

# Supplementary Material: Ontogeny of long distance migration

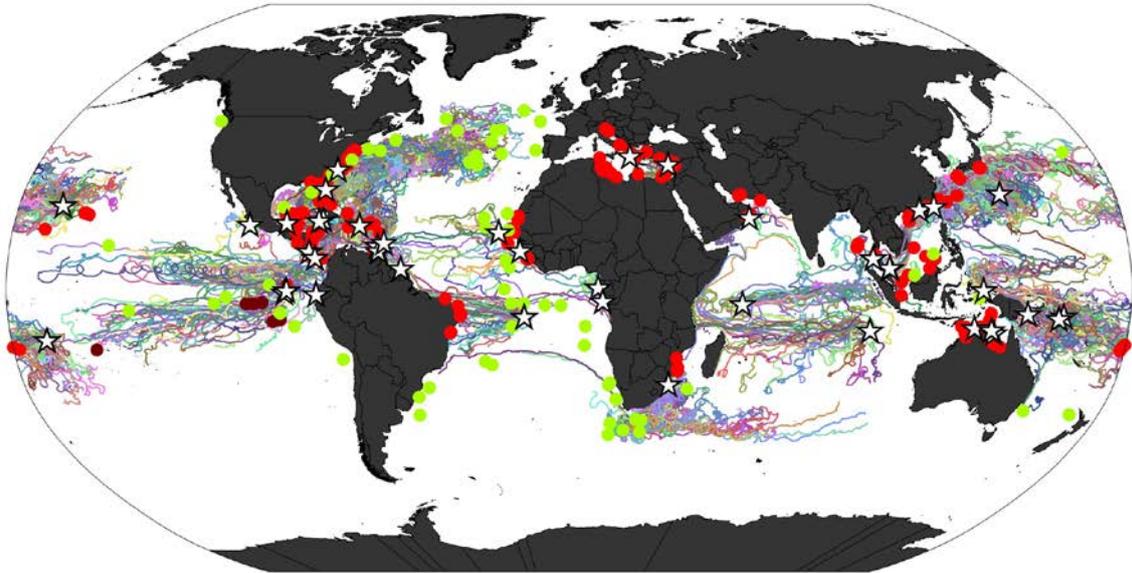
## Appendix A

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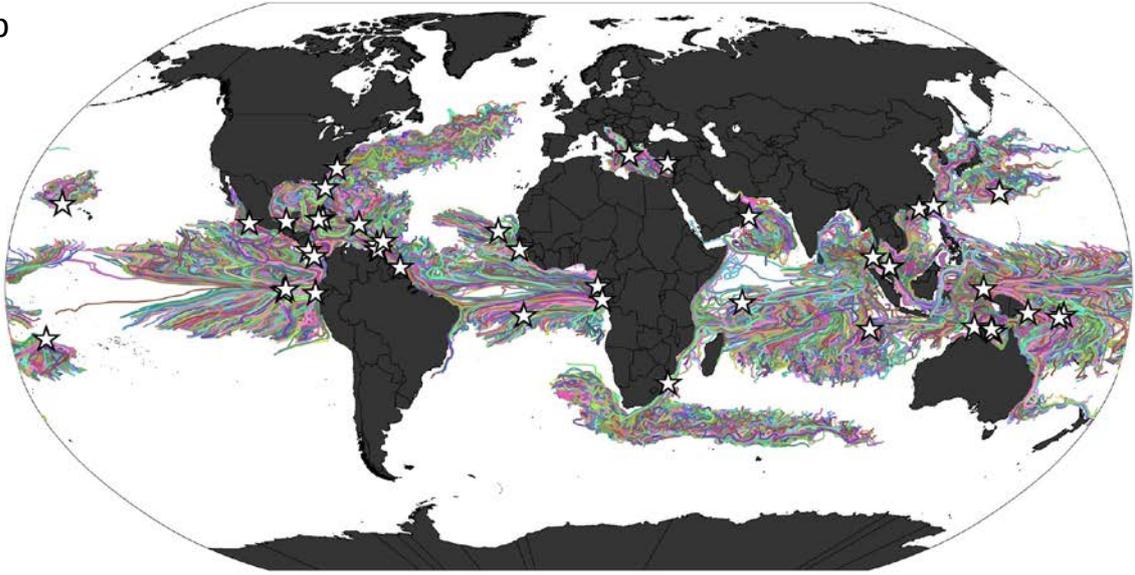
### FIGS. A1 TO A4 AND REFERENCE LIST

**FIG. A1. Lagrangian hatchling drift trajectories and adult foraging locations from 42 nesting sites (stars).** (a) 1794 1-year long trajectories derived from 1398 surface drifter buoys (spanning the years 1981–2011). Colors simply differentiate the trajectories. Foraging locations for >400 satellite tracked adult sea turtles are indicated by colored circles: cheloniid hard-shelled turtles (light red) and leatherbacks (green). Dark red circles depict end locations of cheloniid tracks where tags ceased transmitting before foraging locations could be confirmed (see supplementary references and Figs. A2–A4 for foraging location references). (b) 42,000 1-year long particle trajectories derived from NEMO simulations (during periods of peak hatchling emergence, spanning the years 2000–2006). The large-scale circulation is broadly similar in both observed and simulated drifts: within  $\pm 15^\circ$  of the Equator, flows are predominantly westward, incorporating some Ekman divergence about the Equator itself; in the subtropics, drifts follow the major western boundary currents, most conspicuously the Gulf Stream, the Kuroshio, the Agulhas, and the East Australian Currents; elsewhere in the subtropics, flows are sluggish and less organized (see also supplementary video).

