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Movement patterns of pelagic sharks in the Southern and Indian Oceans: determining critical habitats and migration paths

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Final Report to Nature Foundation South Australia Inc

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SUMMARY

1. Satellite tags were used to investigate the critical habitats and migration paths of five Shortfin Makos (*Isurus oxyrinchus*) and a Blue Shark (*Prionace glauca*) in the Southern and Indian Oceans between March 2008 and February 2009;

2. Tagged Shortfin Makos ranged in size between ~1.7 and 2.0 m total length (TL) and the Blue Shark was ~220 cm TL;

3. Satellite tags reported 3,844 positions for the tagged sharks;

4. A total of 2,126 (55%) positions were reliable and these were retained for subsequent analyses;

5. Times at liberty for Shortfin Makos ranged between 46 and 348+ days. The Blue Shark provided positions for 288 days;

6. Shortfin Makos moved minimum straight-line distances between 1,165 km in 46 days and 13,314 km in 263 days. The Blue shark travelled 9,347 km in 288 days; Mean minimum swim speeds for Shortfin Makos ranged between 1–2.1 km/hr. The Blue Shark had a mean minimum swim speed of 1.3 km/hr;

7. Data recorded by satellite tags indicated that Shortfin Makos inhabited a broad range of water temperatures between 10 and >24°C. The preferred temperatures for two individuals were 16 (29%) and 18°C (41%), respectively;

8. Shortfin Makos generally displayed broad depth distributions with peaks at 5 and 80 m. Maximum dive depth reported was 600 m. Shortfin Mako 52466 spent ~80% of daylight hours at depths of 320–600 m in the central Great Australian Bight (GAB). During the night/dark period it inhabited a narrower depth range and spent 44% of it's time at depths <80 m;

9. Thermal preferences and depth distributions were similar to those of previously published studies of juvenile Shortfin Mako and White Sharks in the NE Pacific Ocean;

10. One Shortfin Mako and the Blue Shark, made broad-scale migrations along the continental shelf slope in the GAB, to oceanic areas in the NE Indian Ocean that were beyond Australia's Exclusive Economic Zone (EEZ, 200 nm). This Shortfin Mako and the Blue Shark spent ~29 (11%) and 82 days (28.5%) in International waters, respectively;

11. Satellite tagging data indicated that there is spatial connectivity between Shortfin Mako and Blue Shark populations in the Southern and NW Indian Oceans;

12. Project web-pages were developed to enhance the public profiles of southern Australia's unique top marine predator populations, including pelagic sharks. There were >2,500 visits to the website following the inclusion of pages about tracking 'Lilly the Mako';

13. Our preliminary findings suggest that future management arrangements for these pelagic shark species need to consider spatial scales that encompass Australian State, Commonwealth and adjacent International jurisdictions in the Southern and NE Indian Ocean.

BACKGROUND

The United Nations Food and Agriculture Organisation's (FAO), *Code of Conduct for Responsible Fisheries* expects that UN affiliated countries have fisheries management strategies that adequately conserve and protect biodiversity, habitats and ecosystems. In Australia, the EPBC Act (1999) requires fisheries to undergo ecological assessment processes relating to impacts on ecosystems and *Threatened* species. The Commonwealth Government's *Australian Ocean Policy* also provides a framework of guidelines for Ecologically-Based Fisheries Management (EBFM). Given the well documented declining global trends in pelagic shark populations (Baum *et al.* 2003; Myers and Worm 2003; Baum and Myers 2005) and their importance to the structure and functioning of marine ecosystems (Myers *et al.* 2007), key populations in Australian State and Commonwealth waters require further attention. Management of highly mobile, pelagic shark species is difficult in the absence of information about variability in distribution with changing ontogeny, space utilization, and migration patterns.

Shortfin Makos *Isurus oxyrinchus* (family Lamnidae) have a global temperate and tropical distribution (Last and Stevens 2009). Lamnid sharks have thermo-regulatory systems that provide distinct metabolic advantages including the ability to forage over a broad range of thermal habitats (Bernal *et al.* 2005). This trait is likely to facilitate swimming and spatial extension of foraging into cool waters, such as those below thermoclines and near upwelling frontal systems. Due to recognition that Shortfin Mako populations have declined in the northern hemisphere, they were listed as a *Vulnerable* species under the International Union of Conservation of Nature (IUCN) (Dulvy *et al*. 2008), and the Convention of Migratory Species (CMS). Shortfin Makos are among the top pelagic predators in southern Australian continental shelf and gulf ecosystems.

Recreational and game fishers target Shortfin Makos around Australia, and take them incidentally while targeting other species. They are also taken as bycatch by commercial fisheries (Findlay and Bromhead 2003), however data is limited (Stevens 2008). About 1,594 Shortfin Makos were taken per year in the Japanese long-line fishery off the east coast of Australia between 1988 and 1990 (Stevens 1992). In New Zealand waters, 25,000 Shortfin Makos were taken as by-catch in the tuna longline fishery in the periods between 1988–9 and 1997–8 (Francis *et al.* 2001). In Australia, there is minimal evidence to suggest populations are declining, however no fishery independent surveys of relative abundance have been undertaken, fishery-based assessments are hamstrung by data quality issues (Stevens 2008) and a precautionary management approach is warranted due to their *K*-selected life history strategies.

Collection of movement and behavioural data is central to the definition of critical habitats and migration paths of marine predators. Electronic tagging technology and the ARGOS system (French 1994; Mate *et al.* 2007) have been utilised to track the movement patterns and environmental preferences of a variety of shark species, including Shortfin Makos (Loefer *et al.* 2005), Tiger Sharks (*Galocerdo cuvier*) (Heithaus *et al.* 2007), White Sharks (*Carcharodon carcharias*) (Boustany *et al.* 2002; Dewar *et al.* 2004; Bonfil *et al.* 2005; Bruce *et al.* 2006; Weng *et al.* 2007a; Domeier and Nasby-Lucas 2008), and Salmon Sharks (*Lamna ditropis*) (Hulbert *et al.* 2005; Weng *et al.* 2005). Oceanographic and dive data collected by satellite tagged predators identifies habitat usage and facilitates the characterization of ecologically important regions, as well as an understanding of environmental variability in these regions. This 'predator collected' environmental information may also be important for predicting the future impacts of climatic oceanic variability on the distribution and foraging dynamics of marine predators (Maury and Lehodey 2005; Harley *et al.* 2006).

Very little is known about the movement patterns, thermal preferences and site fidelity of juvenile Shortfin Makos. Similarly, there are no published studies of the movement patterns of Blue Sharks using fin-mounted satellite tags and use of standard tags is likely to underestimate movement of both species. Tracking studies in the northern hemisphere showed Shortfin Makos oscillate throughout the water column and spend considerable time in the surface layer at night (Klimley *et al.* 2002; Sepulveda *et al.* 2004; Loefer *et al.* 2005). In the California Bight and North Atlantic shelf ecosystems, juveniles have extensive home ranges (Casey and Kohler 1992; Holts and Bedford 1993). From a total of 5,333 Shortfin Makos tagged using fin and dart tags in the North Atlantic Ocean, the estimated maximum distance travelled was 5,310 km (Kohler *et al.* 2002). Maximum distance travelled estimated using acoustic tags was 145 km in 45 hours (Sepulveda *et al.* 2004). There have been no similar published studies of the movement patterns or dive behaviour of this species in southern hemisphere oceans. During this study, we investigated the movement, critical habitat and migration paths of five juvenile Shortfin Makos and a sub-adult Blue Shark in the Southern and NE Indian Oceans.

OBJECTIVES

The objectives of this study were to:

1) Investigate the movement patterns, critical habitats and migration paths of Shortfin Mako and Blue Sharks in southern Australia;

2) Facilitate greater public and scientific understanding of the ecological roles and significance of pelagic sharks

OBJECTIVE 1. MOVEMENT PATTERNS, CRITICAL HABITATS, AND MIGRATION PATHS

Materials and Methods

Capture and tagging processes

Juvenile Shortfin Makos (*Isurus oxryrinchus*) and a sub-adult Blue Shark (*Prionace glauca*) were satellite tagged in shelf slope waters of the eastern and central Great Australian Bight (GAB) in South Australia (SA) in 2008. Sharks were attracted to a commercial fishing vessel using berley consisting of sardine (*Sardinops sagax*), blue mackerel (*Scomber australasicus*) and tunas (*Thunnus. alulunga* and *T. maccoyyi*). Sharks were caught using either blue mackerel or tuna as bait, on a single galvanized steel hook (J-style and tuna circle, 10/0 to 16/0) attached to a one metre stainless steel wire trace (3mm diam.). Baits were attached to hooks using small cable ties to minimise the chance of deep ingestion and capture stress. The trace was attached to a weighted stainless steel swivel and 70–90 mm diameter rubber buoy(s) attached to 9 mm nylon floating rope. Sharks were caught and removed from the water using an aluminium chute (Fig. 1) that was deployed from the sea-door. Once onboard, sharks were physically restrained using a dense foam mattress, their eyes were covered and their gills were irrigated using a deck-hose covered with PVC pipe (Fig. 1). Sharks were captured and tagged at locations in eastern and central GAB near the continental shelf slope (200 m depth contour). Sharks were sexed and total lengths (TL) were estimated to within 10 cm using length increments marked on the aluminium chute.

