Marine Ecosystems

Innovative ways to ensure the future sustainability of the recreational fishery for shortfin makos in Victoria

Rogers, P. J. and Bailleul, F.

SARDI Publication No. F2015/000618-1
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SARDI Aquatics Sciences
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October 2015

The State of Victoria, Department of Economic Development, Jobs, Transport & Resources Recreational Fishing Grants Program Research Report

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EXECUTIVE SUMMARY

The shortfin mako (*Isurus oxyrinchus*) is a significant recreational and gamefishing species off Victoria, Tasmania, New South Wales and south-eastern South Australia.

The National Recreational Mako Shark Fishery Management Forum in May 2010 highlighted the need to ensure that recreational fishing for the shortfin mako and other sharks in Australian waters was sustainable, and that there was a need to promote the adoption of world's best fishing practices. The Australasian Mako Shark Workshop in February 2012 identified key research priorities for shortfin makos that included improved information on the population structure, connectivity and movement of the Australasian population.

Specific aims of this project were to identify the migration paths, and assess residency of shortfin makos in the Victorian recreational and game fishery, develop a fishery Code of Practice for sustainable handling and release practices for pelagic sharks, provide media detailing the highlights of the project and present preliminary results of the satellite tagging online.

Satellite tags were deployed on eight shortfin makos (120–270 cm, total length, TL) at locations off Portland, western Victoria, central and eastern Bass Strait between December 2012 and July 2013. Tracking durations ranged between 93 and 953 days: four tags providing data for durations >1 year and two provided 2 year and 2.6 year tracks.

Shortfin makos travelled estimated minimal distances ranging between 1,734 (99 d) and 37,846 km (953 d). At the time of preparation of this report, the tags on two sharks were still transmitting to Argos satellites after 2.6 and 2.0 years (953 d and 744 d, respectively).

Shortfin makos tagged off western Victoria inhabited the eastern and western Great Australian Bight (GAB), and Bass Strait in summer and migrated to the lowest latitudes of 44–45° S near the Subtropical Front (STF) in autumn during all three years (2013–15). Northward migrations into the tropical NE Indian Ocean, SW Pacific Ocean and Coral Sea occurred during the three winter and spring periods.

Switching state-space model fits to the tracking data showed the migration pathways used by shortfin makos tagged off western Victoria included: the outer shelf and slope of the GAB, and off SW Western Australia between Cape Leeuwin and Esperance. Migration phases consistently occurred in the oceanic high seas areas of the Southern, Indian and SW Pacific Oceans, with the end-points including the NE Indian Ocean, STF, Coral Sea, New Zealand managed waters, French managed territory off New Caledonia and Vanuatu-managed waters. The continental shelf break (200 m), ancient coastline (80–130 m depth) and submarine features, such as seamounts, table mounts, and mid-oceanic ridges were key migration paths.

Time spent per area (TSA) analyses indicated that key areas where shortfin makos displayed residency included the continental shelf and slope off southern Western Australia and the western central and eastern GAB, the northern frontal area of the Bonney Upwelling Region off south-eastern South Australia, and to a lesser extent, the continental shelf areas off Cape Otway and Portland, Victoria. Commonwealth waters off southern New South Wales and in New Zealand Fisheries Management Areas were also important for selected individuals.

Project Extension and Education

Experiences during the satellite tagging processes informed the development of a fishery Code of Practice for handling and release of pelagic sharks captured in the Victorian recreational and game fishery. This included a step by step guide outlining a series of methods to safely handle and release shortfin makos, and a summary of the equipment required on recreational and game fishing vessels. These methods aim to improve the chance of post-release survival of line-caught shortfin makos.

A key focus of this study was to provide public feedback on the project via media articles in popular game fishing magazines, and present preliminary results of satellite tagging on-line via project webpages. At the beginning of the project, a series of web-pages were developed using the satellite tracking and analysis tools (STAT) (Coyne and Godley 2005) provided on: http://www.wildlifetracking.org/index.shtml?project_id=308&dyn=1443749323.

Interactive maps showing satellite tracks of all shortfin makos tagged are shown on the webpage and they received 87,774 visits.

Implications for Management

The study off Victoria focused on Commonwealth-managed waters and provided further support to previous studies that showed minimal connectivity exists between the Southern and Northern Hemisphere stocks of shortfin makos. Given the highly migratory life history of the shortfin mako, further consideration should be given to the sustainable management of: reproductive-aged and -sized individuals, key juvenile nursery areas, and potential cumulative effects on populations across the broad geographical range of the stock.

Future Research Needs

Further investigations into the extent of movements and connectivity between Australian, South African, and New Zealand waters would benefit from satellite tracking of mature adult individuals from the Indian and the SW Pacific Ocean areas. This project could be used as a case study on which to base the development of projects to assess and identify the key habitats of other listed pelagic shark species (e.g. common thresher, porbeagle and school shark) that are of emerging importance in recreational and game fisheries off southern Australia. This could be achieved via a combination of pelagic long-line survey methods and satellite telemetry.

INTRODUCTION

Background

In comparison to the information available for large terrestrial animals, migration is poorly described for large marine animals. Migration is driven by the ability to predict the location and timing of availability of food resources, the need to move between breeding areas, and other con-specific interactions and environmental factors (Block *et al.* 2011). For highly migratory species (HMS) with regular surface swimming behaviours, the importance of different habitats can be investigated using satellite telemetry, and this was the approach taken during the current study on the shortfin mako (*Isurus oxyrinchus* (Rafinesque) Lamnidae) in southern Australian waters.

The shortfin mako is a HMS that ranges across multiple international and high seas jurisdictions. This species constitutes the most important target shark species in recreational and game fisheries in Victoria, Tasmania, eastern South Australia and New South Wales. Victoria, Tasmania and the eastern area of South Australia have substantial populations of game and recreational fishers, yet the coastal and shelf waters generally lack the diversity and abundance of large-bodied bony fish species that comprise suitable game fishing targets, when compared to those of the northern States. Access to the shortfin mako as a target species, therefore, has a high social and economic value placed on it by fishers in these southern temperate regions.

The May 2010 National Recreational Mako Shark Fishery Management Forum highlighted the need to ensure that recreational fishing for shortfin mako and other sharks in Australian waters is sustainable, and to acknowledge the importance of pelagic shark fishing to recreational fishers. Workshop participants outlined the importance of preparation of effective education and communication activities to promote the adoption of world's best fishing practices. This formed part of the impetus for the development of this study. Subsequently, the Fisheries Research and Development Corporation (FRDC) funded the Australasian Mako Shark Workshop in February 2012. This identified key research priorities for shortfin makos that included improved information on the population structure, connectivity and movement of the Australasian population (Bruce 2014).

Satellite tracking in the Great Australian Bight (GAB), southern Australia showed that juvenile shortfin makos are capable of broad-scale oceanic movements (>10,000 $km.yr^{-1}$) into high seas jurisdictions, and extended periods of fidelity in shelf waters (Rogers *et al.* 2015a). This was consistent with other parts of the world, where shortfin makos also have a movement strategy that incorporates fidelity in shelf and near shelf waters and large-scale, oceanic movements (Loefer *et al*. 2005; Vetter *et al.* 2008; Stevens *et al*. 2010; Abascal *et al*. 2011; Block *et al*. 2011). Satellite tags also provide a means to collect quantitative data and related insights into the capture and handling methods that result in post-release survival (e.g. Heberer *et al*. 2010), and these can be used to inform the development of best practice guidelines for pelagic fisheries.

Prior to this study, information was needed to determine the appropriate spatial scale at which to manage the shortfin mako in Australasian waters where target recreational and game fisheries are centred. For HMS such as the shortfin mako and other listed pelagic sharks (e.g. porbeagle and thresher shark spp.), this information is important in informing future policy discussions. Specifically, the extent and timing of movements between Australian fishery regions was poorly understood and this was critical to interpreting the information obtained during a recent study of the genetic population structure of the shortfin mako in Australasia, and to better understand the linkages with distant populations in Northern Hemisphere regions (Rogers *et al.* 2015b). This study was designed to address some of these gaps.