a

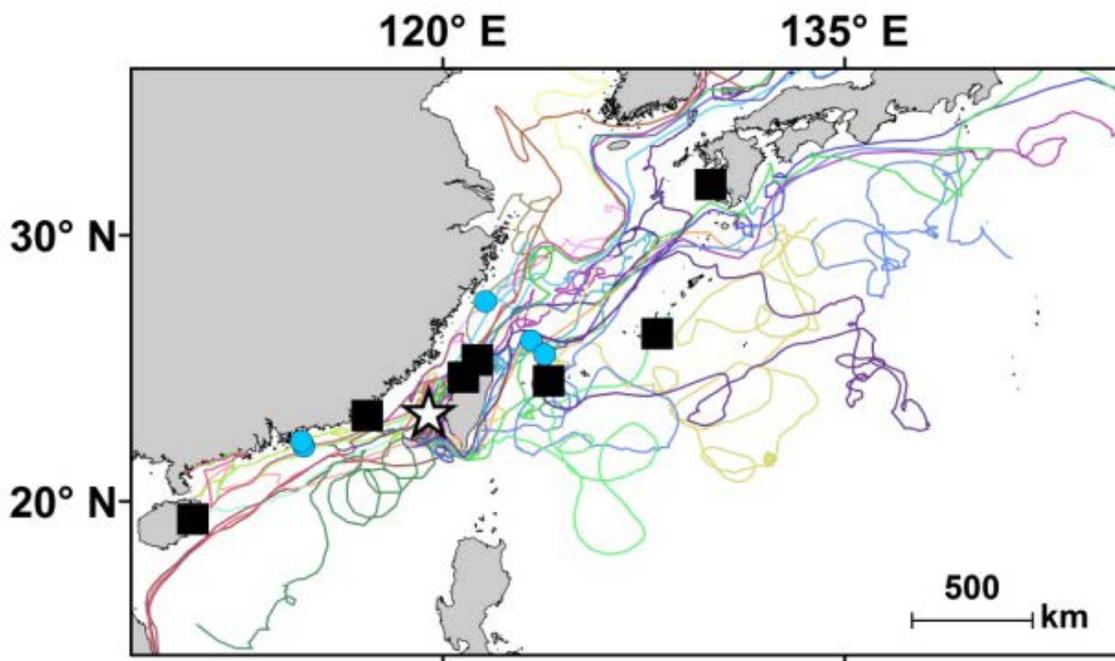


b

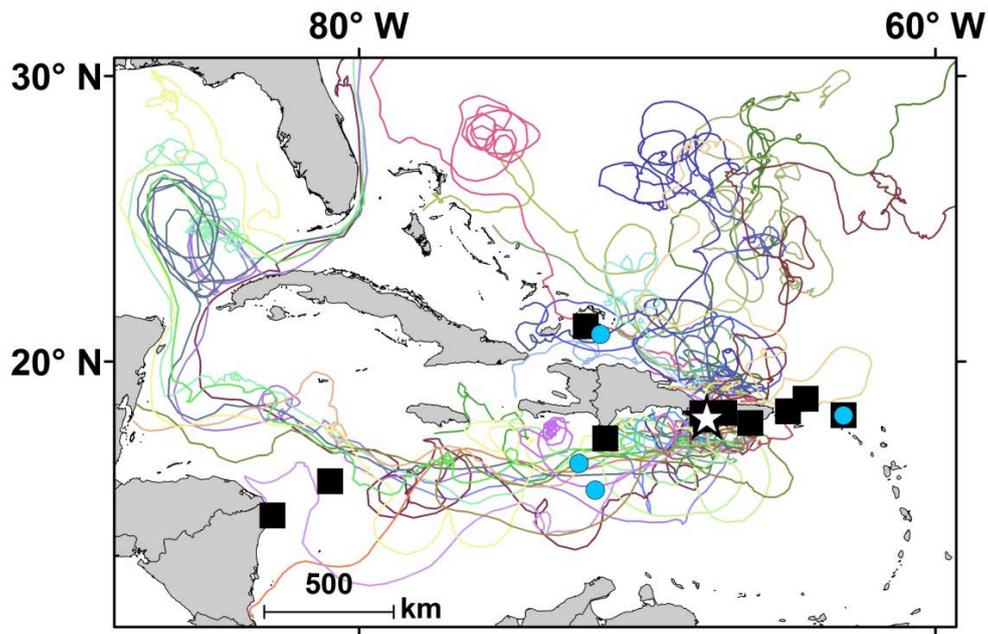


**FIGS. A2a–b. Further mechanism one populations with significant overlap and directionality in turtle and drift directions. Colored lines represent a selection of (c. 25–50) hatchling drift trajectories to reflect the spread of drift scenarios from the natal area (star), blue circles reflect adult locations 500 km from the natal area (displayed only for populations where  $\geq 3$  turtles traveled  $> 500$  km), black squares correspond to adult turtle foraging locations.**

**South China Sea**



**FIG. A2a.** Green turtles ( $n = 8$ ) from Taiwan (Cheng 2000). Adult turtles migrated along broadly NE or SW trajectories in accordance with the bifurcation of drifters, seven turtles reached their foraging habitats. Significantly more turtles than expected by chance traveled in the same direction as drifters ( $p < 0.001$ ; see also Fig 3.d).



**FIG. A2b.** Hawksbill turtles ( $n = 15$ ) tracked from Mona Island, Puerto Rica (Van Dam et al. 2008). Eight turtles foraged locally around Puerto Rica, three turtles migrated east towards the U.S. and British Virgin Islands and the French West Indies. One turtle migrated NW towards the Turks and Caicos Islands, three turtles migrated broadly west to the Dominican Republic, Nicaragua and Honduras. c. 60 % of Lagrangian drifters traveled broadly north or east of the Dominican Republic, the rest traveled broadly west along the southern coast of the Dominican Republic, into the Caribbean Sea and towards the coasts of Nicaragua, Honduras, Belize and Mexico. c. 32% of drifters entered the Gulf of Mexico and 28% drifted east of Florida in the Gulf Stream. Significantly more turtles than could be expected by chance migrated in the same direction as drifters ( $P < 0.002$ ; see also Fig 3.e).

FIGS. A2c–o. Further mechanism one populations where ocean currents and turtle migrations were more dispersed or turtle migrations reflected a subset of a broad range of potential drift routes. Map symbols follow those detailed in previous figures and red squares correspond to locations where tags ceased transmitting before adult turtles reached their foraging habitats.

Indian Ocean

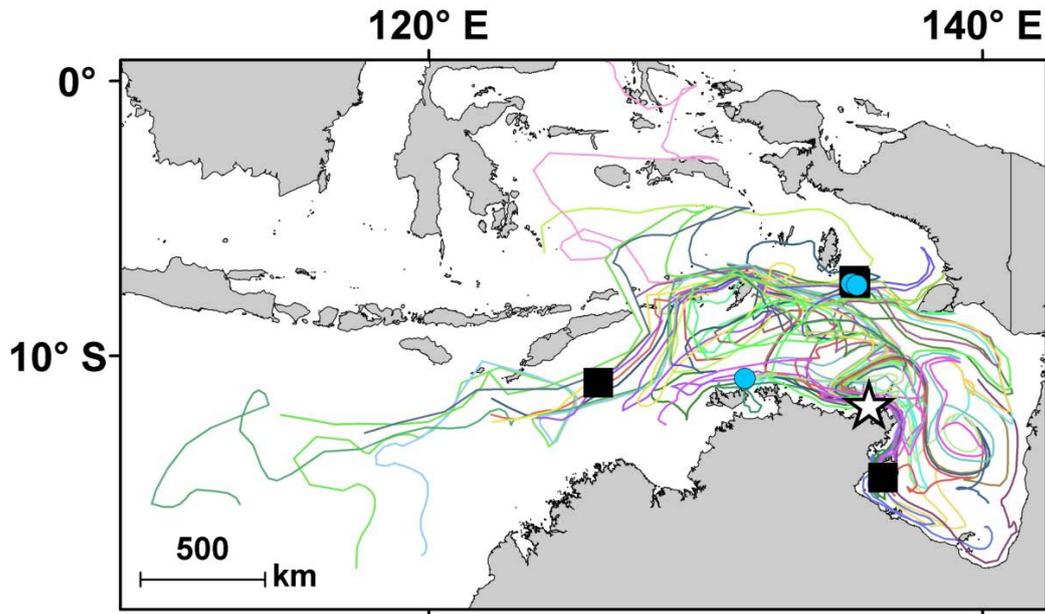


FIG. A2c. Olive ridley turtles ( $n = 4$ ) from the Wessel Islands, northern Australia (Kennet et al. 2004). All turtles migrated along a subset of a range of drift trajectories. Buoys dispersed widely, with c.50% first entering the Gulf of Carpentaria (where one turtle migrated), before remaining in the Gulf of Carpentaria or streaming broadly north then west.