Satellite transmitters, data recovery and environmental parameters

SIRTRACK KiwiSat 202 ‘position only’ satellite tags were fixed to the first dorsal fin of nine Shortfin Makos (1.5–1.9 m, TL) and one Blue Shark (~2.2, male) using two stainless steel bolts and nylex locknuts. Bolts were passed through holes that were drilled using a cordless drill. Stainless steel washers were placed on the opposite side of the fin to the tag and lock-nuts were used to fasten the tag to the dorsal fin. SIRTRACK tags contained two AA lithium batteries and a super-capacitor for an expected continuous transmission life of ~42 days. Tags had saltwater switches that turned the tag off while submerged, and on when the dorsal fin broke the surface at a sufficient height for the switch and tag aerial to be exposed. Wildlife Computers (WC) ‘splash’ satellite tags were attached to the first dorsal fin of two Shortfin Makos (1.7 and 2.0 m, TL, both female) using the same method as for the SIRTRACK tags. These tags were duty cycled to transmit location data at 2 day intervals. Coded packages of temperature and depth data were recorded as frequency histograms that were pre-programmed as 0–800 m for depth and 4–24°C for water temperature. Data on the depths and water temperatures experienced by the tagged sharks were pooled over four hour intervals. Expected battery life was 300 days. If these sharks are recaptured and the tags are returned to SARDI Aquatic Sciences, a maximum of 14 megabytes of high resolution (2 minute interval) water temperature and dive depth data will be recovered. Location data provided by the satellite tags were accessed weekly via the ARGOS CLS group's data collection service using Tera Term Pro via Telnet. ARGOS position data is provided in seven location classes ranging from highest to lowest between 3, 2, 1, 0, A, B, and Z. Location classes 3, 2, 1, 0, and A were accepted for analysis if consecutive locations were within reasonable swimming speeds (≤5 km/hr) and not on land. Splash tag histogram data were decoded using WC message decoder software. The resulting datasets were filtered again for any erroneous positions. Vector plots of satellite positions at the surface over bathymetry were produced using MapInfo Version 8 Software. Mean minimum swim speeds and minimum straight-line distances travelled were estimated from aggregates of distances between reliable GPS locations at the surface. Diurnal and regional comparisons of water temperature and depth histogram data were made using the splash tag deployed on Shortfin Mako 52466.

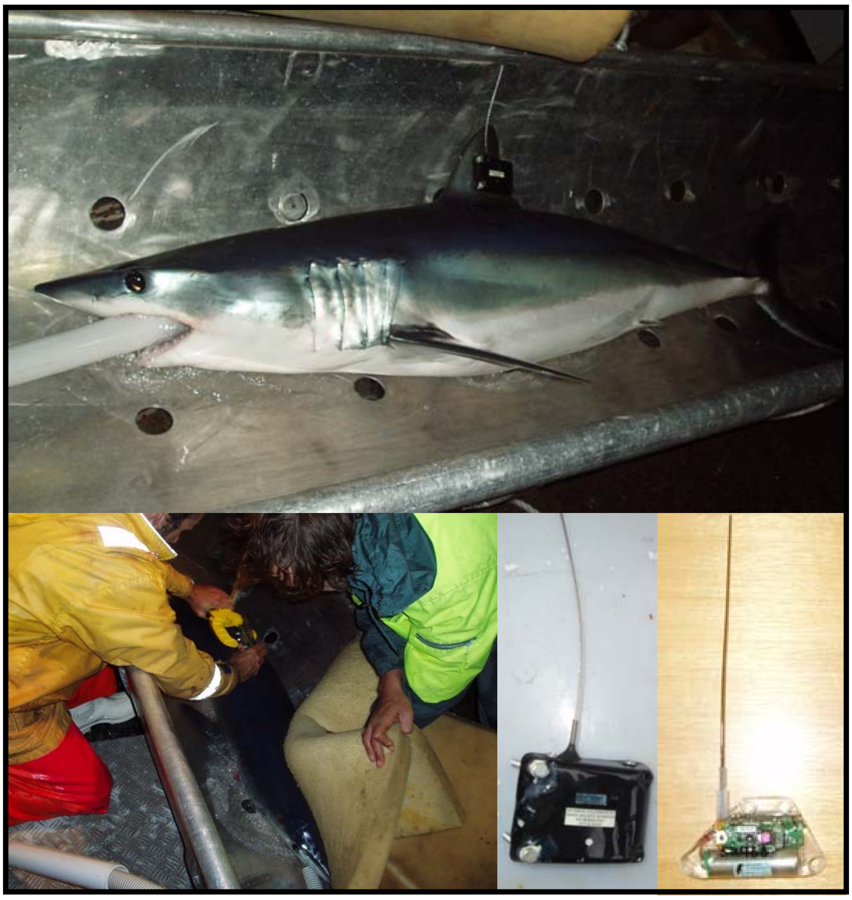

Fig 1. Shortfin Mako *Isurus oxyrinchus* (~1.8 m, TL) in the chute with a SIRTRACK satellite tag attached to the dorsal fin prior to release. Left bottom. Positioning a satellite tag on the dorsal fin. Bottom right. SIRTRACK 'position only' (black, 8.5 cm in length) and Wildlife Computers 'splash' satellite tags (clear, 8 cm in length).

Table 1. Summary data for five Shortfin Makos and a Blue Shark tagged in the GAB between March and June 2008. Male: m, Female: f. Days at liberty represents the number of days between tag deployment and the last location; + indicating that the tag was still reporting reliable position data at the time of preparation of this report.

Satellite tag ID, species, Tag type	Date deployed	Est. TL	Sex	N positions	3	2	ARGOS 1	cls 0	A	B	Z	N reliable positions	Days at liberty	Last position	Minimum distance travelled	Mean minimum swim speed km/h
55947 Shortfin Mako SIRTRACK	12/3/08	1.7	m	1609	0	9	273	883	159	259	26	875	348+	22/2/09+	11,121	1.3
52463 Blue Shark SIR TRACK	15/3/08	2.2	m	899	3	45	223	217	146	248	16	487	288	28/12/08	9,347	1.3
52481 Shortfin Mako SIRTRACK	14/3/08	1.8	m	176	5	32	61	49	13	13	3	108	46	29/4/08	1,165	1.0
52478 Shortfin Mako SIRTRACK	6/4/08	1.9	f	253	6	13	81	74	30	44	5	136	106	20/7/08	3,454	1.4
52466 Shortfin Mako WC splash	4/6/08	2.0	f	395	11	79	128	42	58	70	7	217	263+	22/2/09+	13,314	2.1
55951 Shortfin Mako WC splash	2/6/08	1.8	f	512	9	91	154	104	57	82	15	303	267+	21/2/09+	7,713	1.2

Results

Of the ten satellite tags deployed a total of six produced reliable location data (Table 1). The six successful deployments included five Shortfin Makos and one Blue Shark. Estimated lengths of the five Shortfin Makos ranged from 1.7 to 2.0 m TL (1.8–2.0 m TL and 1.7–1.8 m TL for females and males, respectively). The Blue Shark was a male and was estimated to be 2.2 m TL. A total of 3,844 locations of ARGOS quality classes between 3–B were recorded from these six tags (range 176–1609 locations). Of these, 2,126 (55%, range 53.8–61.4%) usable positions of classes 3,2,1,0 and A were retained for subsequent analyses. Of the remaining four tags deployed, two did not transmit, and the remaining two only produced a single location each soon after release.

Three tagged sharks provided data describing migrations into Western Australian (WA) shelf waters in the Southern Ocean, and two undertook migrations from the GAB into oceanic waters in the North-east Indian Ocean (Figs, 2–6). The remaining tagged shark undertook a single south-eastern movement along the outer continental shelf and slope off SA, before the tag stopped transmitting south of Kangaroo Island, SA.

Time at liberty, minimal straight-line distance travelled and mean minimum swim speed

Time at liberty for satellite tagged Shortfin Makos ranged between 46 and 348+ days (Table 1). The Blue Shark provided positions for 288 days. One SIRTRACK and the two 'splash' tags were still transmitting at the time of preparation of this report. For Shortfin Makos, minimal straight-line distances travelled ranged from 1,165 km in 46 days to 13,314 km in 263 days. Mean minimum swim speeds typically ranged between 1–1.4 km/hr for the four Shortfin Makos that remained in the Southern Ocean. The largest Shortfin Mako travelled 13,314 km at a mean minimum swim speed of 2.1 km/hr. The Blue shark travelled 9,347 km in 288 days and had a mean minimum swim speed of 1.3 km/hr.

Movement and inferred focal foraging areas

Four of the five tagged Shortfin Makos mostly remained in the central and eastern GAB on the continental shelf during autumn and early winter. Four Shortfin Makos and the Blue Shark moved west from the GAB into WA shelf waters between June and September (Figs. 2a, 3, 4a and 5). This coincided with declines in sea surface temperatures (SST) from about 18–20 to 15–16°C in the GAB and the intrusion of 18–20°C water from the Leuwinn Current on the shelf in southern WA (Fig. 7). Shortfin Mako 55947 covered a broad area of continental shelf in the central and western GAB (Fig. 2a) where bottom depths range between 50–200 m. This shark periodically foraged at the shelf slope region near the 200 m contour, and spent considerable time at the surface in the central and western GAB during the 348 day+ deployment. This large area extended to within 2 km from shore and out to the shelf slope ~200 km offshore. This animal was unique in that it foraged in inner and outer shelf and slope waters. This shark moved to an inner shelf area W/SW of Esperance, WA for a short period (Fig. 2a) during mid-late winter and then returned to inshore waters of the central GAB during spring. During two relatively short deployments, Makos 52478 and 52481 covered distances of 1,165 and 3,454 km along the outer shelf and shelf slope. Notably, 52481 moved SE along the shelf-slope, to Du Couedic Canyon S/SW of Kangaroo Island (Fig 3). Tags on both sharks stopped reporting prematurely off Kangaroo Island and Flinders Island, respectively. Shortfin Mako 52466 moved rapidly from the central GAB in June to WA waters (Fig. 4a). This shark departed from the shelf/shelf slope near Cape Leuwinn and moved North-west into oceanic waters ~1,040 km W-NW of Shark Bay. This shark then moved along the shelf slope off WA to the GAB, and remained off the Bonney Coast off SE SA between October and December 2008 (Fig. 4b). In January 2009, Shortfin Mako 52466 followed a similar path along the shelf slope and returned to the Indian Ocean off Cape Leuwinn, in late February 2009. Shortfin Mako 55951 spent most of winter travelling in waters of the outer shelf and shelf slope in the central GAB (Figs. 5a and b). This shark made one excursion into WA waters in spring but returned to the central GAB by December and showed a high degree of site fidelity within the central GAB. The Blue Shark (52463) remained in the eastern GAB between March and July and then migrated into WA waters (Figs. 6a and b). This shark continued northward into oceanic waters of the NE Indian Ocean and moved a minimum straight line distance of 9,347 km. The tag on the Blue Shark stopped reporting continuous data on December 28, 2008, ~1,620 km west of Shark Bay, WA.

Utilisation of the outer shelf and slope

Tagged sharks returned periodically to the outer shelf and slope (200 m contour) and may use the steep decline of the slope as a geographical reference point and/or a migration path. This pattern was: (1) characterised by highly directional movements of 100's of km along the outer shelf followed by intermittent returns to the slope or (2) linear movements that trace the slope. The two largest sharks (Shortfin Mako 52466 and Blue Shark 52463) made broad-scale movements along the shelf slope from the tagging locations in the GAB, to oceanic areas well beyond Australia's Exclusive Economic Zone (EEZ, 200 nm) in the North-eastern Indian Ocean, off WA. These animals were 2.0 and 2.2 m, TL respectively. This Shortfin Mako and the Blue Shark spent ~29 and 82 days in International waters, respectively.