Need

Concern regarding the status of shortfin mako populations in the Northern Hemisphere led to the listing of this species as ‘Critically Endangered’ in the Mediterranean and ‘Vulnerable’ in other regions, including the North Atlantic, by the International Union for Conservation of Nature Species Survival Commission on 22 February 2007. The species was subsequently listed under the Convention on the Conservation of Migratory Species (CMS, Appendix II: Migratory). This was followed by the nomination of the species for protection under the *Australian Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). In November 2009, the Australian Commonwealth Government Department of the Environment declared that from 29 January 2010, shortfin mako, longfin mako (*I. paucus*), and porbeagle (*Lamna nasus*) would be listed under the EPBC Act, making it an offence to kill, injure, take, trade, retain, or move shortfin makos in Australian Commonwealth managed waters. EPBC Act provisions also afforded protection measures for each species in State (inside 3 nm), and Australian Commonwealth managed waters (outside 3 nm). This listing was debated and petitioned against by recreational, game and charter fishers, especially in Victoria, Tasmania and New South Wales. This was followed by amendments to the Act that allowed recreational fishers to continue to target shortfin makos. Proposed restrictions were debated due to: 1) limited information regarding the extent of linkages between Australian and Northern Hemisphere shortfin mako populations; and 2) limited information on the movement and mixing of the shortfin makos that support the Victorian recreational fishery, and other regions of Australia. These key information gaps formed the impetus for this study.

AIMS

Specific aims of this project were to:

1. Identify the migration paths, and assess residency of shortfin makos in the Victorian recreational fishery;

2. Develop a Code of Practice for sustainable handling and release of pelagic sharks;

3. Provide media detailing the highlights of the project and present preliminary results of the satellite tagging online.

METHODOLOGY

Capture and satellite tagging techniques

Eight satellite tags were deployed on shortfin makos in western and eastern Victoria in 2012 and 2013 (Fig. 1). Tags were deployed in shelf waters off Portland, south-western Victoria, Phillip Island, and Lakes Entrance in eastern Bass Strait. Deployment summary details, including total length, sex and tagging locations are shown in Table 1 and Figure 1.

Three different dorsal-fin mounted satellite tags were deployed: Sirtrack K2F161A, Wildlife Computers™ (WC) Smart Position or Temperature (SPOT), and WC data collecting Argos tags (Mk10A). Tag selection was based on shark body and corresponding first dorsal fin size. Sirtrack 161A tags were designed for tagging of marine mammals and incorporate a single pin attachment and two small, flexible tabs. These tags were deployed on the trailing edge of the first dorsal fin of two small juveniles (M2 and M3). Satellite tags were deployed on shortfin makos from game fishing and research vessels (Fig. 1, Table 1). Sharks were either captured by game fishers using standard game fishing tackle that comprised 24 or 37 kg breaking strain monofilament main-lines, nylon coated wire traces with J-style, or circle hooks, or by researchers using a 12 mm diameter rope and 70 mm diameter rubber buoy, attached to ~1 m of stainless steel cable leader (2 mm diameter) and circle hooks (12/0–16/0). Depending on the weather and vessel (deck configuration and gunwale height), the small-medium sized sharks were lifted from the water using either a solid aluminium or collapsible rubber sling. In some cases, off Portland, sharks were captured by recreational game-fishers and switched across to the research vessels for tag attachment. Once on-board, small-medium sized sharks were supported and restrained using a wet, high-density foam mattress, aerated using a reinforced deck-hose and their eyes covered. Larger sharks were maintained and supported in the water in a purpose built aluminium cradle on research vessels, or a rubber sling suspended from the gunwale of the recreational fishing vessels.

Given that shortfin makos have internal temperatures warmer than ambient water temperature (Carey and Teal 1969), four steps were taken to minimise on-deck handling time, as outlined in Rogers *et al.* (2015a). Firstly, the stainless steel tag bolts were pre-glued into each tag using Araldite™ epoxy. Secondly, a modified Stanley™ bench-clamp attached to a tag shape template was used to enable the drilling of holes in the dorsal fin to accurately match the spacing of the tag bolts. Thirdly, the stainless steel lock nuts were fastened using a cordless drill and deep socket. Finally, the total length of each shark was estimated (± 10 cm) from increments marked on the slings/cradle. These steps reduced the handling time to between three and six minutes and were found to optimise the survival of satellite tagged sharks.

Data analyses

Satellite tags transmitted signals to the low polar orbiting environmental satellite network receiver stations, which were forwarded to ARGOS centres in France and the USA (ARGOS, 2008). ARGOS position estimates were accessed using Telnet and Tera Term Pro software. Argos data are categorised into six quality classes (3, 2, 1, 0, A, B) based on the number of uplinks from transmitter to satellite, time between these uplinks, and time since a previous location was estimated (Austin *et al.* 2003). Manufacturer predicted accuracies of classes are as follows: 3 = <250 m, 2 = 250–500 m, 1 = 500–1500 m and 0–B = >1500 m, Z = no position (www.argos-system.org). Positions of class 3–B were mapped using the GIS software package, MapInfo Ver. 11.5 (Mapinfo Corporation, New York) and the Satellite Tracking and Analysis Tool (STAT) (Coyne and Godley 2005). A set of spatial movement parameters were estimated and statistical results reported as mean ± standard error with 5th and 95th percentiles, unless otherwise stated.

The estimation errors associated with the Argos quality classes vary through time. Furthermore, the Argos-derived locations are observed irregularly through time, which can impose an artificial perspective on the movement processes, which is why Bayesian filtering methods tend to be used. For each individual track, the ‘raw’ satellite derived (Argos) locations were filtered using Bayesian state-space models (SSM) following the methods of Jonsen *et al.* (2005). The state-space distribution models are time-series methods that allow unobserved assumed behavioural states and biological parameters to be estimated from data observed with position estimation error. This approach enables the management of the biological and statistical complexities associated with satellite tracking data. We used hierarchical switching models (hDCRWS) that account for these features of the data and allow both filtering spatial positions and estimating behavioural states (i.e.

residency/area restricted search (ARS) vs transit/migration). Spatial models were fitted using JAGS 3.1.0 (Just Another Gibbs Sampler, http://martynplummer.wordpress.com; http://mcmc-jags.sourceforge.net) accessed from R (R Core Team 2014) using the package ‘bsam’ (Jonsen *et al.* 2014). Two Markov chains with a total of 50,000 simulations were computed, only keeping one out of ten samples to minimise sample autocorrelation. The analyses assumed a time-step of 4 h and generated 25,000 samples per chain for each position. A 0.4 x 0.4° grid was drawn over the study area. From the filtered tracks, the time spent by each individual in each square of the grid (Time Spent per Area, TSA) was calculated using the function ‘tripGrid’ (package ‘trip’, R Core Team 2014). The values of time were then converted to percentage of the total record duration for each individual. The boundaries of the EEZ (World EEZ v8 / 2014-02-28) were downloaded from the website http://marineregions.org/downloads.php. To assess seasonal movements, we grouped the monthly long-term track segments in 2012–13 and 2013–14, and from summer to winter in 2015.