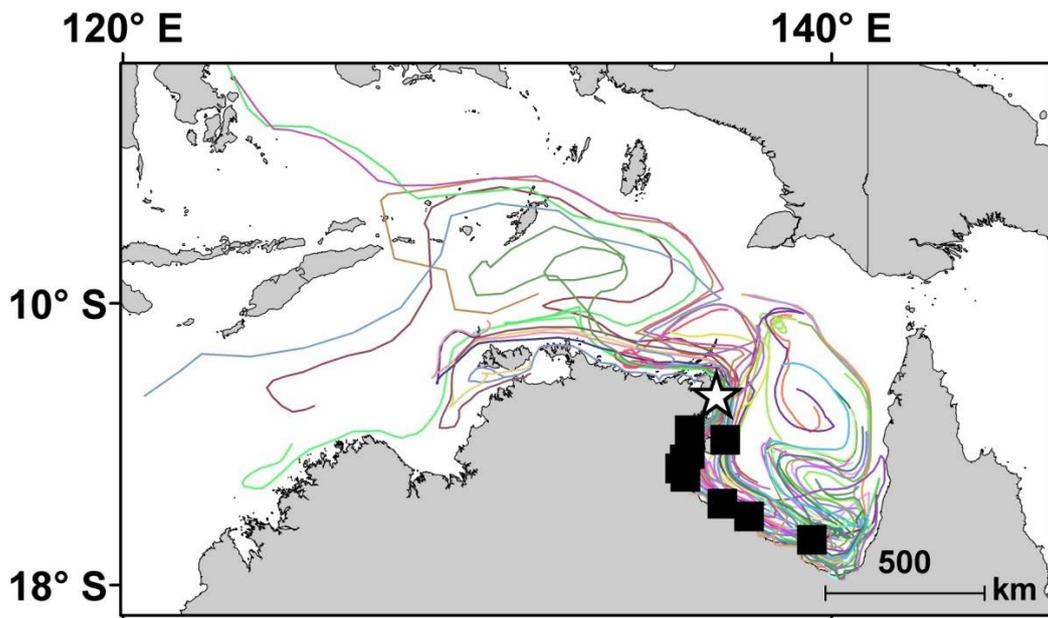
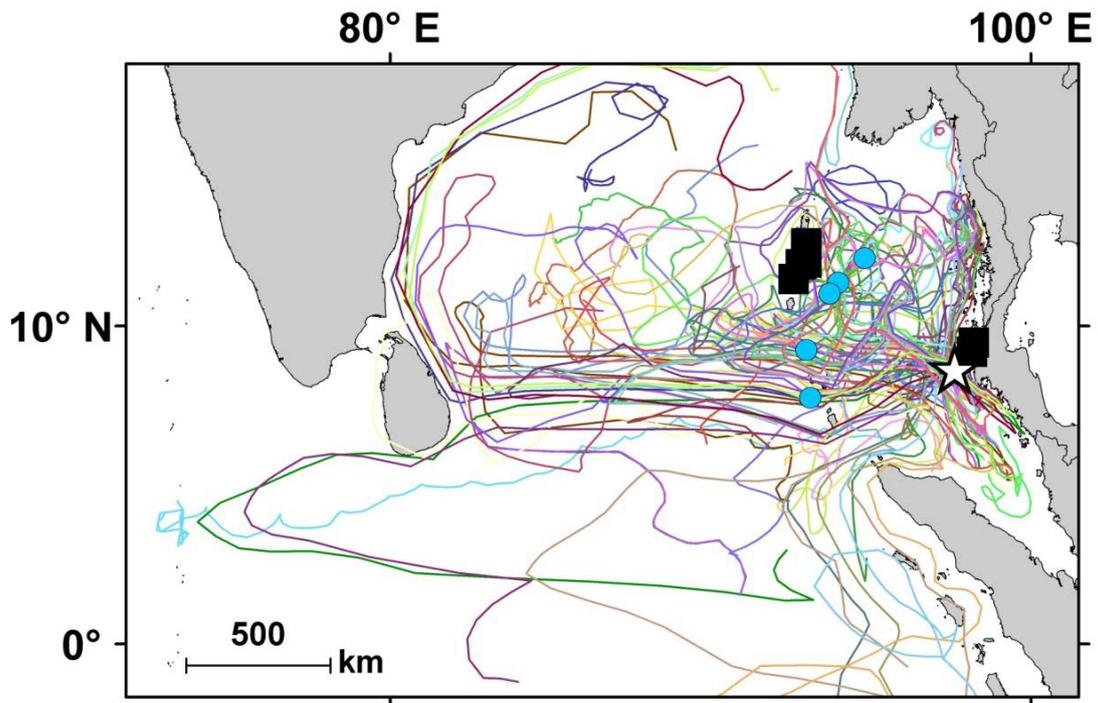
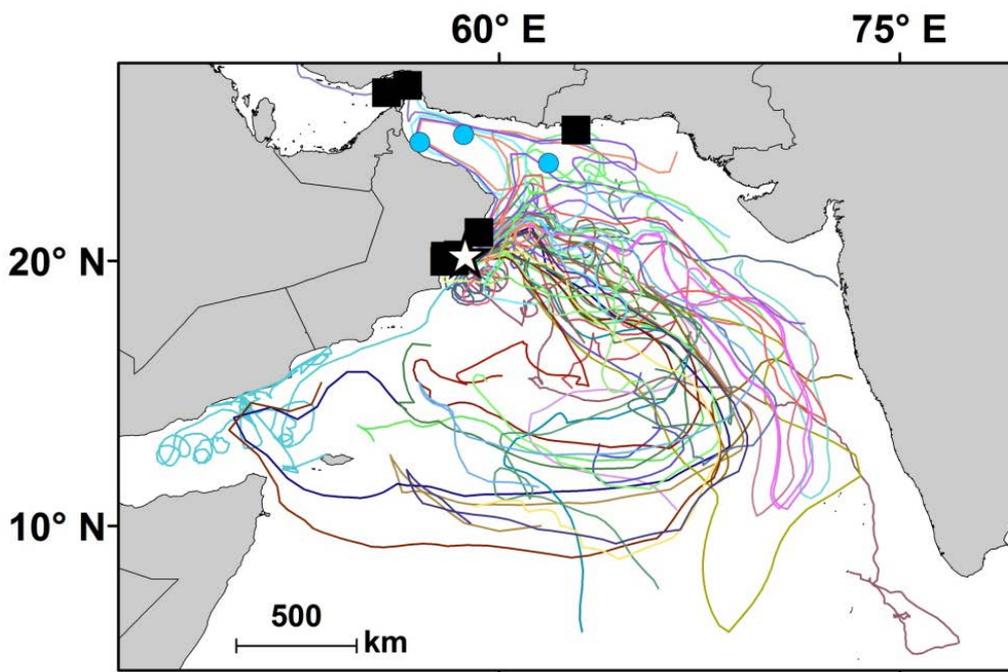


FIG. A2d. Green turtles ( $n = 20$ ) tracked from Djulpan nesting beach, northern Australia (4). All turtles migrated into the Gulf of Carpentaria. The majority (>99%) of buoys also drifted into the Gulf of Carpentaria, 36% of which then left the Gulf and drifted broadly west.

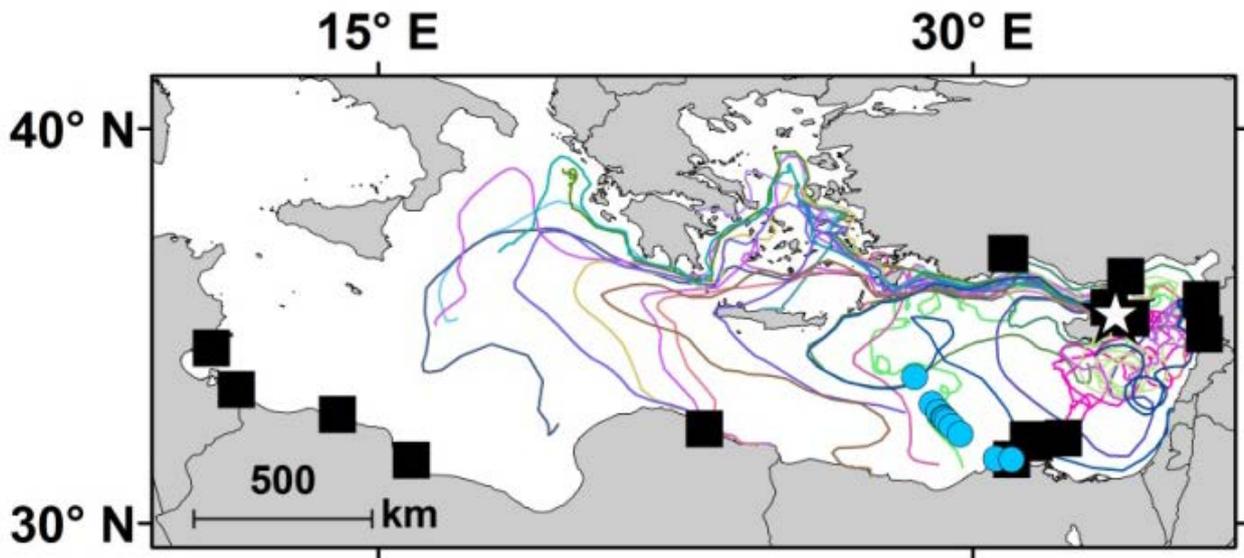


**FIG. A2e.** Green turtles ( $n = 7$ ) tracked from Huyong Island, Thailand (McMahon et al. 2007). Turtles traveled along a subset of a broad range of potential drift routes, five turtles migrated broadly west and NW to foraging habitats in the Indian Andaman Islands, while two migrated much shorter distances to a nearby Island off the coast of mainland Thailand. Drifters dispersed broadly throughout the Andaman Sea, Bay of Bengal and south into the Indian Ocean.



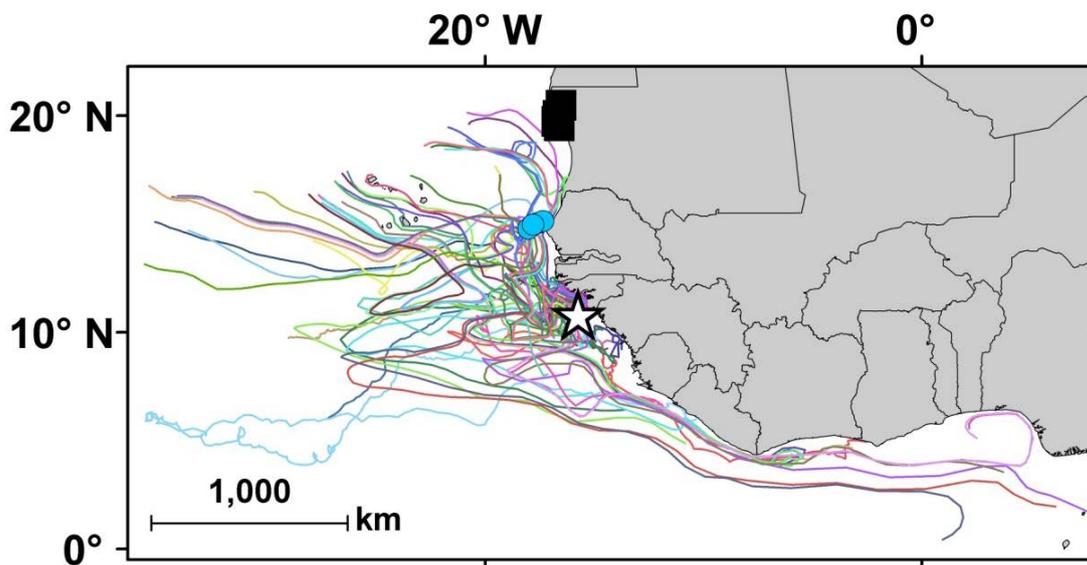
**FIG. A2f.** Olive ridleys ( $n = 9$ ) from Oman (Rees et al. 2012). Nine turtles migrated to discrete neritic foraging habitats, while one turtle performed pelagic wandering movements (more akin to leatherback turtles). Drifters dispersed broadly throughout the Arabian Sea and into the Gulf of Oman. Most turtles foraged locally near their natal area, while the other three migrated along a subset of a wide range of potential drift trajectories.