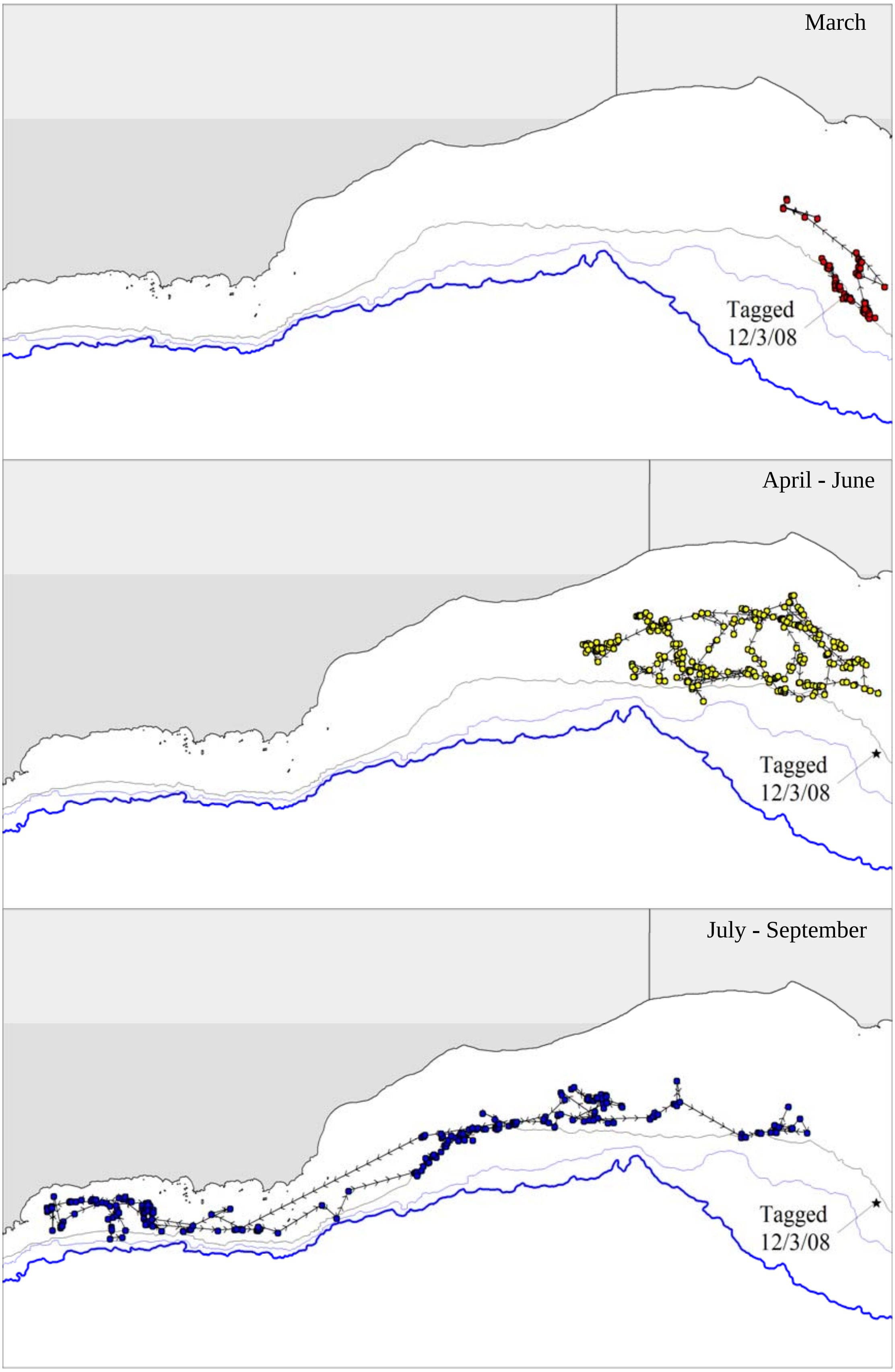

Fig 2a. Satellite tag track for Shortfin Mako 55947 between March and September 2008.

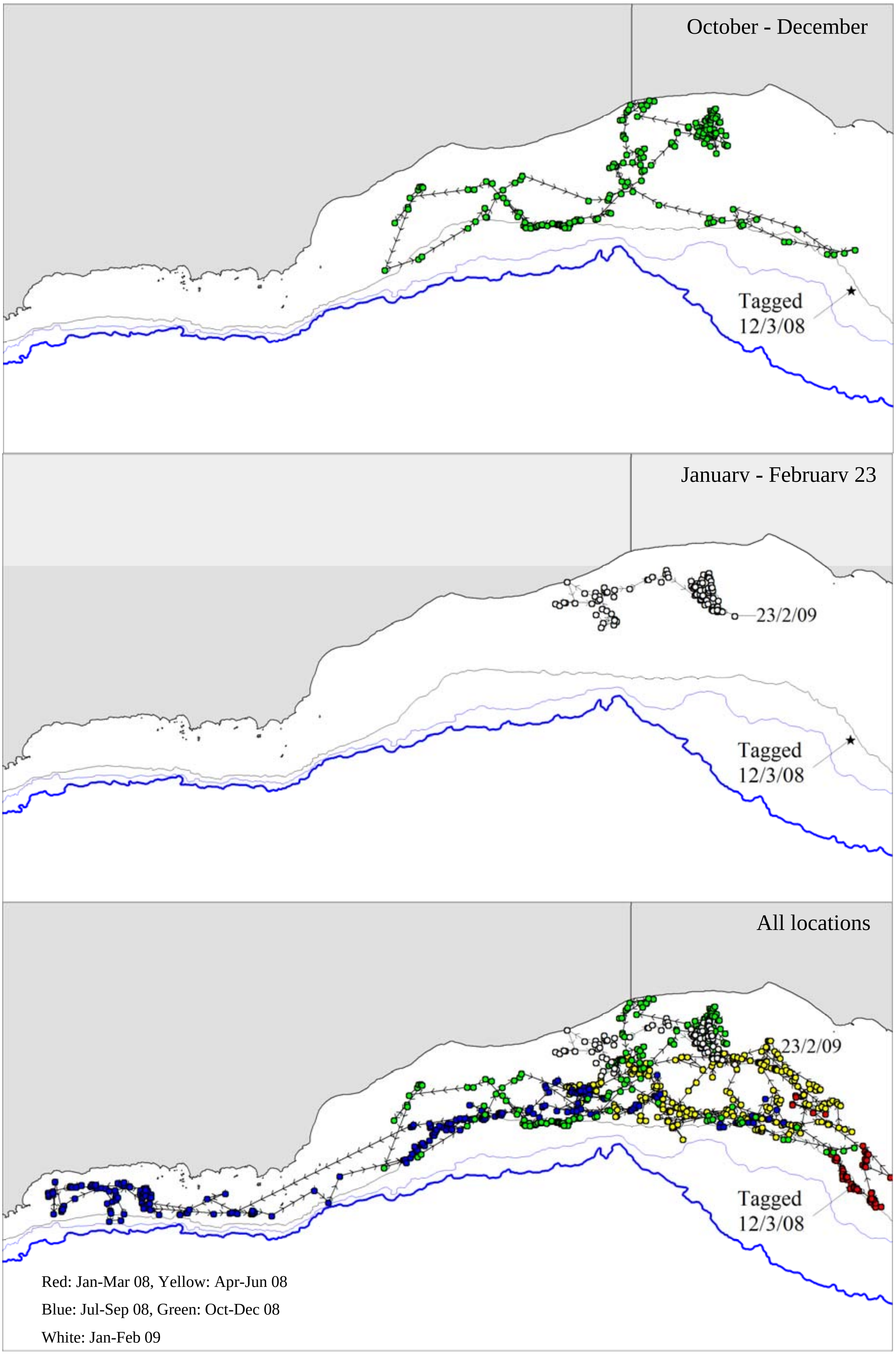

Fig. 2b. Satellite tag track for Shortfin Mako 55947 between October 2008 and February 23 2009.