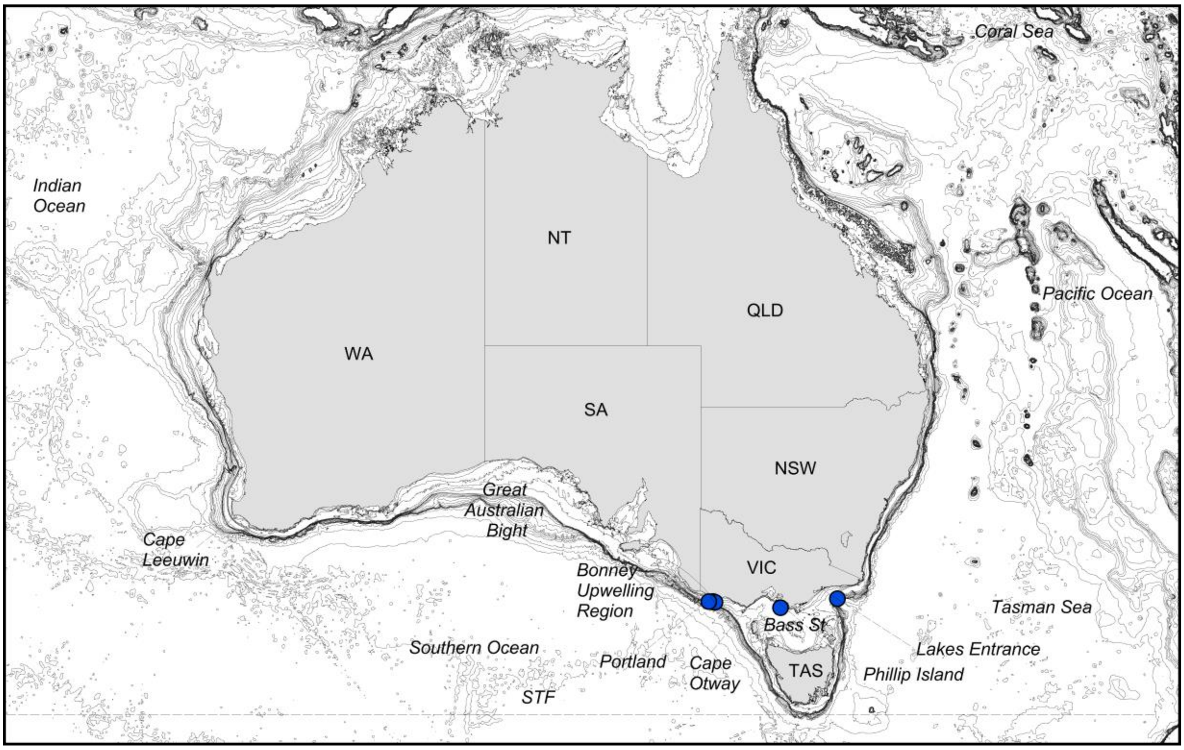


Figure 1. Locations where satellite tags were deployed on shortfin makos are shown by blue symbols. The dashed line shown to the south of Tasmania indicates the approximate location of the Sub-Tropical Front (STF).

RESULTS

Deployment details

Satellite tags were deployed on eight shortfin makos at locations off western Victoria, central Victoria and in the eastern Bass Strait, between December 2012 and July 2013 (Fig. 1, Table 1). Deployment summary statistics are provided in Table 1. Tagged shortfin makos ranged between 120 and 270 cm total length (TL), and comprised one male and seven females. Two small juveniles (120–130 cm), two large juveniles (180 and 190 cm), three sub-adult females (250–270 cm), and an adult male (205 cm) were tagged. Figure 2 shows a satellite tag being deployed on a shortfin mako in Victorian waters. Sirtrack 161A tags with single bolt attachments were deployed on the two small juveniles (M2 and M3) (Table 1). Sharks M2 and M3 moved in a north-westerly direction and mostly travelled in the vicinity of the outer continental shelf and slope. Shark M2 travelled along the outer shelf and slope to the Murray Canyon complex south of Kangaroo Island and the last location was near Port MacDonnell in the Bonney Upwelling Region. Shark M3 travelled inshore and visited semi-enclosed bays off the south coast of Eyre Peninsula, and deepwater habitats in central southern Spencer Gulf waters (Fig. 3). These two single bolt tags both stopped transmitting after three months (93 and 99 days, respectively), suggesting that the tags moved out of the upright position required to transmit signals to satellites. These short-term tracks lacked sufficient temporal coverage compared to the long-term tracks and were analysed separately for M1, M4, M6, M7 and M8. Shark M5 was recaptured and taken <24 h after the satellite tag deployment and, subsequently, does not have complete summary statistics, or a TSA analysis. Its tag was recovered, archival information downloaded and tag redeployed on M6. Movement summary statistics for individual shortfin makos are shown in Table 2. In summary, satellite tags provided 5,563 position estimates of quality classes 3–B, and 117,160 km of tracking data. Tracking durations ranged between 93 and 953 days (mean = 423 ± 124 d, n = 7) for a total of 2,962 days of tracking data. Four tags provided data for durations >1 year, and two provided 2 (M4) and 2.6 (M7) years of data, allowing for a biennial seasonal analysis. Sharks travelled estimated minimum distances of between 1,734 (99 d) and 37,846 km (953 d). Daily rates of movement ranged between 17.5–53.6 km.d^{-1}.

Table 1. Deployment statistics for tagging of shortfin makos in Victorian shelf waters in 2012 and 2013. *Denotes shark was recaptured. **denotes tag active at time of report preparation. WC = Wildlife Computers. TL = total length (cm). LH = life history.

Shark ID & Argos frequency	Tag type	Deployment location	Deployment date	Sex	Size (TL)	LH stage
M1–115559	WC Mk10A	Portland	17/12/2012	F	260	Sub-adult
M2–115161	Sirtrack 161A	Portland	18/12/2012	F	132	Juv
M3–115158	Sirtrack 161A	Portland	18/12/2012	F	120	Juv
**M4–115160	Sirtrack 161A	Portland	18/12/2012	M	205	Adult
*M5–115562	WC Mk10A	Central Bass St	10/03/2013	F	250	Sub-adult
M6–115562	WC Mk10A	Portland	28/06/2013	F	270	Sub-adult
**M7–115162	Sirtrack 161A	Eastern Bass St	10/07/2013	F	180	Juv
M8–115159	Sirtrack 161A	Eastern Bass St	11/07/2013	F	190	Juv

Table 2. Summary statistics for shortfin makos tracked in Victorian shelf waters in 2012 and 2013. *Denotes shark was recaptured. **denotes tag active at time of report preparation.

Shark ID & Argos tag frequency	Position estimates cls 3–B	Estimated minimum distance travelled (km)	Rate of movement $Km.d^{-1}$	Time at liberty (days/yrs)	Average bearing of travel (degrees) (±SE)
M1 - 115559	1669	15,958	49.8	320 (0.9 y)	320 ± 0.33
M2 - 115161	180	2,093	21.1	93 (0.3 y)	302 ± 0.62
M3 - 115158	79	1,734	17.5	99 (0.3 y)	297 ± 0.35
**M4 - 115160	840	37,846	39.7	953 (2.6 y)	283 ± 0.96
*M5 – 115562I	5	9	-	<1	143 ± 0.80
M6 – 115562II	1370	13,162	53.6	246 (0.7 y)	287 ± 1.46
**M7 - 115162	683	23,398	31.5	744 (2.0 y)	152 ± 4.05
M8 - 115159	737	22,960	45.4	506 (1.4 y)	69 ± 0.85

Figure 2. A shortfin mako captured by game fishers from Portland, western Victoria (above) is transferred to the research vessel (below) and fitted with a dorsal-fin mounted satellite tag.