## Mediterranean Sea

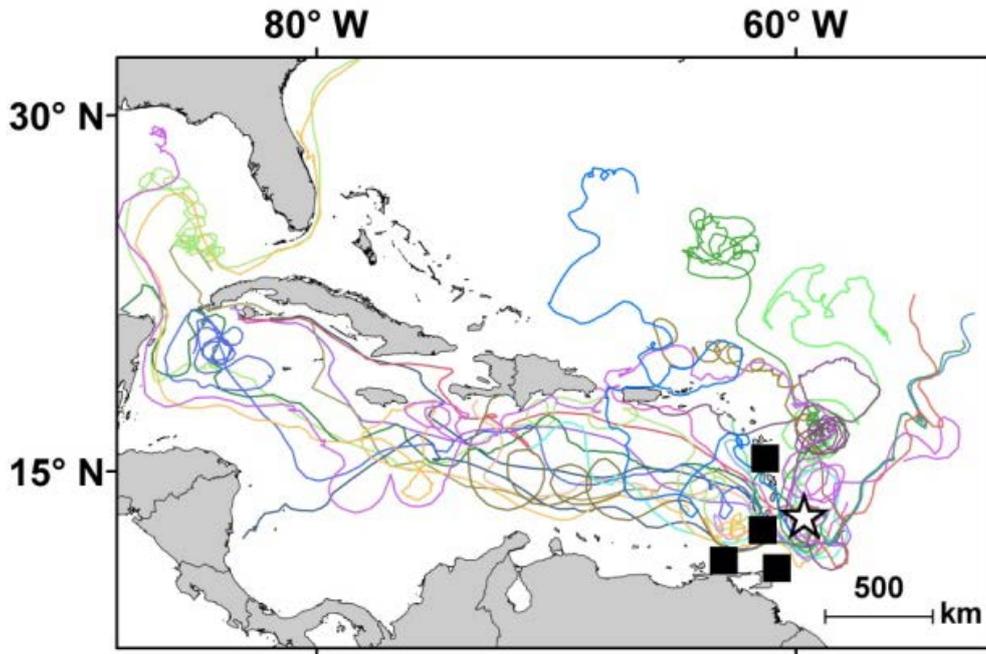


**FIG. A2g.** Green ( $n = 10$ ) and loggerhead ( $n = 10$ ) turtles tracked from Cyprus, Mediterranean (Godley et al. 2002, Godley et al. 2003, Broderick et al. 2007). All Lagrangian drifters that traveled  $> 500$  km drifted north to the coast of Turkey and then west before looping back round to various sites along the south and east boundaries of the eastern Mediterranean basin. Turtles that traveled  $> 500$  km however took more direct routes (along SW trajectories) to sites in the southern basin that they would have passively drifted to. Individuals that traveled shorter distances all foraged around the coast of Turkey, Cyprus and Syria; again to sites they would have encountered while drifting.

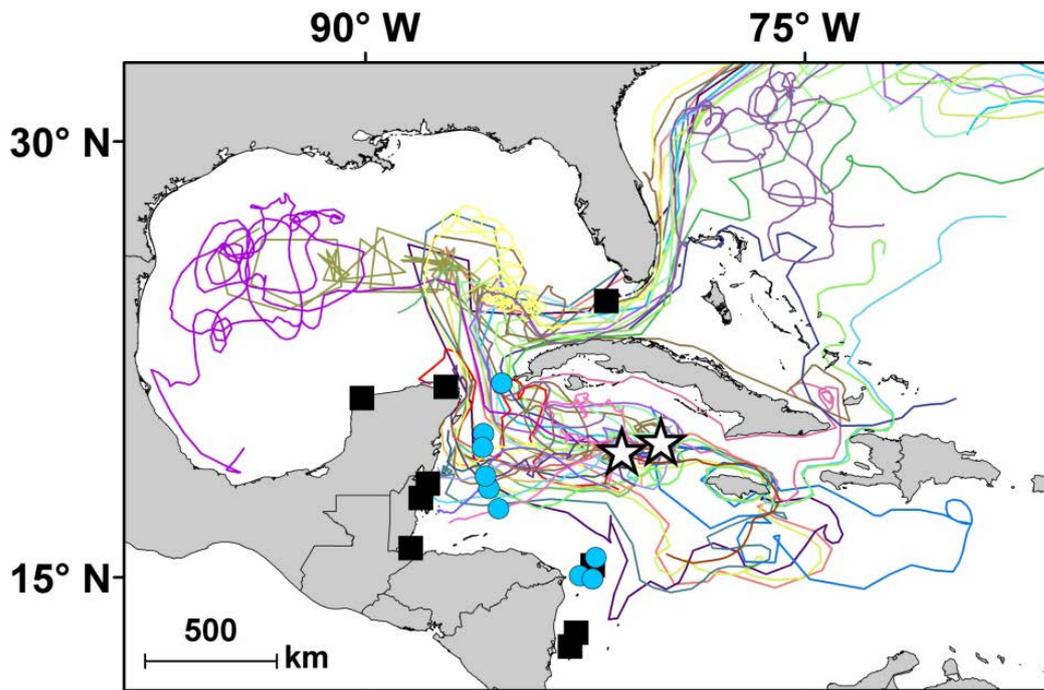
## North Atlantic



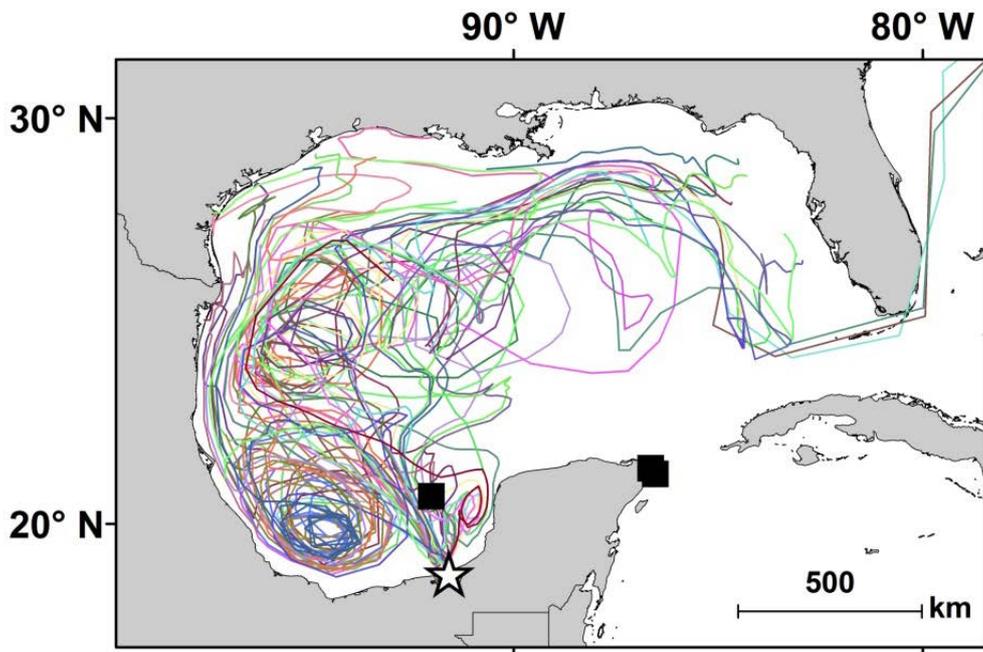
**FIG. A2h.** Green turtles ( $n = 3$ ) from Poilão Island, Guinea Bissau (Godley et al. 2010). Turtles all migrated north along the coast c. 1000 km to Mauritania. Drifters dispersed either broadly north along the coast towards Mauritania or south along the coast of Africa, or towards the Cape Verde Islands/into the North Atlantic Gyre.