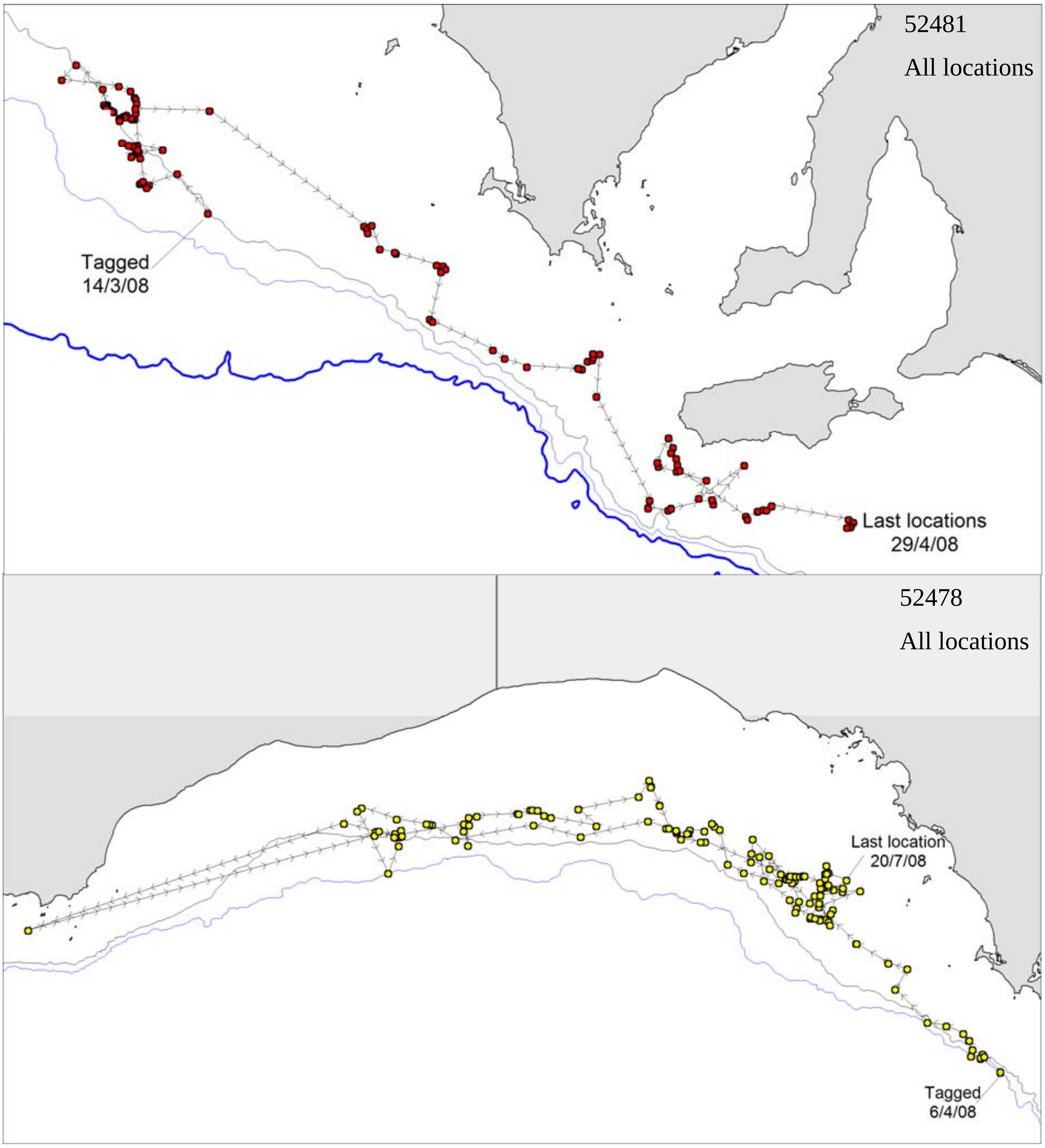

Fig. 3. (above) Satellite tag tracks for Shortfin Mako *Isurus oxyrinchus* 52481 and (below) Shortfin Mako 52478 showing all locations.

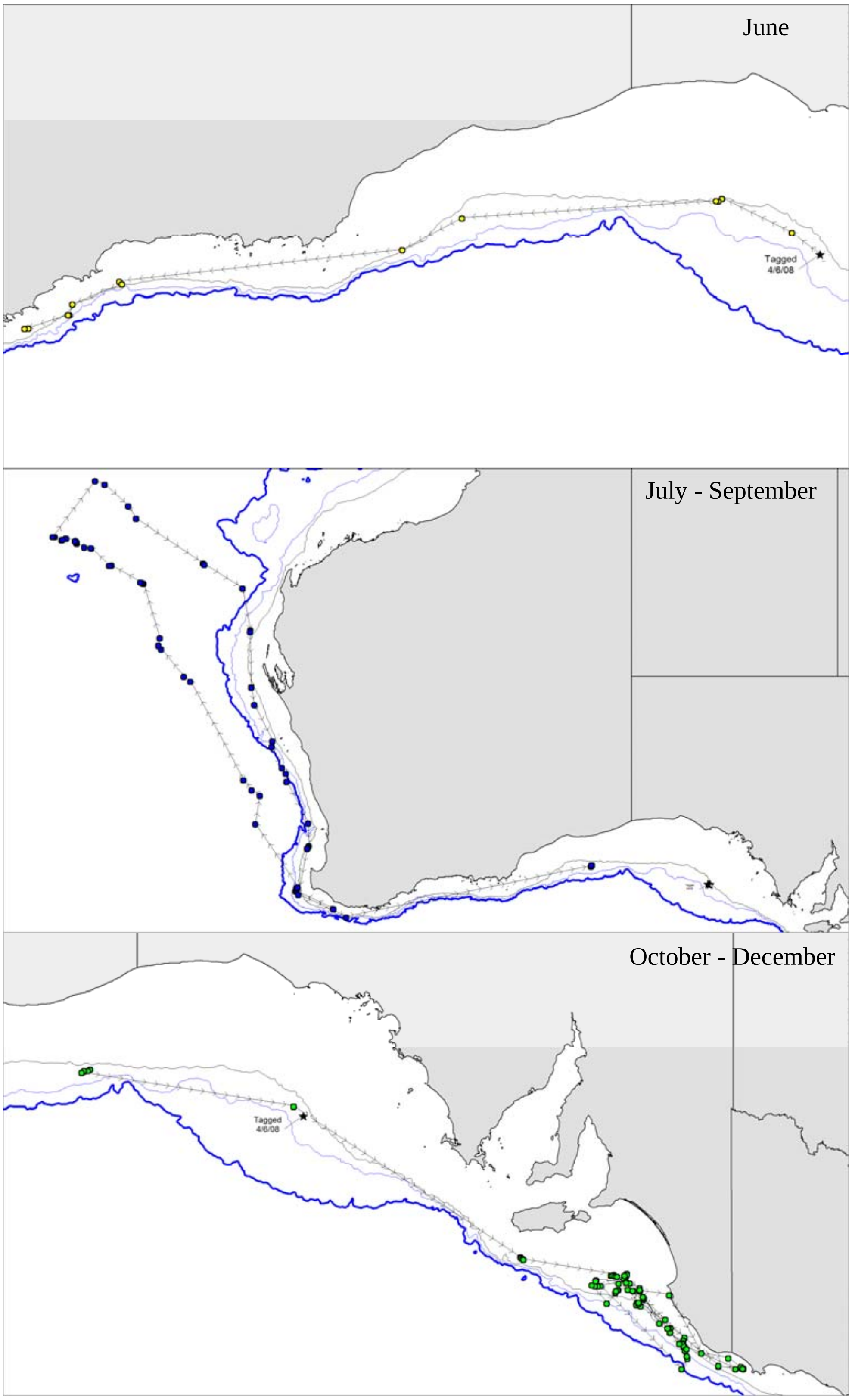

Fig. 4a. Satellite tag track for Shortfin Mako *Isurus oxyrinchus* 52466 between June and December 2008

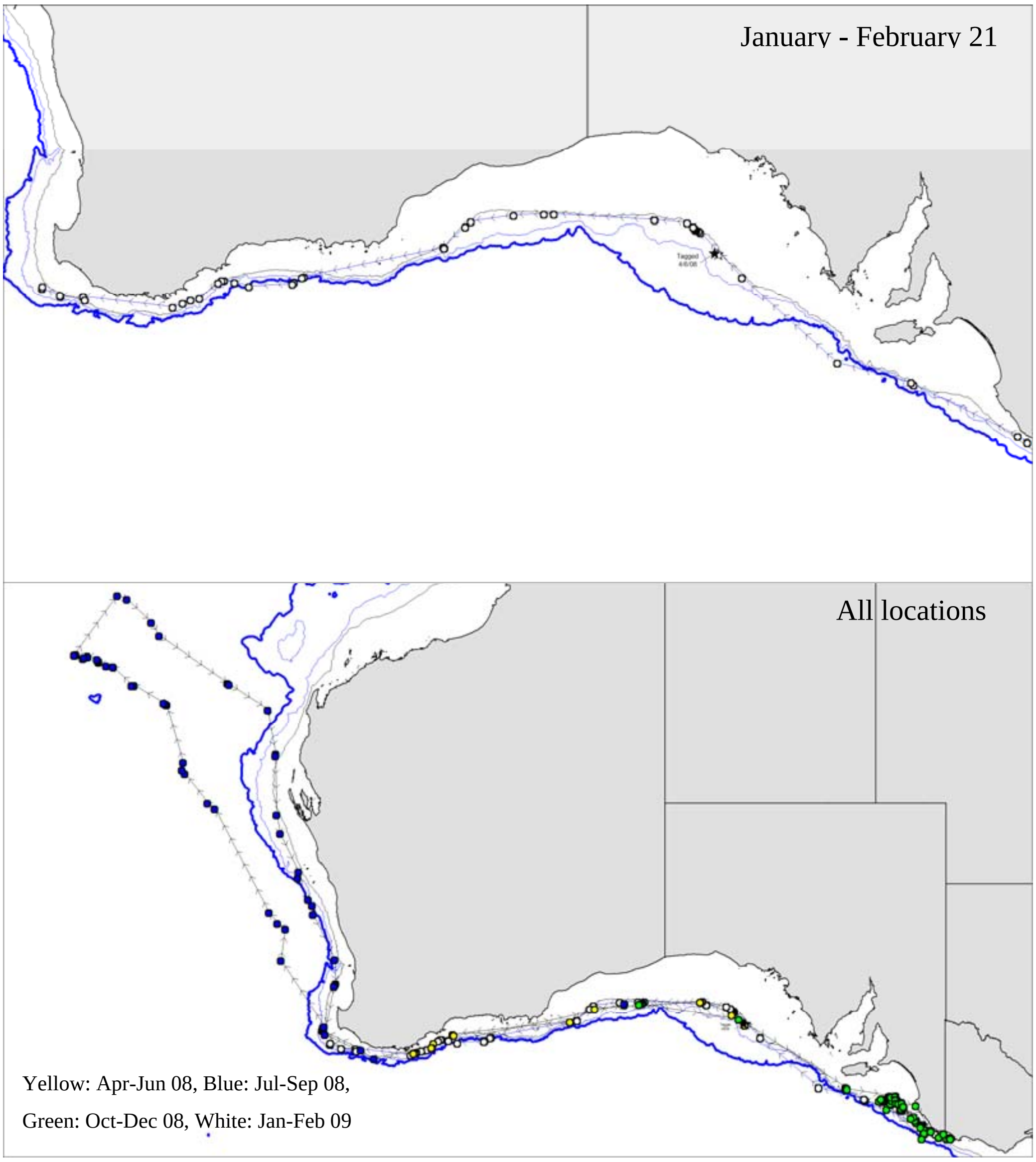

Fig. 4b. (above). Satellite tag track for Shortfin Mako *Isurus oxyrinchus* 52466 between January and February, 2009 and (below) all locations between 4 June 2008 and February 21, 2009.