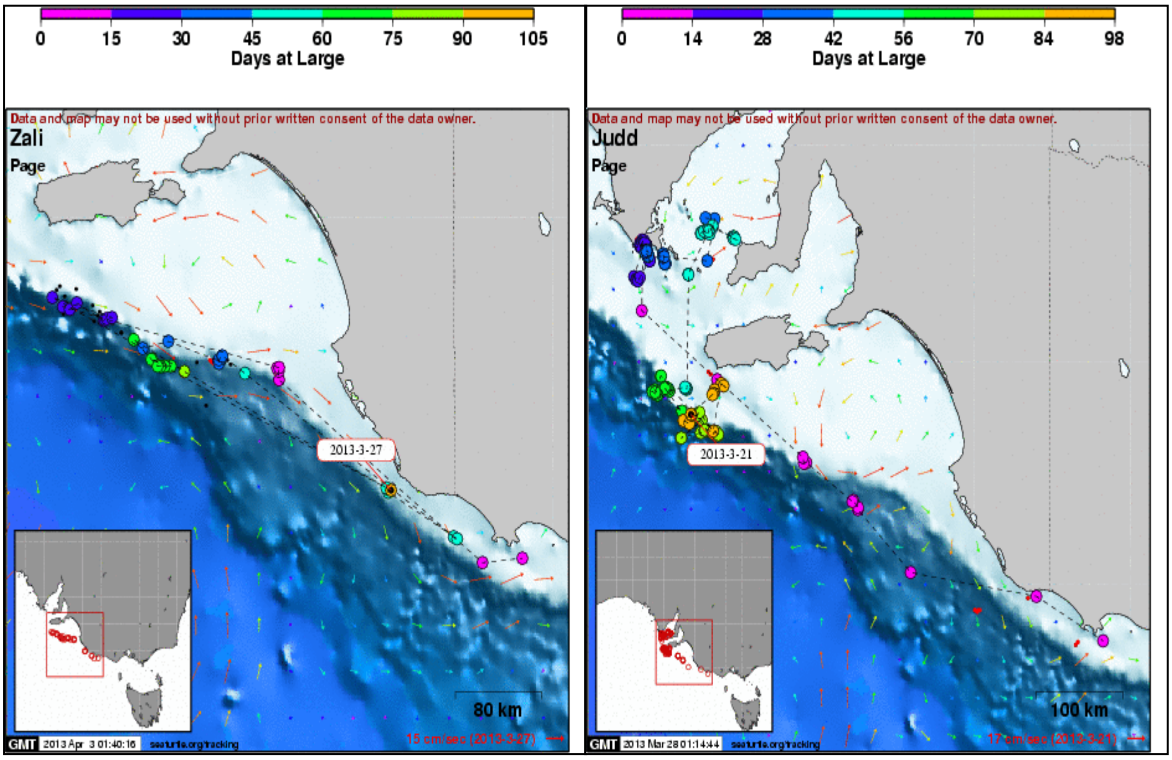


Figure 3. Short-term tracks for two small juvenile shortfin makos (M2 - left and M3 - right) tagged off western Victoria. Coloured arrows represent current speed and direction (STAT: Coyne and Godley 2005).

Movement patterns

Long-term track segments

One shortfin mako (M8) tagged in eastern Bass Strait migrated across the Tasman Sea to New Zealand during summer (Fig. 4). M8 migrated north from New Zealand to New Caledonia and Vanuatu. Median latitudes of <33° S were mostly inhabited during the three summer periods, with one trip observed into oceanic regions of the SE Indian Ocean (Fig. 4). Sharks tagged off western Victoria inhabited the eastern and western GAB, Bass Strait and migrated to the lowest latitudes of 44–45° S in the STF in autumn during all three years. Northward migrations into the tropical NE Indian Ocean, SW Pacific Ocean and Coral Sea were observed during winter and spring, as reflected by the highest median and maximal latitudes in Figures 4 and 5. Shortfin makos were present in the GAB during all seasons in 2013 and 2014, yet the two remaining sharks that were transmitting locations toward the end of the study period were focused on broad areas near the STF and SE Indian Ocean in the autumn and winter of 2015.

Biennial tracks: Return movements and affinity for features

At the time of preparation of this report, the tags on sharks M4 and M7 were still transmitting to Argos satellites after 2.6 and 2.0 years (953 d and 744 d), respectively. This provided the opportunity to assess the seasonal patterns for these individuals over two annual cycles. Figure 6 shows the movements of shark M4 from summer 2012–13 to winter 2015 combined, and the insets show each individual season. This track comprised three separate summer-winter and two separate spring periods. Shark M4 showed affinity for the shelf and slope waters of the GAB and Bonney Upwelling region where it returned during the summers of 2012–13, 2013–14 and 2014–15, with a further migration to oceanic SE Indian Ocean waters in summer 2014-15. During the autumns of the first two years, this shark migrated from the eastern GAB to the STF region, and also returned there from the SE Indian Ocean in the autumn of 2015. Winter movements were characterised by time spent in outer shelf and slope waters in all three seasons from 2013–15, with two separate migrations to the tropical Indian Ocean, one of which was initiated from the STF in 2015.

Seasonal migrations by shark M7 were shown during the 2 year, nine season track. Figure 7A shows the movements of M7 from winter 2013 to autumn 2014 combined, and Figure 7B shows the periods from winter 2014 to winter 2015 (the insets show each of the seasons). This track comprised three winters and two spring–summer periods. Notable features included the return usage of eastern, central and western Bass Strait shelf and slope waters during the summer and autumn periods of 2013–14 and 2014-15, respectively. This shark also used the eastern Bass Strait canyon complexes during winter in both years. During the winter of 2013 and 2015, and the spring of 2013 and 2014, shark M7 migrated northward to bathymetric features off Queensland in offshore oceanic areas, which included, but were not restricted to the Recorder Tablemount and the Moreton and Brisbane Seamounts (Fig. 8). These return seasonal migrations featured 18 separate instances in which the track intersected with a previous track, and five separate return movements to the same bathymetric features. This is also reflected in the TSA based residency analyses.