**FIG. A2i.** Hawksbill turtles ( $n = 4$ ) tracked from Barbados, Caribbean (Horrocks et al. 2001). Drifters traveled broadly west and north past the Windward Caribbean Islands and into the North Atlantic or west and south towards the Windward Caribbean Islands and then into the Caribbean sea. All turtles migrated from Barbados (the most Eastern Windward Island), to other Windward Islands (c.200–400 km) to the north, west and south of Barbados.

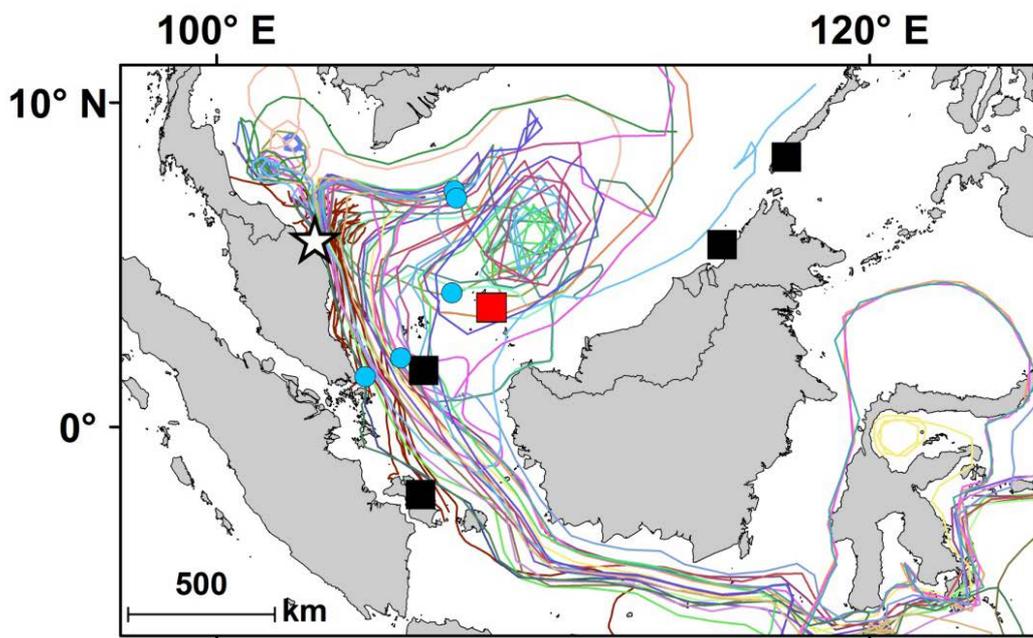


**FIG. A2j.** Green ( $n = 7$ ) and loggerhead ( $n = 3$ ) turtles from the Cayman Islands (Blumenthal et al. 2006). Turtles were tracked to a broad range of foraging habitats broadly south, west and north of the Cayman Islands. Drifters dispersed widely throughout this area, with c.89% of drifters initially travelling broadly west and south, 82% of drifters then passed the east coast of Florida in the Gulf Stream. Turtles migrated to a subset of a range of sites they could have encountered.



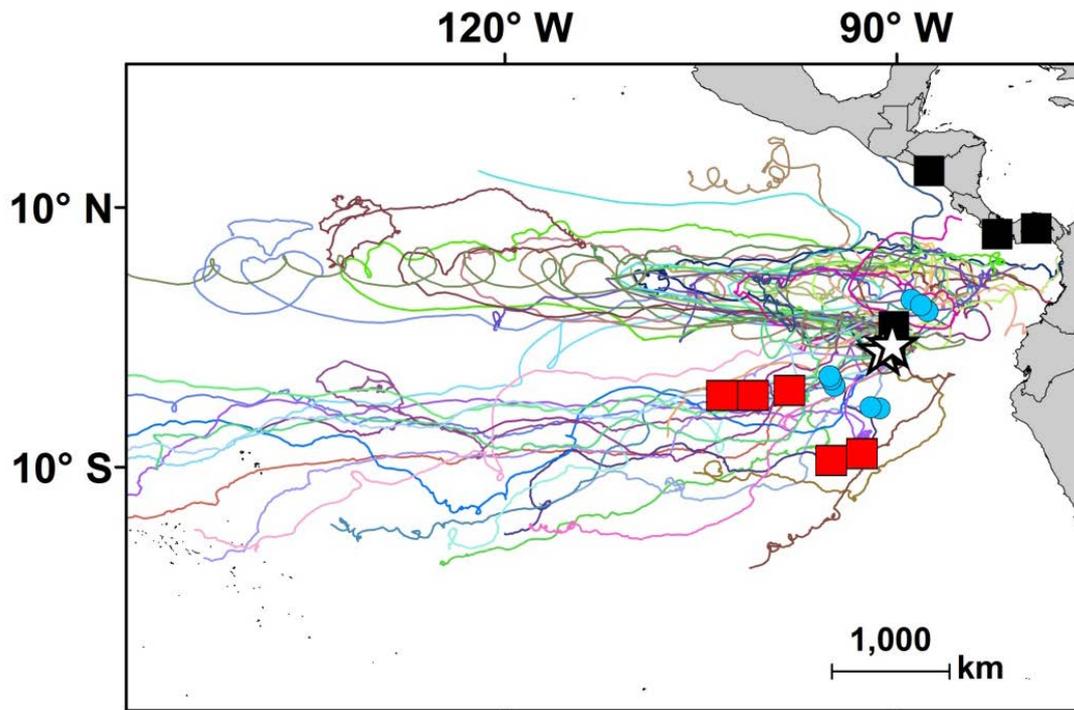
**FIG. A2k.** Hawksbill turtles ( $n = 3$ ) from Campeche, Mexico (Cuevas et al. 2008). One turtle foraged c. 100 km north of the natal area, while two turtles traveled along the coast broadly NE then east around the Yucatan Peninsula to their foraging habitats (c. 600 km away). Local retention of drifters was high, only 8% passed the east coast of Florida with the Gulf Stream, the rest remained within the Gulf of Mexico and hence turtles are anticipated to have encountered there foraging habitats within the Gulf of Mexico during their first few years of life.

#### South China Sea

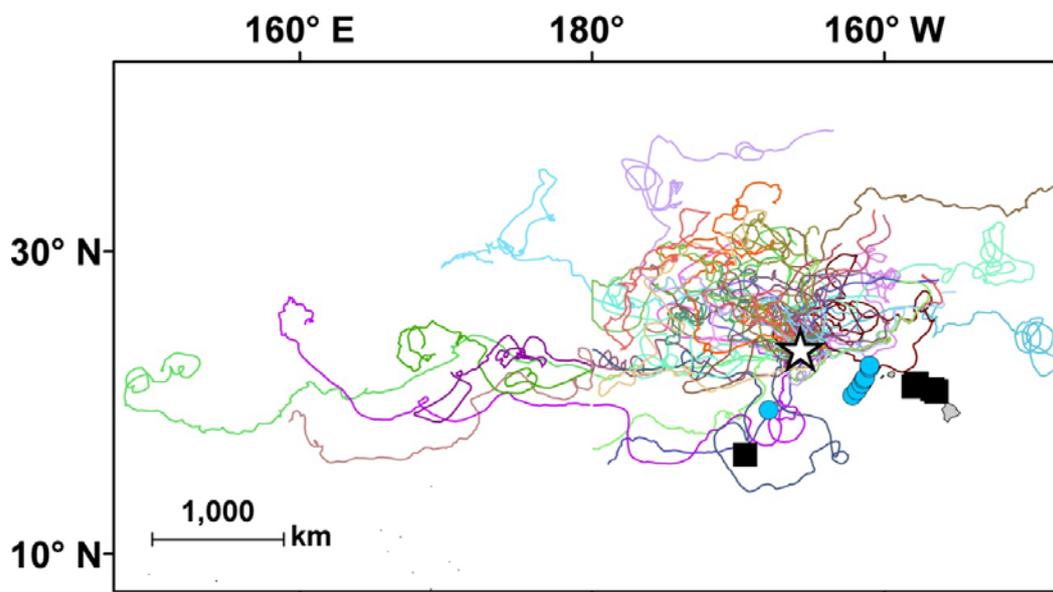


**FIG. A2l.** Green turtles ( $n = 5$ ) tracked from Redang Island, Malaysia (Papi et al. 1995, Luschi et al. 1996). Turtles traveled to their foraging habitats along broadly easterly-southerly trajectories. The tag transmissions stopped for one turtle in a location c. 600 km SE of the natal area before it reached its foraging habit. Drifters spread along broadly easterly-southerly trajectories in accordance with the movements of turtles.

