pattern would have profound implications for the conservation strategies addressing turtle bycatch in the Gulf (Casale *et al.,* 2012c), therefore investigation into this specific aspect should be considered as a priority.

In its winter wandering phase, turtle C movements coincided with the counterclockwise South Adriatic gyre (Zavatarelli & Pinardi, 2003) and the turtle went along very similar paths in both the complete rounds it made. These two observations suggest that sea surface currents were the primary driver of the turtle route but also that an active adjustment by the turtle occurred, as observed elsewhere (e.g., Mencacci *et al.,* 2010). Turtle C also showed a remarkable fidelity to the same small coastal spot. Fidelity to a foraging area by juveniles after seasonal migrations has been observed in a few cases (Arendt *et al.,* 2012; Avens *et al.,* 2003; Cardona *et al.,* 2009; Carman *et al.,* 2016; Casale *et al.,* 2012a; Mansfield *et al.,* 2009). However, fidelity to such a small home range is atypical for juveniles (Barceló *et al.,* 2013; Carman *et al.,* 2016) and is more similar to home ranges observed in some adults (Casale *et al.,* 2013; Schofield *et al.,* 2010).

Three out of five turtles transmitted for a relatively short period of time. Transmissions may have stopped because of PTT detachment, damage or animal death, caused by natural or anthropogenic factors (e.g. incidental catch in fishing gear). In the Gulf of Manfredonia a high level of turtle incidental catch by trawlers is known to occur (Casale *et al.,* 2012c), which is also the suspected cause of the low turtle annual survival probability estimated in the area (Casale *et al.,* 2015). In this respect it is interesting that the three turtles with the shortest transmission periods frequented coastal areas of the Gulf, the one with a longer period stayed offshore in the border of the Gulf and the one with the longest period was almost always outside the Gulf. Given these suspected problems, for future studies in the same area we recommend the use of a different type of PTT that can reduce detachment problems and can provide more clues about different factors causing transmission stop, e.g. pop-up tags (Patel *et al.,* 2015).

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