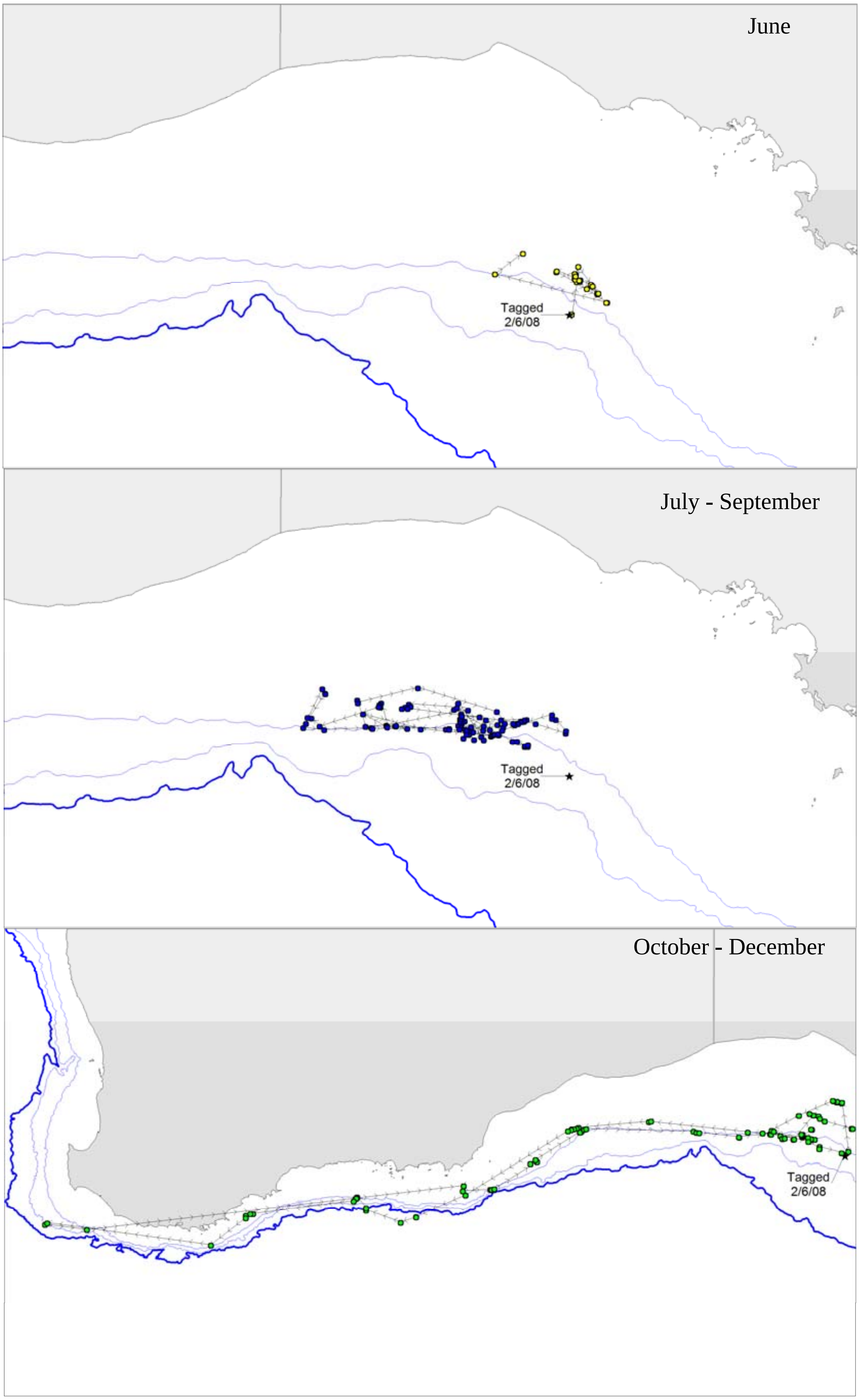

Fig. 5a. Satellite tag track for Shortfin Mako *Isurus oxyrinchus* 55951 between June and December 2008.

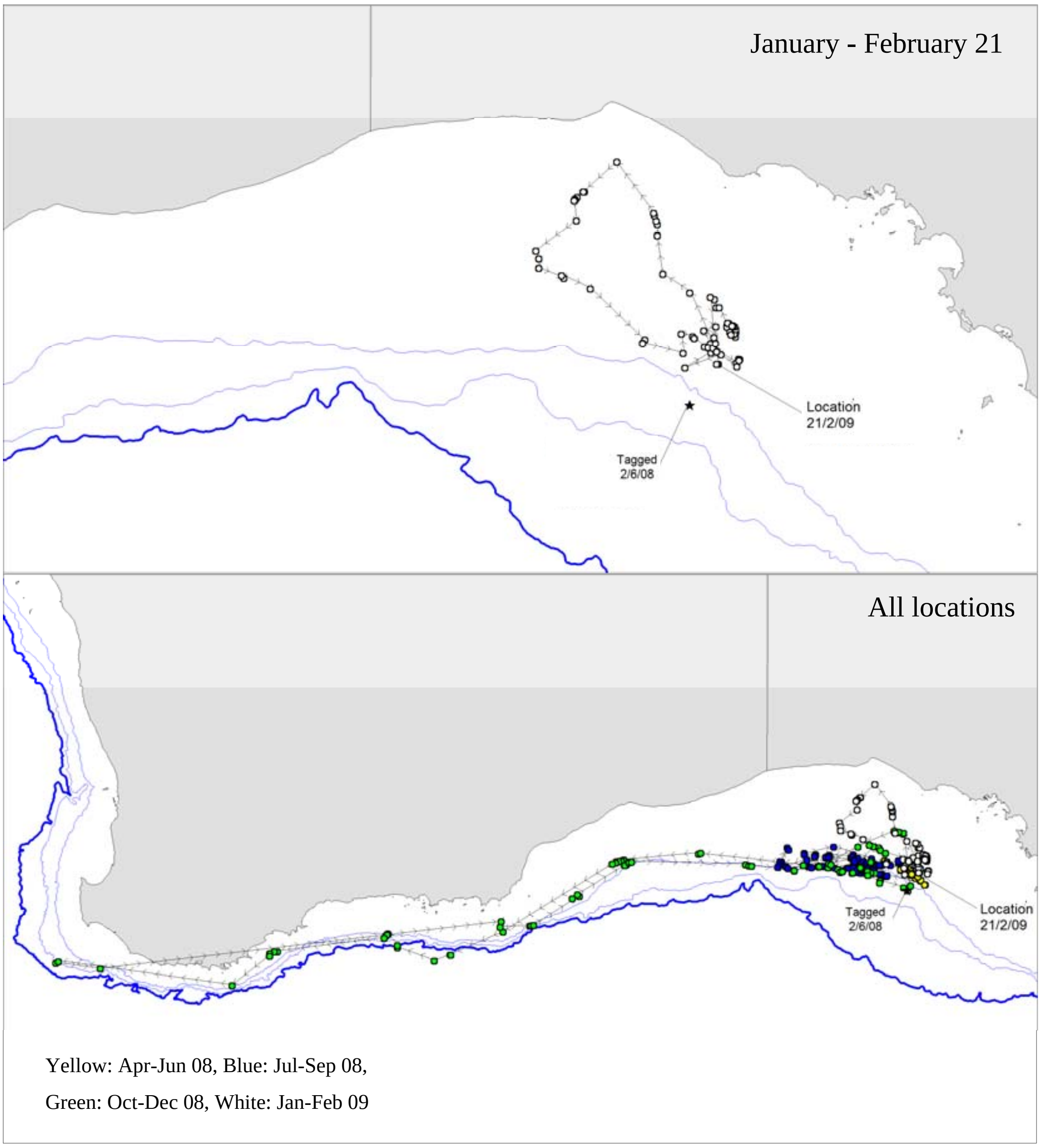

Fig. 5b. (above). Satellite tag track for Shortfin Mako *Isurus oxyrinchus* 55951 between January and February 2009 and (below) all locations between June 2008 and February 2009.

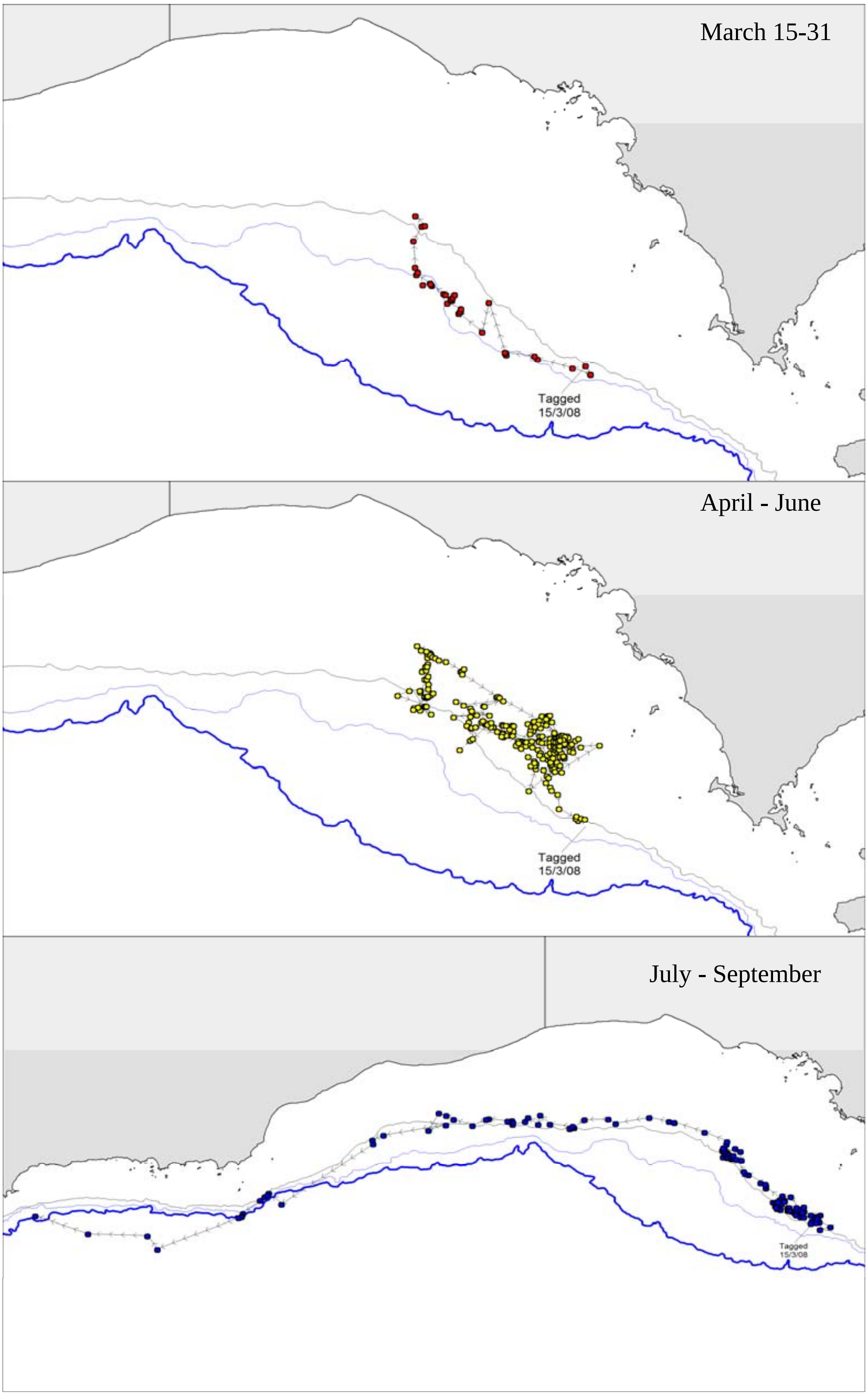

Fig 6a. Satellite tag track for the sub-adult Blue Shark *Prionace glauca* 52463 between March and September 2008.