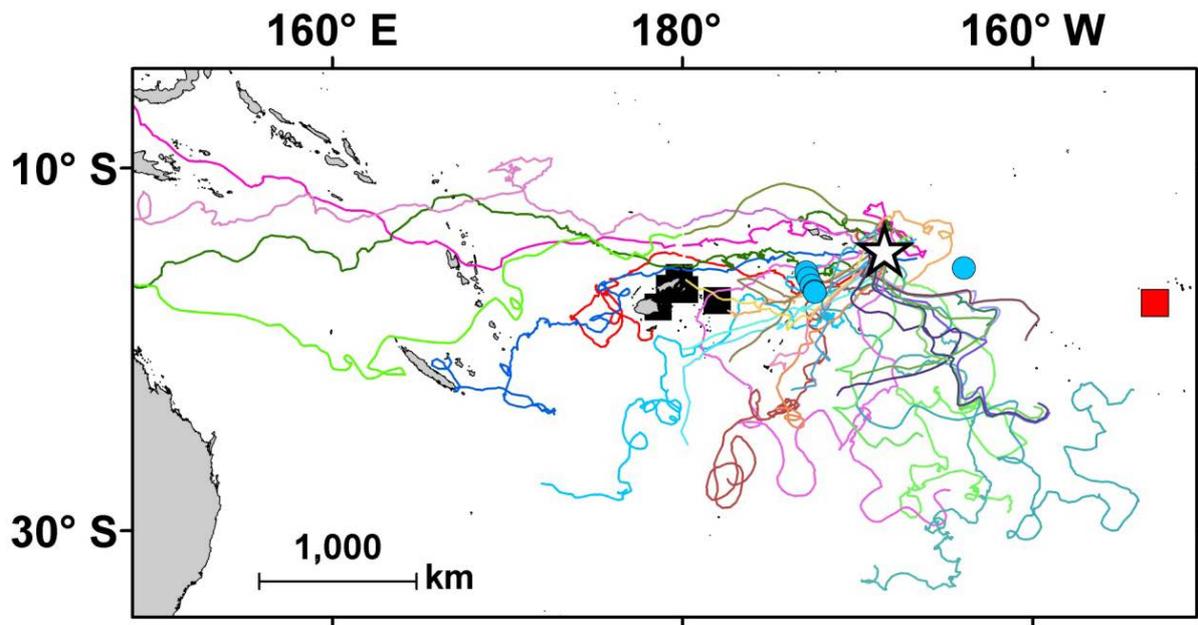
North Pacific



**FIG. A2m.** Green turtles ( $n = 10$ ) from the Galapagos Islands (Seminoff et al. 2008). Three turtles migrated NW to neritic foraging habitats in central America, two turtles remained resident in the Galapagos. Five turtles migrate and tag transmissions stopped in oceanic areas (red squares). Seminoff et al. (2008) suggested these turtles may be oceanic foragers (although the early failure of tags could not provide conclusive evidence for this). Drifters dispersed broadly north towards central America and west or broadly south and west. The nearest substantial land mass (the French Polynesia islands) along the south westerly trajectories lie  $>5000$  km from the natal area.



**FIG. A2n.** Green turtles ( $n = 8$ ) from the French Frigate Shoals (NW Hawaii) (Balazs 1994, Balazs et al. 1994, Balazs and Ellis 1998). Seven turtles migrated SE towards the SW Hawaii islands, while one turtle migrated to a neritic area in Johnston Atoll. Local retention was high for some drifters due to high eddy activity, while others started to drift along trajectories that would lead to transoceanic movements in the North Pacific Gyre. Turtles migrated c.1000 km to the nearest land masses away from their natal rookeries that they would be expected to have encountered as hatchlings.

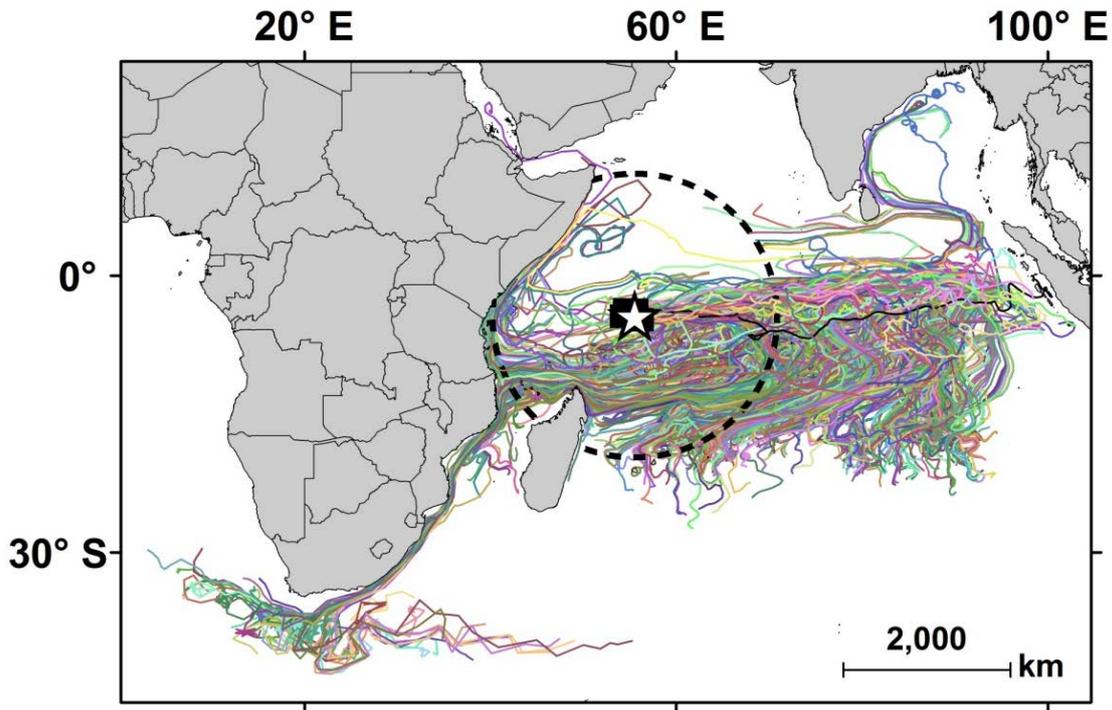


**FIG. A2o.** Green turtles ( $n = 7$ ) from America Samoa (Craig 2004). Six turtles migrated broadly WSW towards Fiji (in agreement with the prevailing south and westerly ocean current flows). Five of these turtles reached their foraging grounds. The seventh turtle traveled broadly east towards French Polynesia; however transmissions stopped before its foraging ground could be confirmed. Drift trajectories reveal that this turtle is likely to have encountered French Polynesia through a more convoluted drift trajectory as c. 20% of drifters started to drift in this direction.

**FIG. A3 a–c.** Further mechanism two populations where turtles adopted an atypical migration strategy and the downstream distance of nearest landmasses to nesting beaches were too far for adult cheloniid turtles to travel. Map symbols follow those detailed in Fig. A2 but all Lagrangian drift trajectories ( $> 1000$ )

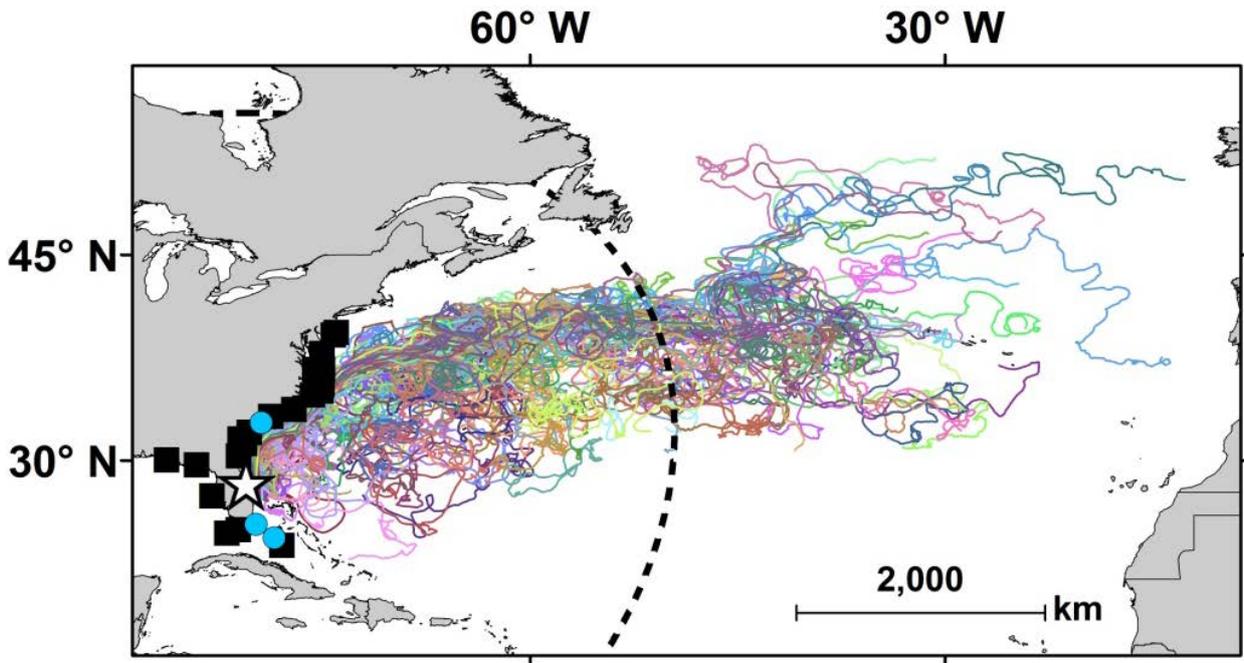
are plotted and dashed lines represent a 3000 km buffer (upper migration ceiling (Hays and Scott 2013)) from the nesting sites.