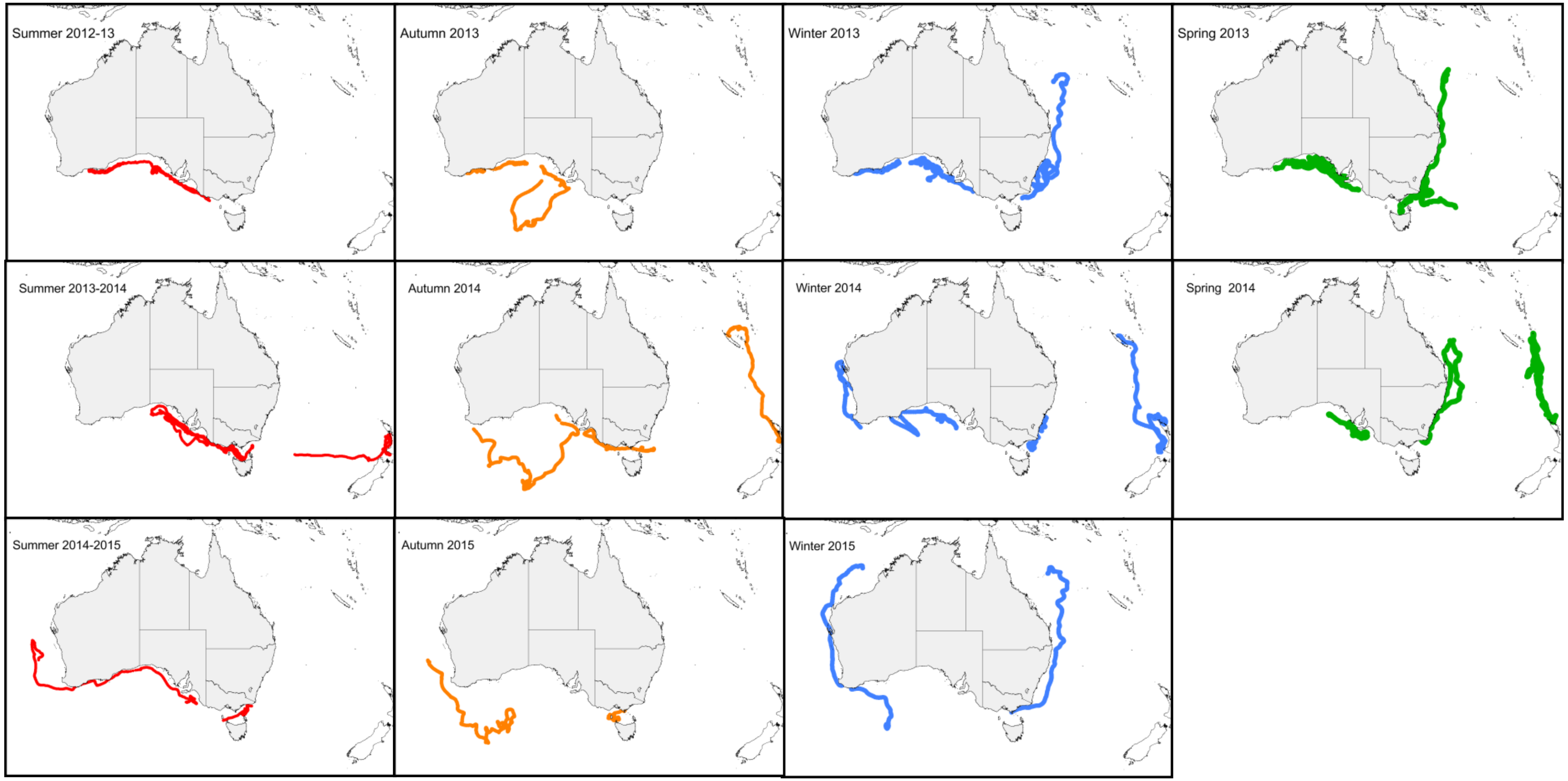


Figure 4. Seasonal movement patterns of shortfin makos between December 2012 and July 2015. Maps show the segments of tracks by season for all individuals (n = 5). Red =summer, orange = autumn, blue = winter, and green = spring.

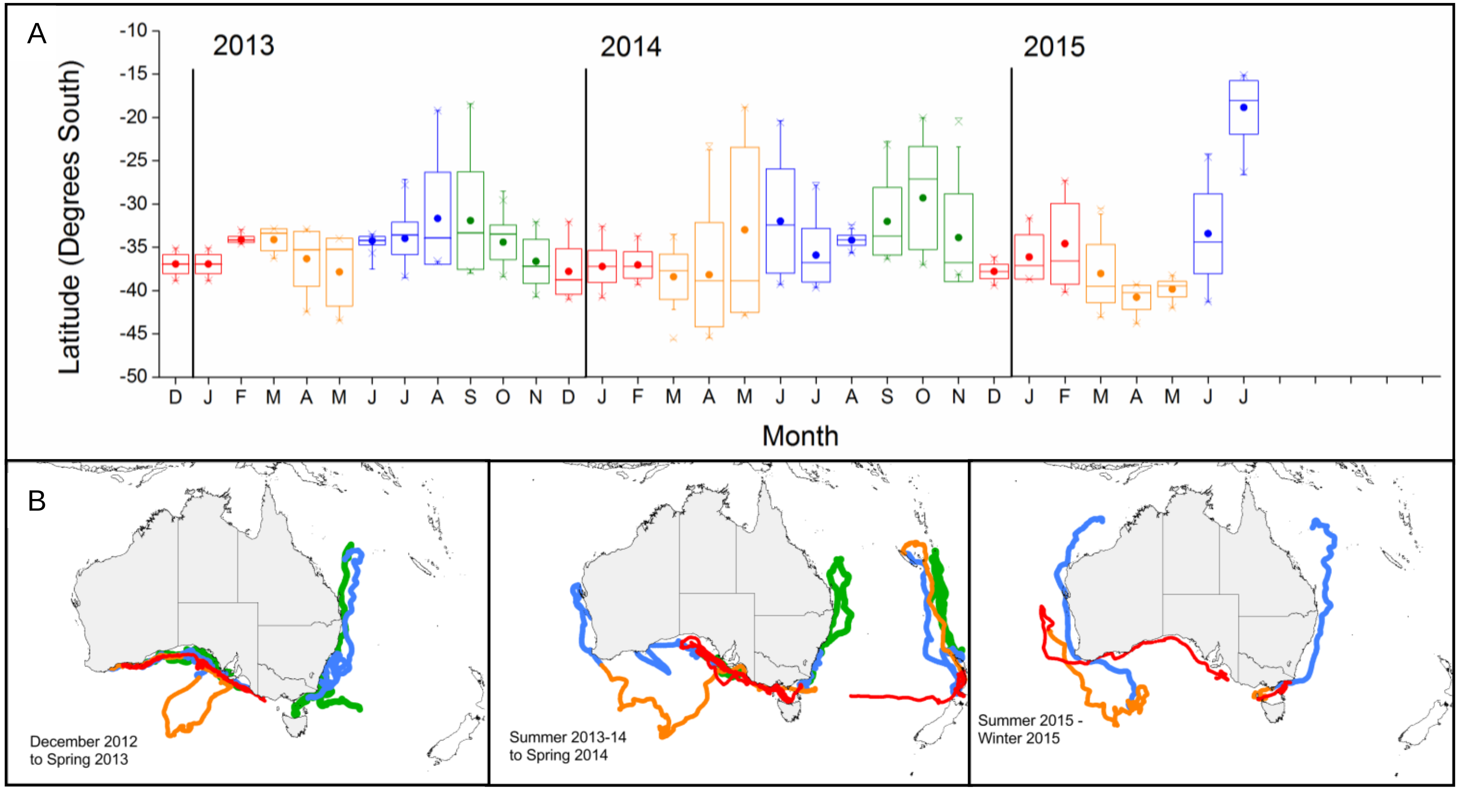


Figure 5. A. Inter-annual seasonal movements by latitude for shortfin makos (n = 5) between December 2012 and July 2015. Round symbols represent the means, line in box shows the medians, crosses are 1 and 99 percentiles, error bars show max and mins, and the boxes are ± 1 S.D. B. Seasonal track segments for all individuals by year. Red =summer, orange = autumn, blue = winter, and green = spring.