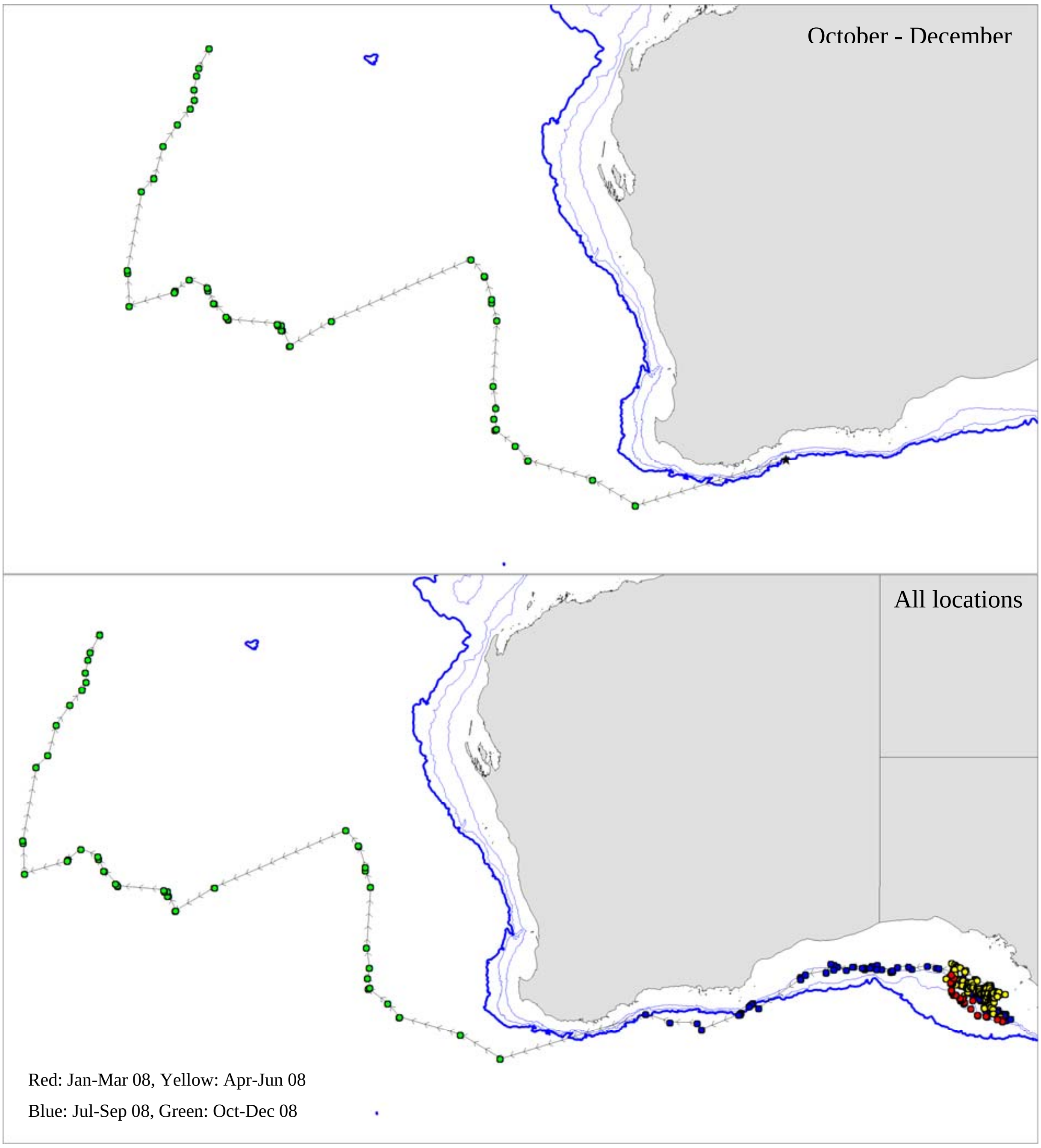

Fig. 6b. (above). Satellite tag track for the sub-adult Blue Shark *Prionace glauca* 52463 between October and December 2008 (below) all locations between March and December 2008.

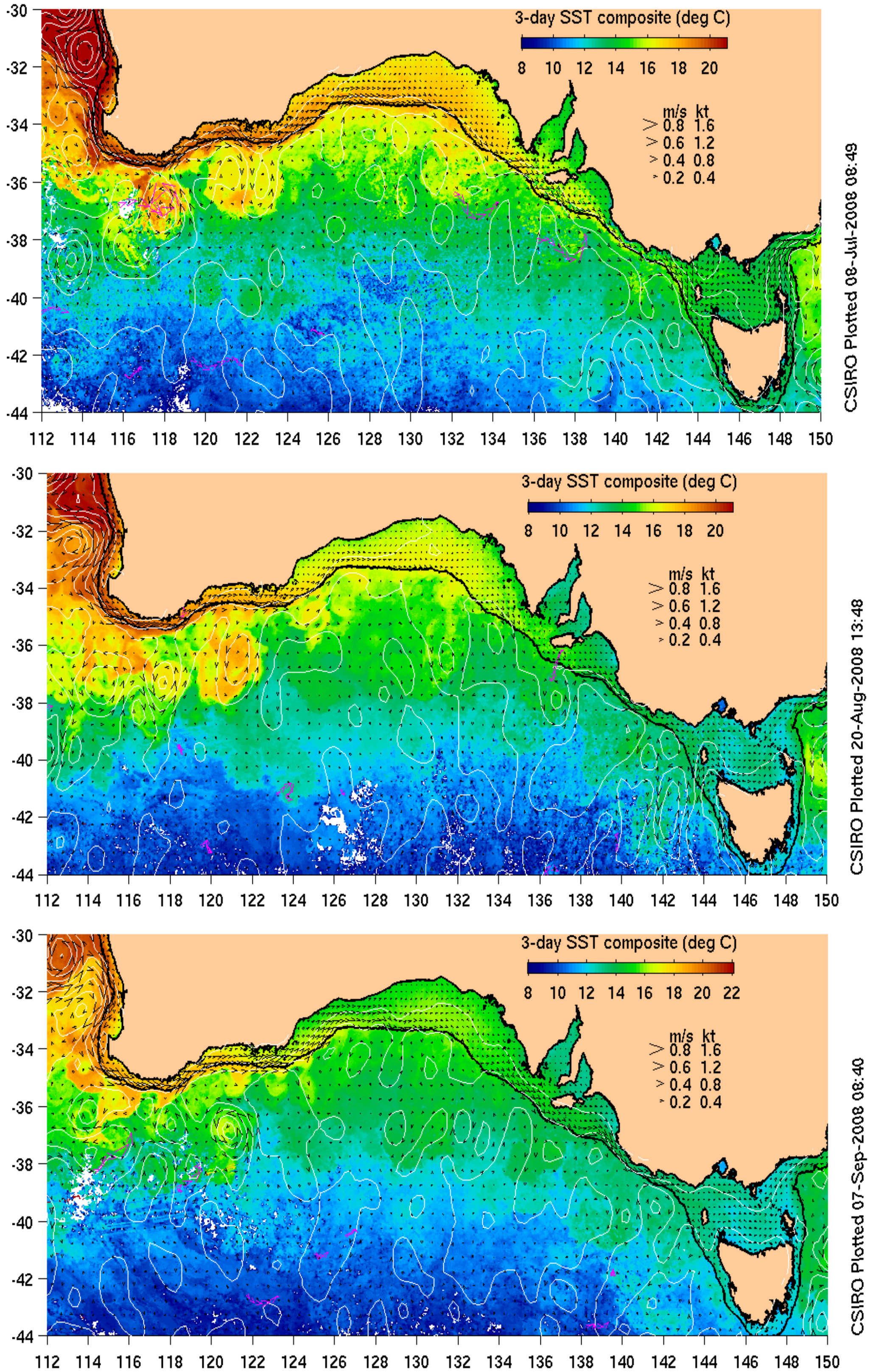

Fig. 7. Sea-surface temperature plots showing cooling of surface water in the GAB during July, August and September 2008, which coincided with westward movement of some satellite tagged Shortfin Makos and the Blue Shark. Images courtesy of CSIRO, Hobart: http://www.marine.csiro.au

Water temperature and depth preference

Totals of 303 and 478 (n = 781) temperature histograms were collected by WC splash tags deployed on Shortfin Makos 52466 and 55951, respectively. Pooled histogram data indicated that the Shortfin Makos inhabited water temperatures between 10 and >24° C. Mako 52466 spent ~86% of her time at water temperatures between 16 and 24°C. The water temperature of highest residency for this shark was 16º C (29%) off SE SA. Shortfin Mako 55951 spent 97% of her time at water temperatures between 16 and 22°C. The water temperature corresponding with the highest residency was 18°C (41%) and this occurred in the central GAB.

Totals of 298 and 437 (n = 735) depth histograms were collected by WC splash tags deployed on Shortfin Makos 52466 and 55951, respectively. Pooled histogram data indicated that Shortfin Makos had a bimodal depth distribution with peaks at 5 m and 80 m. Shortfin Mako 52466 spent ~23% of it's time at depths of 5 m and 30% at 40–80 m. This depth range is where thermoclines typically form in the GAB (SARDI unpublished data). The depth of highest residency for Mako 52466 was 5 m and the max depth reported was 600 m. Shortfin Mako 55951 spent 14% of reported time at 5 m and 45% at depths between 80 and 160 m. This depth range was also where they displayed the highest residency (80 m, 23% c.f. 160 m, 22%). The maximum dive depth reported for this animal was 500 m.