### Indian Ocean



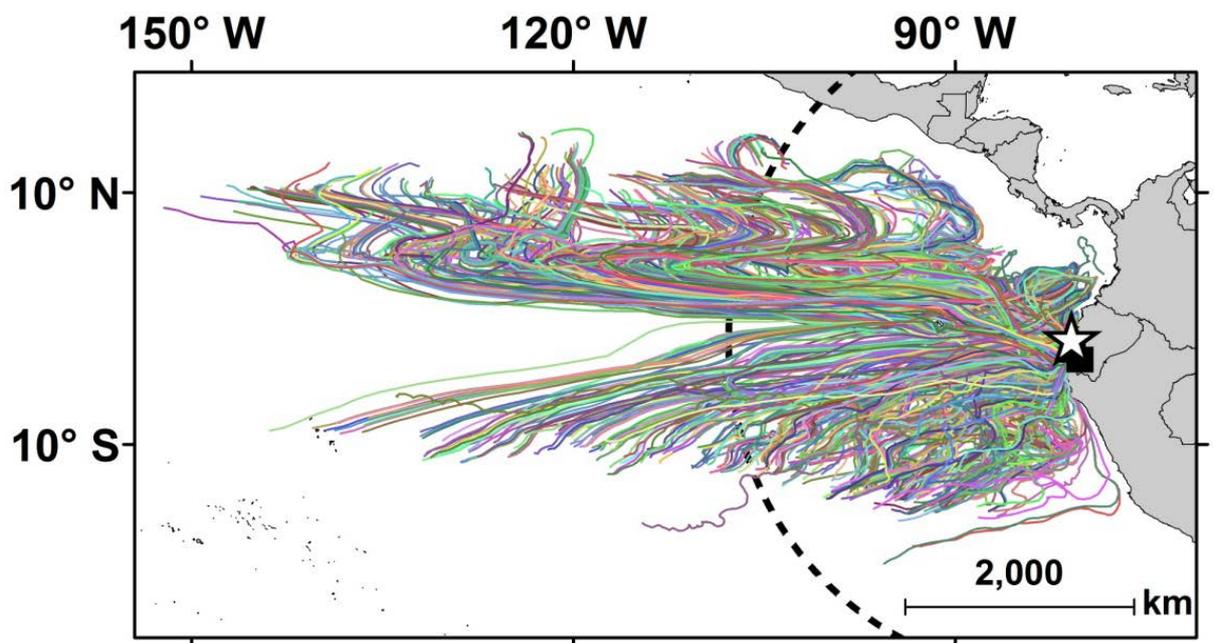
**FIG. A3a.** Hawksbills turtles ( $n = 5$ ) from Cousin Island, Seychelles (Mortimer and Balazs 2000). All turtles remained locally resident within the Seychelles Archipelago. The majority ( $>80\%$ ) of drifters traveled broadly east where they would not have encountered any other land mass for c.5000 km along this trajectory, drifters then traveled broadly south (in the Indian Ocean) or north (into the Bay of Bengal) or back west (towards Africa/Madagascar). A few drifters left the natal area and then traveled broadly west, then north/south towards Africa/Madagascar. These land masses lay within the 3000 km upper migration ceiling (dashed line) that post-nesting adult cheloniid turtles can travel to their foraging habitats.

### North Atlantic



**FIG. A3b.** Loggerhead turtles ( $n = 16$ ) from Cape Canaveral, east Florida (Arden et al. 2012). All turtles (bar one) migrated both north and south along the coast and around the Florida Panhandle and into the Gulf of Mexico. One turtle crossed open water to reach its foraging location in the Bahamas. Drifters tended to dispersed north, then east in the North Atlantic Gyre. The nearest landmass along this easterly drift trajectory is  $>5000$  km away and hence too far for adult cheloniid turtles to return. Some drifters did not reach the eastern Atlantic and were entrained in eddies offshore from the mainland USA. Most notably, some of these drifters passed near the Bahamas (the only other land mass within 3000 km that drifters encountered) and also where the only turtle that left the mainland USA migrated.