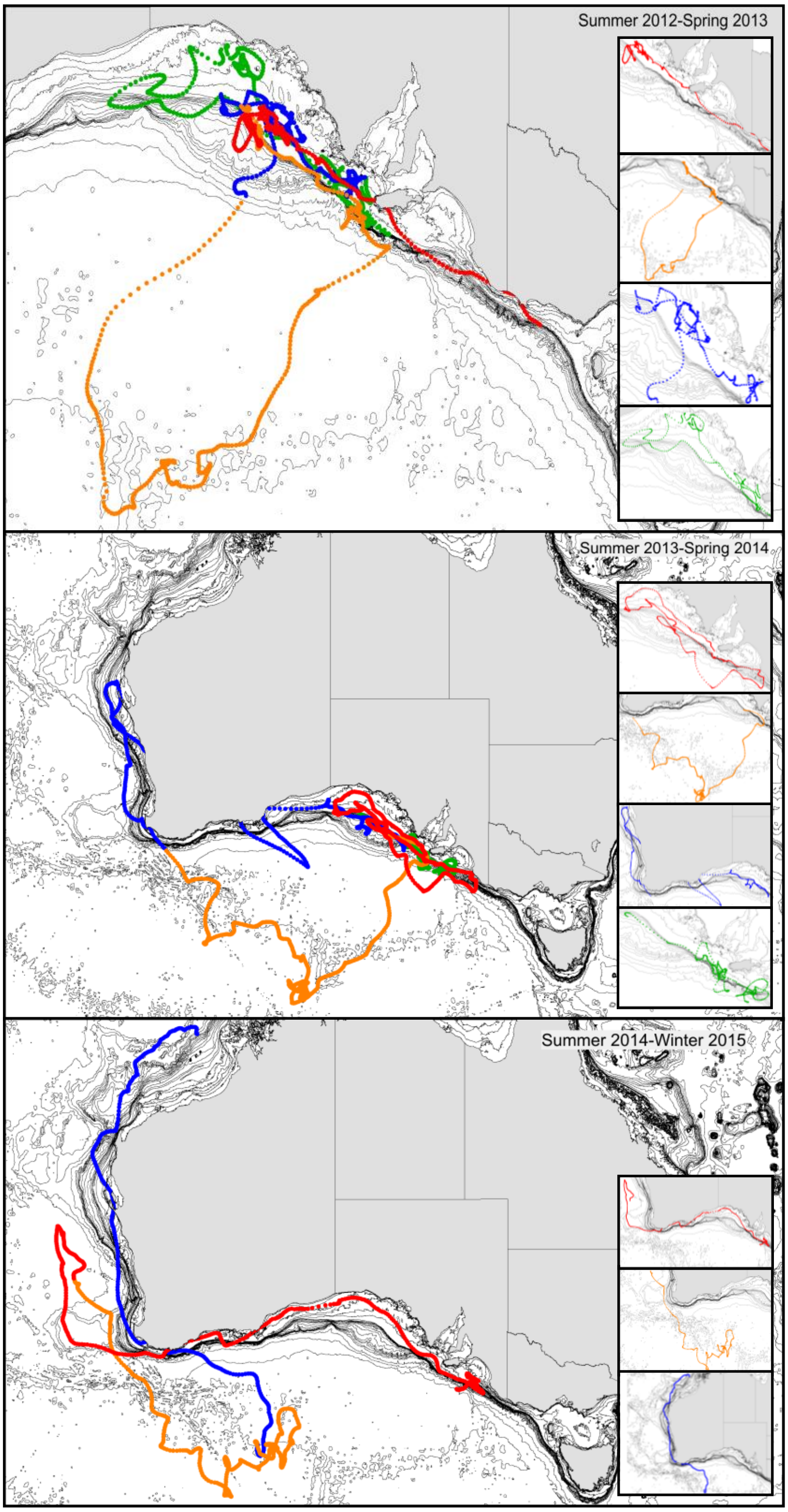


Figure 6. Seasonal migrations for shark M4 during the 11 season track. Summer = red, autumn = orange, winter = blue, and green = spring.

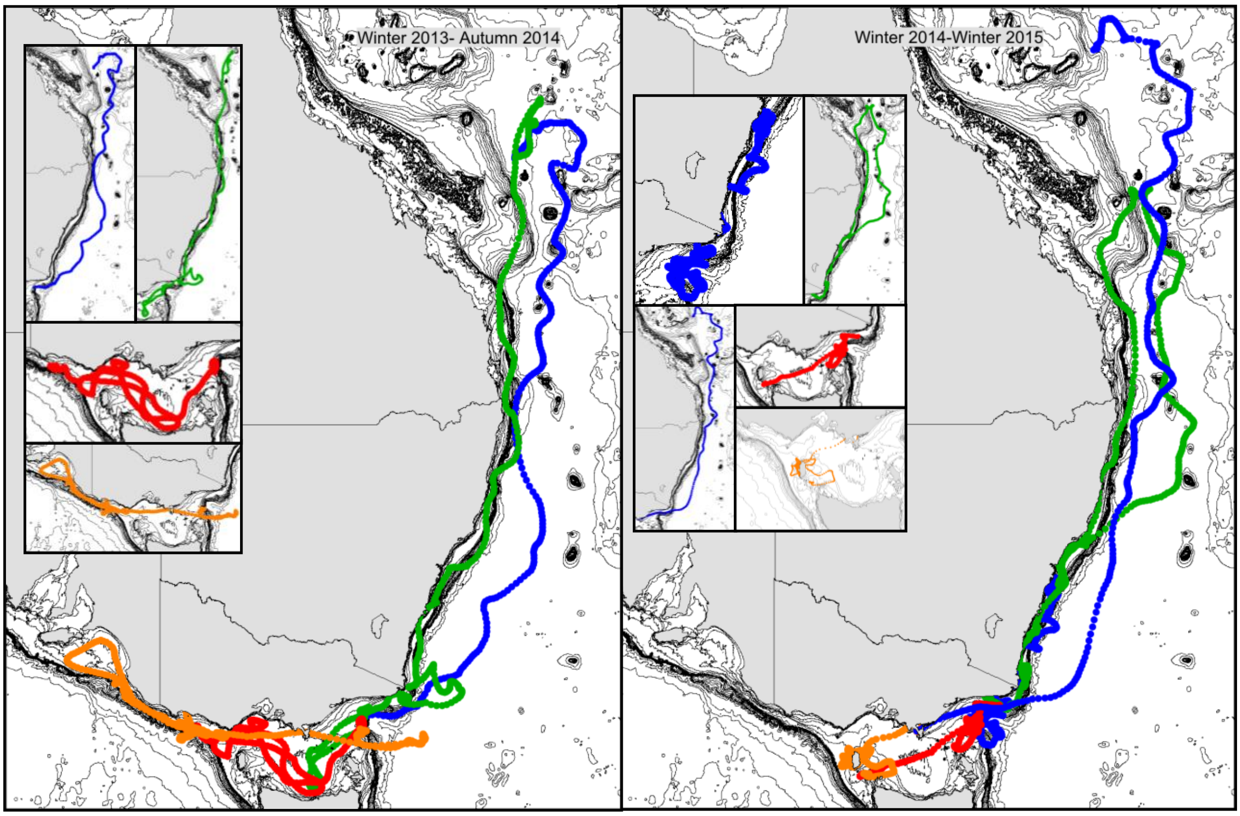


Figure 7. Seasonal migrations for shark M7 during the nine season track. Summer = red, autumn = orange, winter = blue, and green = spring.

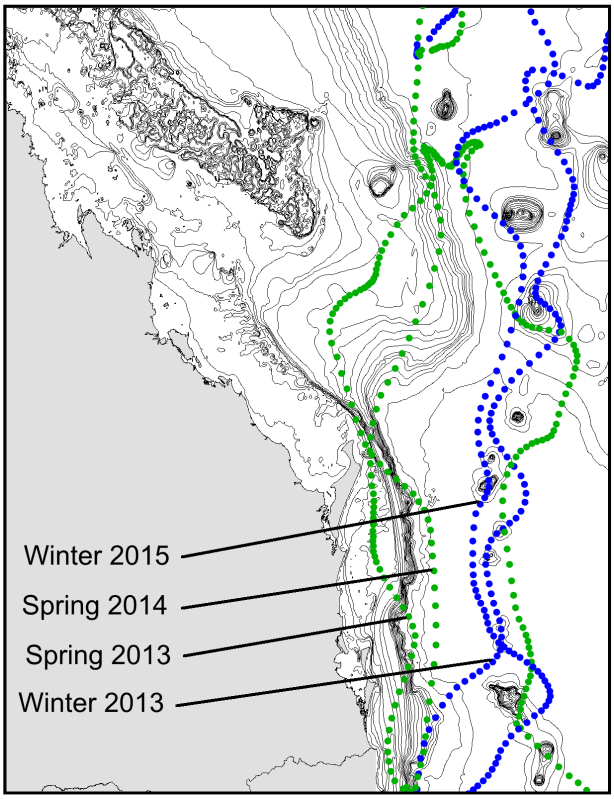


Figure 8. Return seasonal migrations by shark M7 to offshore bathymetric features in oceanic habitats off Queensland. Winter = blue, and green = spring.