Diurnal and regional comparisons of depth and temperature profiles.

Diurnal and regional comparisons of depth profiles were made for Shortfin Mako 52466 at five key locations in the Southern and Indian Oceans. In the central GAB, on January 16, 2009 this shark spent ~80% of her daylight hours at depths of 320–600 m. During the night/dark period she inhabited a narrower depth range and spent 44% of her time at depths <80m and 49% of her time at 320–400 m. In contrast, in the SE SA on November 1, 2008 this animal spent 78% of her daylight hours at 40 m, whereas during the night/dark period, 48% of her time was spent in the surface layer (5 m), 20% at 10 m, and 18% at 20 m depths. In the western GAB on January 29, 2009 this shark inhabited a broad range of depths between 10 and 400 m during the day, whereas during the night/dark period 52% of her time was spent in the surface layer and she remained at depths ≤80 m. This shark inhabited a broad range of depths between 5 and 320 m during daylight hours off central and NW WA in August, and a narrower range of depths between 5 and 160 m during the night/dark period.

Shortfin Mako 52466 experienced a broader range of water temperatures during the day in all regions except the oceanic waters off NW WA and inhabited warmer thermal layers during the dark periods. The warmest water temperatures were recorded off NW WA and the coolest were in the central GAB. For example, this shark experienced water temperatures as low as 10 °C in the central GAB during the day. In SE SA, she experienced 14 ºC water temperatures during the day.

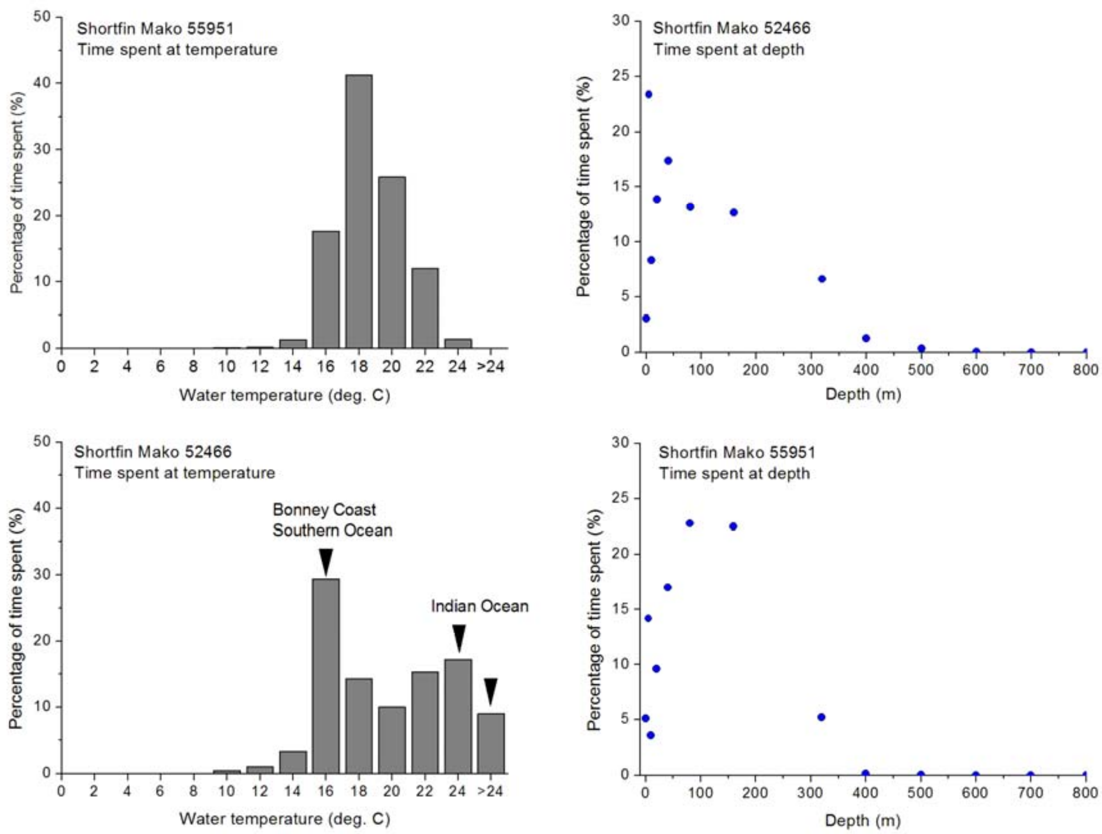

Fig. 8. Aggregated percentage of time spent at water temperature and depth ranges as recorded by two WC splash satellite tags deployed on Shortfin Makos in the Southern and Indian Oceans between June 2008 and February 2009.

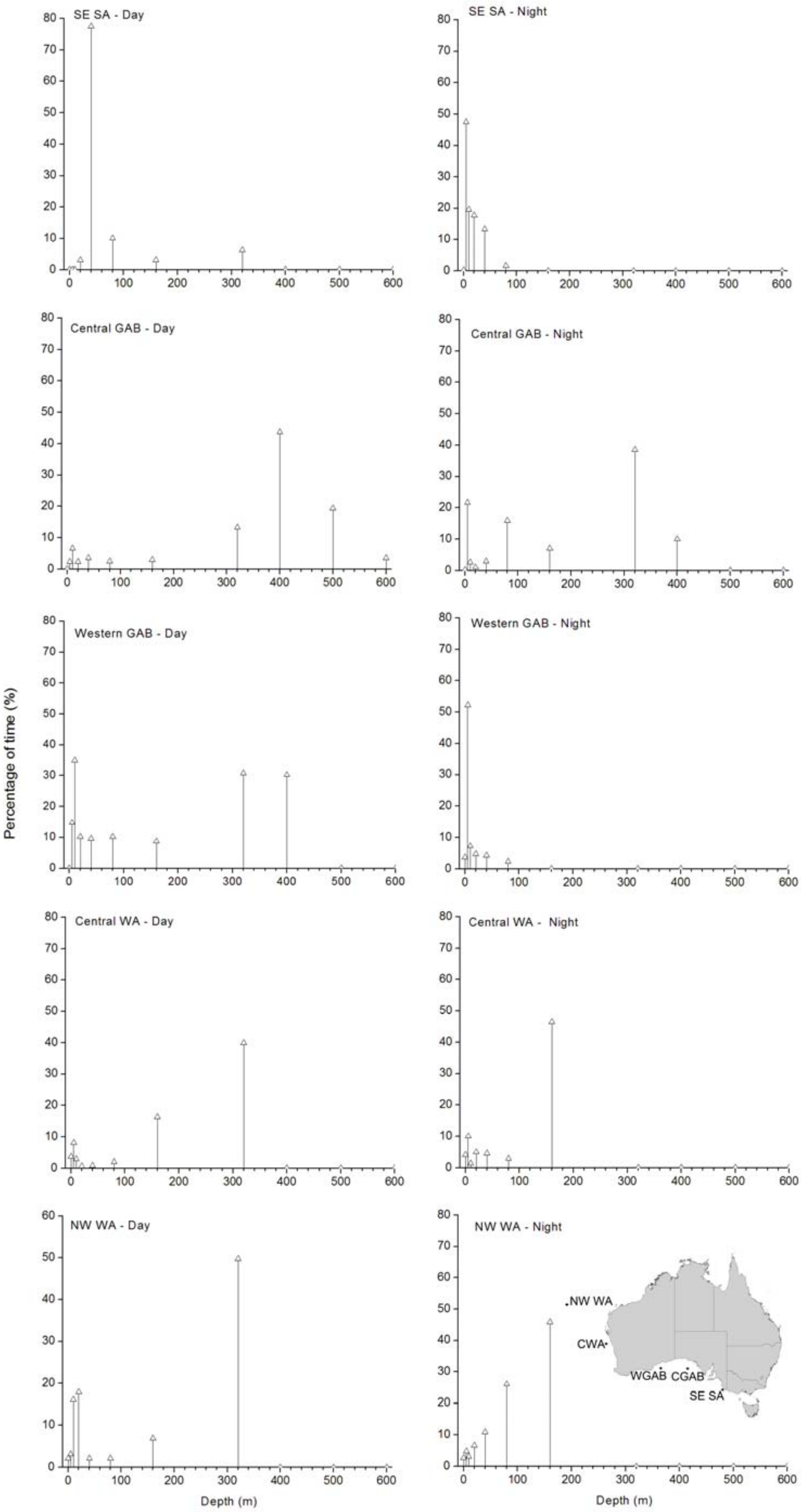

Fig. 9. Diurnal patterns of time spent at depth for Shortfin Mako 52466 in the south-east of SA (Bonney Coast), central and western GAB, central WA shelf, and off NW WA.