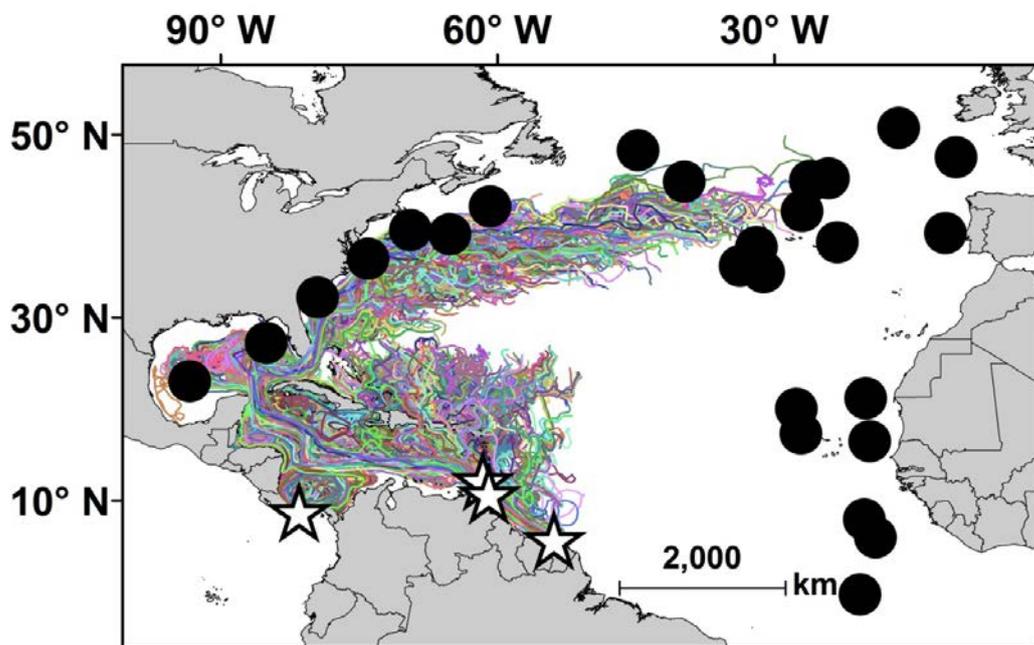
#### North Pacific



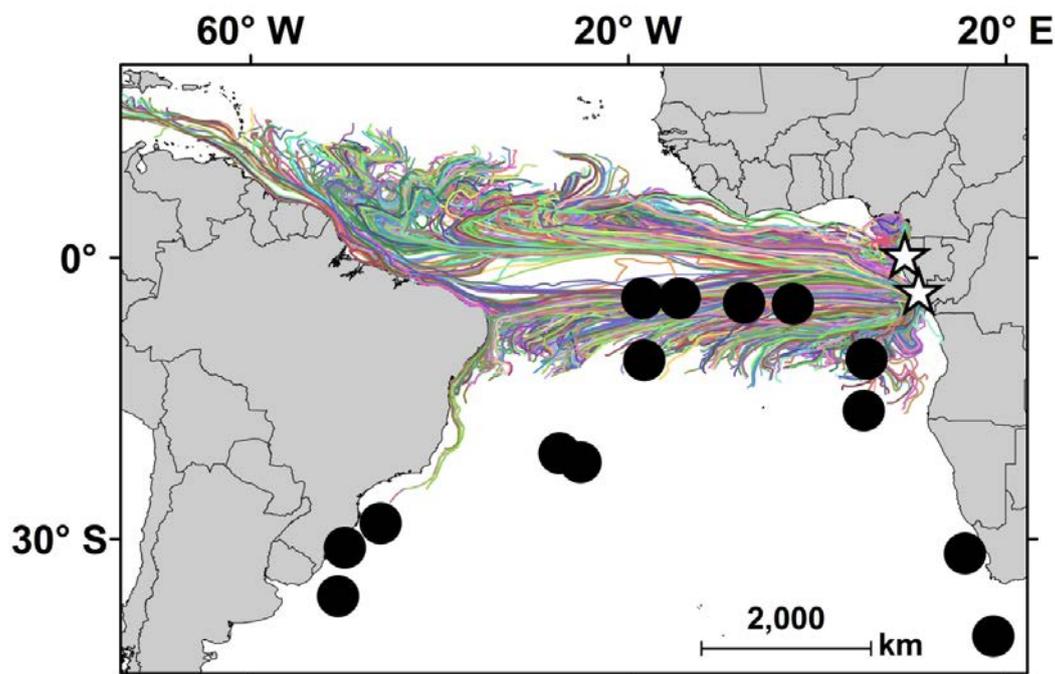
**FIG. A3c.** Hawksbill turtles ( $n = 3$ ) from Ecuador (Gaos et al. 2012). Turtles migrate short distances (c.  $< 200$  km) along the coast. Drifters disperse broadly north and then west or south and then west, not encountering any land mass away from the mainland that an adult turtle could migrate to.

**FIG. A4 a-d. Further leatherback turtle populations where broad scale movement patterns reflect broad scale patterns in ocean circulation systems. All Lagrangian drift trajectories (>1000) at each site are plotted. Black circles correspond to the location of leatherback tracks at their furthest from their natal area (stars).**

**Atlantic Ocean**

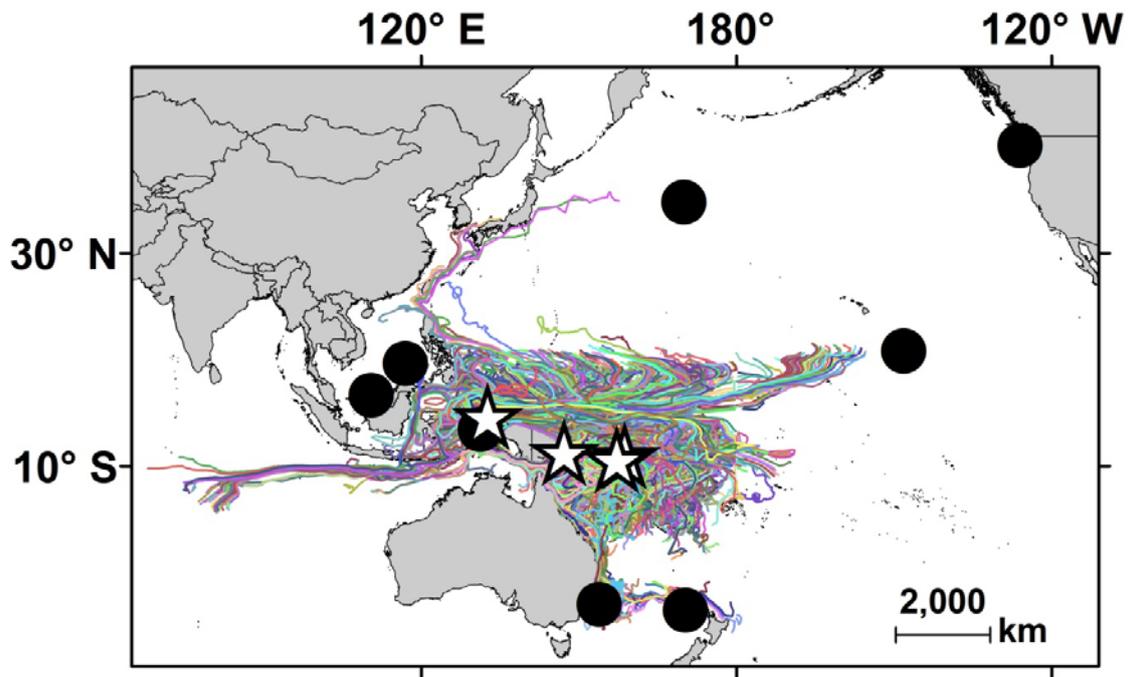


**FIG. A4a.** Leatherback turtles tracked from the French Guinea/Suriname Nesting complex, Trinidad, Grenada and Panama (Eckert 2006, Ferraroli et al. 2004, Hays et al. 2006, Fossette et al. 2010). Turtles dispersed widely throughout the North Atlantic, Caribbean sea, and Gulf of Mexico and remained north of the Equator. In one year, Lagrangian drifters also started to disperse widely throughout this area.

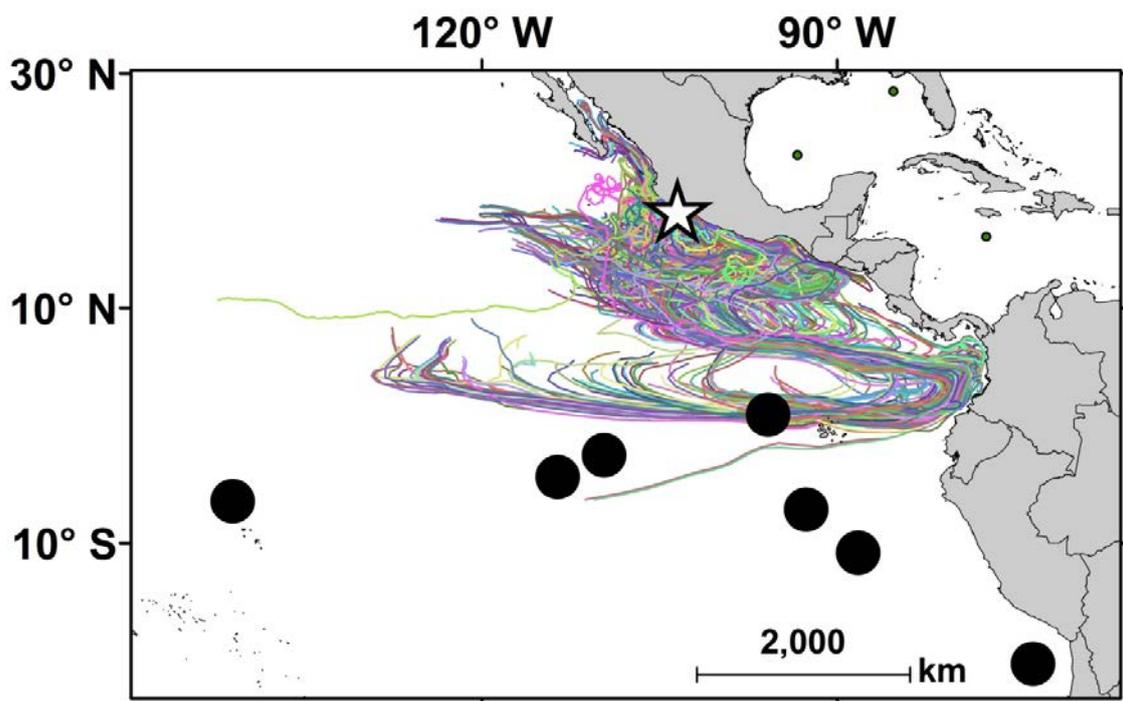


**FIG. A4b.** Leatherback turtles tracked from nesting beaches in the north and south of Gabon (Fossette et al. 2010, Witt et al. 2011). Turtles dispersed widely throughout the South Atlantic remaining south of the Equator. However, it is noteworthy that due to the bifurcation in the westward flowing South Equatorial current, all drifters from the northern nesting site drifted along the northern leg of the bifurcation towards the North Atlantic, while 86% of drifters from the southern nesting site drifted along the southern leg and disperse throughout the South Atlantic.

**Pacific Ocean**



**FIG. A4c.** High use areas of leatherback turtles from nesting sites in Papua New Guinea, Indonesia, and the Solomon Islands (Benson et al. 2011). Turtles traveled widely throughout the Pacific with some turtles foraging c. 11,000 km from their natal area. Due to the large number of tracked individuals black circles correspond to high use areas of multiple individuals.



**FIG. A4d.** Leatherback turtles tracked from Mexiquillo, Mexico (Eckert and Satri 1997). Turtles traveled widely, all crossing the equator and into the South Pacific Ocean, it is noteworthy however that current flows captured by Lagrangian drifters tended to remain North of the equator.

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