Migration paths

Switching state-space model fits to the tracking data show the migration pathways (movement stages with minimal tortuosity) used by shortfin makos tagged off western Victoria included: the ancient coastline (80–130 m depths), outer continental shelf, shelf break and slope (160–200 m) of the GAB and SW WA between Cape Leeuwin and Esperance (Fig. 9). Appendix 1 shows each individual model fit. Migration phases consistently occurred in the oceanic areas of the Southern, Indian and SW Pacific Oceans with the end-points being New Zealand managed waters, the French managed territory off New Caledonia and Vanuatu-managed waters (Fig. 9). Transitory movements were also common in outer continental shelf and slope habitats off southern Australia. Shark M4 made multiple trips from the continental shelf waters of the eastern GAB to the oceanic STF, and SE and NE Indian Ocean (Fig. 6). Shark M7 travelled from its release point in the Bass Strait canyons, Victoria to the Coral Sea, and then returned to Bass Strait and Bonney Upwelling region, off SE SA (Fig. 7). Shark M8 moved from its release point in the Bass Canyons through eastern Australian shelf and slope waters off southern NSW, before crossing the Tasman Sea via a series of mid-oceanic seamounts and rises to shelf waters off the west coast of the North Island, New Zealand (Fig. 9). This was subsequently followed by two separate northward oceanic migrations to the tropical waters of New Caledonia and Vanuatu.

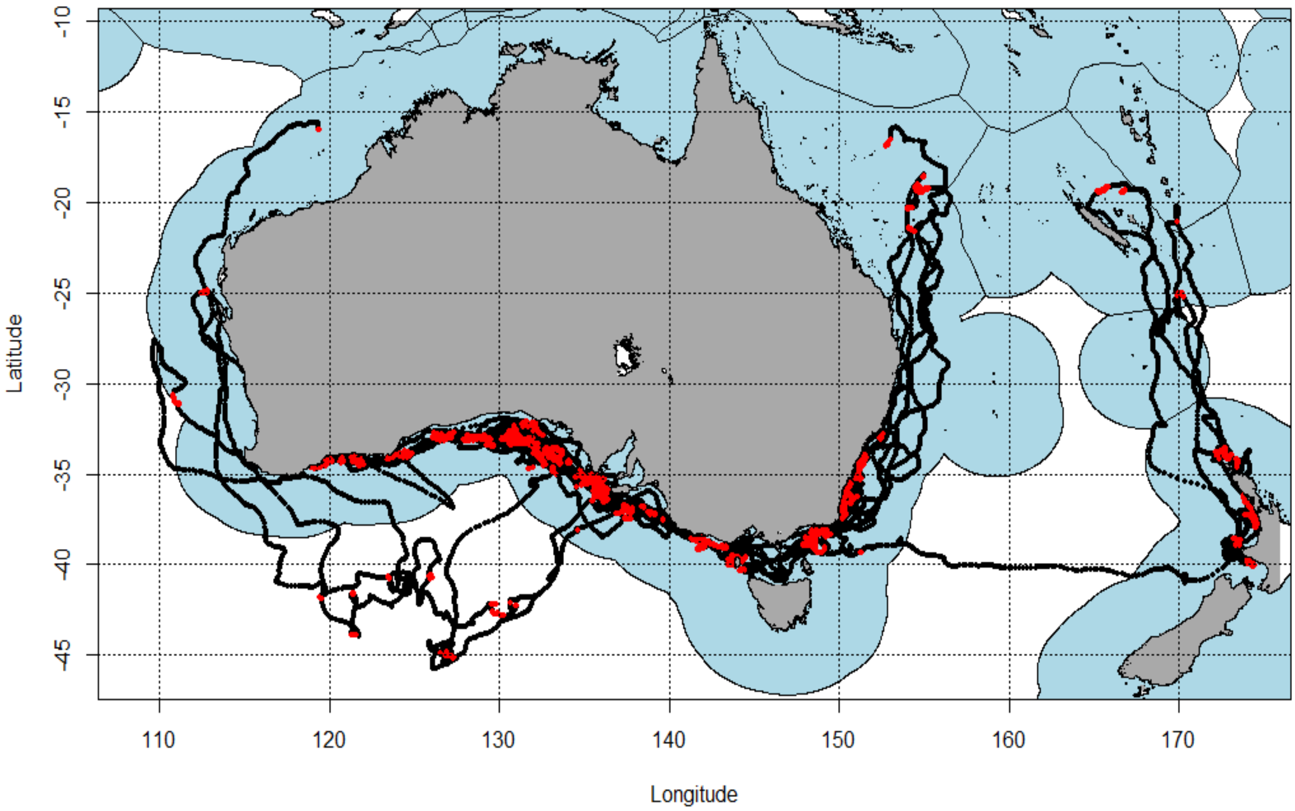


Figure 9. Switching state-space model fits to long-term (n = 5) satellite tracking data for shortfin makos released in Victorian waters. Transit and migratory stages are shown as black symbols and residential or area-restricted movement stages are shown as red symbols. Blue boundaries show the outer boundaries of the Exclusive Economic Zones (EEZ) in the Australasian, Indo Pacific and SW Pacific Regions. The white areas show the International waters.

Residency

Switching state space model fits to long-term data for five shortfin makos identified multiple areas across southern Australia and New Zealand where residency (ARS) classified movement occurred. Key shared areas were the central and eastern GAB, northern frontal area of the Bonney Upwelling Region, southern Western Australia, western Victoria, western and eastern Bass Strait, and the STF. The south-western, western and north-western shelf areas off the North Island, New Zealand were also the focus of periods of residency by one individual (M8). With the exception of the STF, the areas where the highest residency occurred were in Australian Commonwealth (>3 nm) and New Zealand fisheries management areas.

TSA analyses for three sharks M1 (Fig. 10A), M4 (Fig. 10B) and M6 (Fig. 10C) tagged off western Victoria indicated that key areas where sharks displayed residency included the continental shelf and slope off southern Western Australia and the western GAB shelf (e.g. shark M1). For shark M6, areas of highest usage included the outer continental shelf and slope of the central and eastern GAB, the northern frontal area of the Bonney Upwelling off south-eastern South Australia, and to a lesser extent, the continental shelf areas off Cape Otway and Portland, Victoria.

TSA analyses for M7 (Fig. 11A) and M8 (Fig. 11B) tagged in the Bass Canyons indicated that areas of highest residency included the continental shelf waters off southern New South Wales, shelf waters off the western coast-line of the North Island, New Zealand (shark M8), Bass Canyons, and shelf waters off Portland, western Victoria and King Island, western Bass Strait. In terms of time spent in fishery managed areas, the key areas included Australian Commonwealth managed waters to the east of Cape Leeuwin and west of Cape Otway, State and Commonwealth waters off southern New South Wales, and New Zealand Fisheries Management Areas (Auckland east and west 1, 8, and 9).