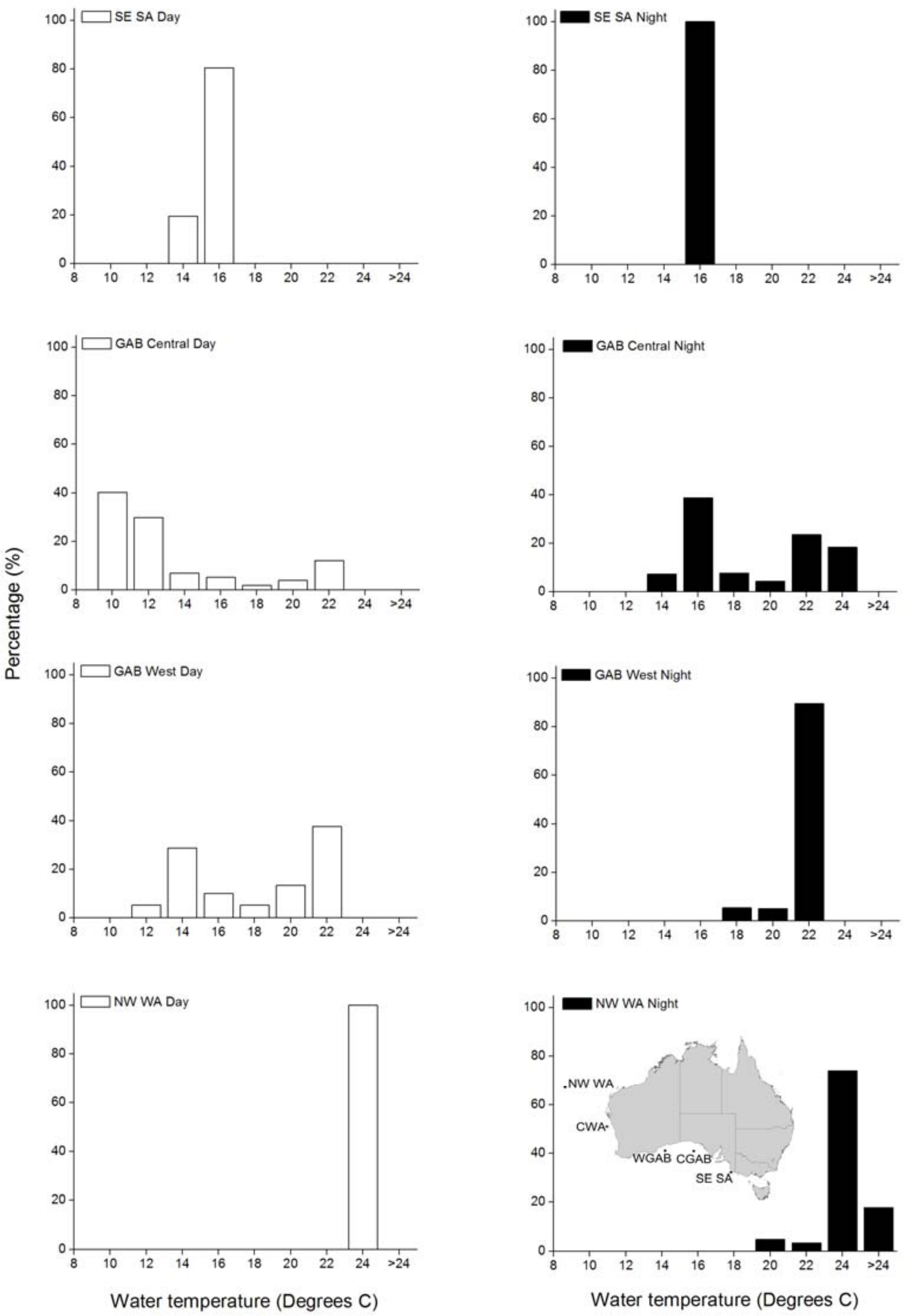

Fig. 10. Diurnal patterns of time spent at water temperature (degrees C) for Shortfin Mako 52466 in the south-east of SA (Bonney Coast), central and western GAB, and off NW WA.

OBJECTIVE 2: GREATER PUBLIC AND SCIENTIFIC UNDERSTANDING OF THE ECOLOGICAL ROLES AND SIGNIFICANCE OF PELAGIC SHARKS IN SOUTH AUSTRALIAN WATERS

Development of a project website

A website detailing the daily activities of top marine predators in southern Australian waters was developed as a collaborative initiative between staff and students of SARDI Aquatic Sciences, Flinders University, and SA Department for Environment and Heritage. The overarching aim of this project was to increase public awareness and enhance the sustainable management profiles of southern Australia's unique top marine predator populations to maintain their long-term survival, recovery and sustainability. This initiative represented an extension of http://www.henrythesealion.com and provides background information on pelagic sharks that is easily accessible to a broad public audience.

The largest satellite tagged shark was used as the feature animal' and she was named 'Lilly the Mako'. A dialogue was then developed which allowed web surfers to feel as if they were sharing the life of this animal. Information about Shortfin Makos, such as 'Lilly', was provided online and public access to 'near-real time' maps of satellite tagging tracks was facilitated through collaboration with Dr Michael Coyne of Seaturtle.org in the USA. The tracks of 'Lilly the Mako' and five other satellite tagged sharks, including four Shortfin Makos and a Blue Shark, were made publicly available on the international website http://www.seaturtle.org.

The update of http://www.henrythesealion.com website was launched by the Environment and Conservation Minister Jay Weatherill on 16/9/08. It received considerable local media coverage and has helped to educate the general public regarding the ecological roles and significance of pelagic sharks and other top predators in Southern Australian waters. The online system on http://www.henrythesealion.com allowed teachers to access information for geography and biology classes. Following the inclusion of the pelagic shark information sections there were > 2,500 visits to the website (to February 2009), and representatives from local schools showed interest in including aspects of the webpage in teaching programs.

Subject to funding, further educational extension will be undertaken on http://www.henrythesealion.com for a range of other marine predators. The senior author gave presentations about the importance of pelagic sharks and other top predators in South Australia's marine ecosystems to members of the general public during the recent Public Sector Week at SARDI Aquatic Sciences in 2008 and presented findings via a poster at the Oceania Chondrichthyan Society Conference in Sydney in September 2008.

Fig. 11. The Tracking 'Lilly the Mako' webpage from henrythesealion.com.

DISCUSSION

Our results indicated that juvenile Shortfin Makos inhabited a vast foraging space and a broad thermal range in the Southern and Indian Oceans between March 2008 and February 2009. These animals moved extensive straight-line distances of between 9,347 and 13,314 km during relatively short periods and dive profiles suggested that the actual distance travelled would be far greater that these minimum distances, as they occupy an extensive portion of the water column during the course of one day. The Shortfin Makos and the Blue Shark occupied surface waters throughout the continental shelf out to the slope off South and Western Australia, and spent considerable time travelling on the mid-outer shelf. Tagged sharks appeared to utilise the outer shelf and slope during migrations to and from the NE Indian Ocean. Shortfin Makos surfaced near submarine canyons, shelf ridges, and other bathymetric features that are likely to support production and aggregation of prey, such as pelagic fishes and cephalopods.

Shortfin Mako 52466 and Blue Shark 52463 made broad-scale migrations from the GAB during mid winter, to oceanic areas in the NE Indian Ocean that were well beyond Australia's EEZ. These individuals spent 29 (11%) and 82 days (28%) in International waters, respectively and the oceanic areas they visited were characterised by sea-mounts, basins, 4,500–6,000 m water depths and winter water temperatures of 23–25°C. The Shortfin Mako made a return migration along the shelf slope off WA to the GAB, remained off SE SA between October and December 2008, and followed the same path along the shelf slope back to the Indian Ocean off Cape Leuwinn, WA, by late February 2009. This suggests that there is connectivity between the populations inhabiting the Southern and Indian Oceans and that management of these species requires arrangements at multi-jurisdictional spatial scales. This finding also indicates that sub-adult Shortfin Makos and Blue Sharks may migrate extensive distances from their natal area prior to reaching a breeding size/age. It is important to note however, that a broader size range of animals would need to be tagged, and genetic techniques would need to be used to identify the spatial scales appropriate for consideration when managing these populations.

Our findings showed that Shortfin Makos inhabited a broad range of water temperatures between 10 and >24 degrees and this was similar to the range of temperatures inhabited by three juvenile Shortfin Makos tagged in the California Bight (Klimley *et al.* 2002). Not surprisingly, there were distinct regional differences in the thermal habitats experienced by our tagged Shortfin Makos. The coolest water temperatures (10–16°C) experienced were off the SE of SA off the Bonney Coast, and the warmest water temperatures (24+°C) were experienced NW of Shark Bay, WA. These were similar to ranges experienced by juvenile White Sharks in the California Bight (Dewar *et al.* 2004). When we analysed depth and temperature profiles for Shortfin Mako (52466), we found there were also diurnal and spatial differences between regions. For example, this shark inhabited a broad bimodal range of depths between 10 and 400 m during the day in the Western GAB during summer, whereas during the night/dark period, half her time was spent in the surface layer at depths ≤80 m. This finding contrasted those of Klimley *et al*. (2002) who found juvenile Shortfin Makos spent most of their time above 40 m regardless of time of day, and was similar to findings for juvenile White Sharks (Dewar *et al.* 2004). It is likely that the dive profiles we observed related to foraging behaviour, suggesting this animal was in a nocturnal surface feeding pattern during this period, and was oscillating through the water column during the daylight hours. Our concurrent diet study has shown that juvenile Shortfin Makos feed on large teleosts and Omastrephids (squids) during autumn off Port MacDonnell, in SE SA (Rogers and Huveneers in press). Given the depths that our tagged animals inhabited, it is likely they were preying upon vertically migrating Omastrephids, pelagic and mesopelagic fishes, and suggests that they could be considered to be 'nocturnal foragers' in some regions. In contrast, when the same animal was in the western GAB, it oscillated throughout the water column between the surface layer and depths of 500–600 m during the day, and displayed a similar pattern between the surface layer and 320 to 400 m during the night/dark periods. Shortfin Makos may also spend time at these depths and cooler water temperatures to thermoregulate, and this may vary with body size.

Diurnal and regional comparisons of water temperature profiles indicated that Shortfin Mako 52466 experienced a slightly broader range of water temperatures during daylight hours in three of four regions, with the exception of the period it inhabited oceanic waters off NW WA. The warmest water temperatures recorded by the tag were off NW WA and the coolest were in the central GAB, where it inhabited waters as cool as 10–12 °C during daylight hours and depths of up to 600 m. In SE SA, this shark experienced 14 ºC water temperatures during the daylight periods and these profiles coincided with depths of up to 320 m. These findings were similar to those of previous studies of juvenile Shortfin Makos and White Sharks in the Northwest Pacific Ocean (Dewar *et al.* 2004; Bonfil *et al.* 2005; Weng *et al.* 2007b) and provides further evidence that Shortfin Makos forage in a wide range of thermal layers within the water column.

CONCLUSIONS

Juvenile Shortfin Makos and the sub-adult Blue Shark moved extensive distances between the Southern and NE Indian Oceans. Shortfin Makos exhibited a highly mobile foraging strategy encompassing the mid to outer continental shelf off southern and western Australia. The outer shelf and slope were utilised during migratory phases. Despite several animals leaving the GAB during mid winter as water temperatures cooled, no clear seasonal pattern was exhibited, as one shark moved to WA in both winter and summer. More effort is required to investigate: (i) ontogenetic variability in movement and migration patterns during all life history stages, and (ii) if autumn/winter aggregations of juvenile Shortfin Makos off the SE SA exhibit similar patterns of movement, thermal habitat and depth preference to those in the GAB. Our study provides evidence that the high mobility and migratory nature of these two pelagic shark species requires that management and conservation arrangements in the future need to encompass Australian State, Commonwealth and International waters.

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