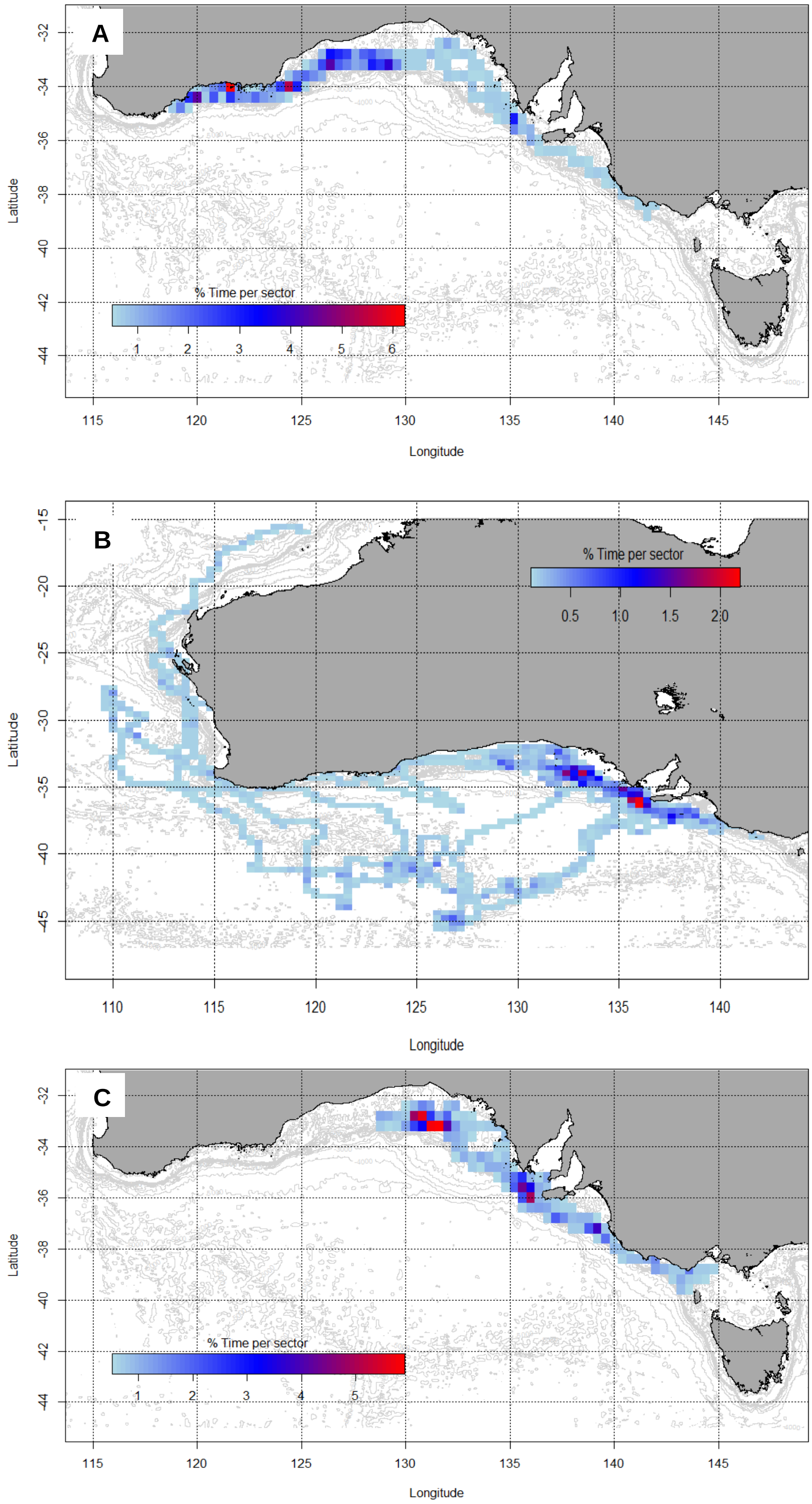


Figure 10. Time spent per area analyses for shortfin makos. **A.** Shark M1 in the Great Australian Bight, Bonney Upwelling and southern Western Australian shelf waters ($N_{\text{Total days}} = 320$). **B.** Shark M4 in the SubTropical Front, Indian Ocean and Great Australian Bight ($N_{\text{Total days}} = 953$). **C.** Shark M6 in the Great Australian Bight, Bonney Upwelling and western Bass Strait ($N_{\text{Total days}} = 246$).

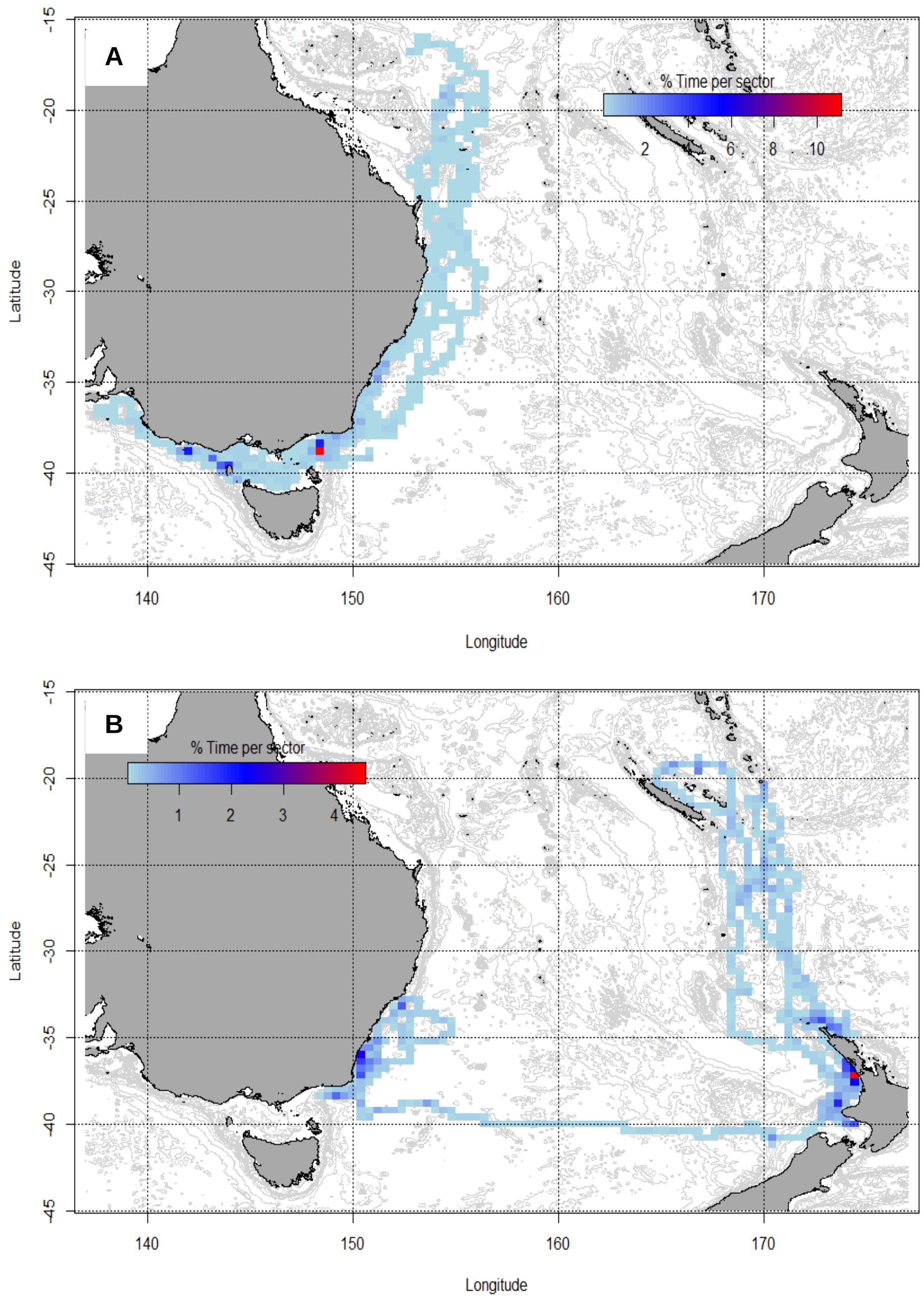


Figure 11. Time spent per area analyses for shortfin mako. **A.** Shark M7 in the Bonney Upwelling, Bass Strait, SW Pacific Ocean and Coral Sea (N $_{\text{Total days}}$ = 744). **B**. Shark M8 in the SW Pacific, New Zealand managed waters and New Caledonia (N $_{\text{Total days}}$ = 506).

GUIDELINES FOR HANDLING AND RELEASE OF PELAGIC SHARKS

The following equipment is required to handle and release pelagic sharks:

- Reinforced heavy-duty fishing gloves to handle the leader.
- 16/0 to 18/0 circle hooks with heat-shrink material to cover crimps and protect the eyes and gills of released sharks.
- Nylon coated leader material to reduce impacts of leader burn on shark eyes, gills and skin.
- Heavy-duty bolt-cutters capable of cutting through a variety of steel hook materials.
- Strong cable cutters capable of cutting through the leader.
- A plastic floating measuring tape attached to a stick with a float on the end, or increments marked on the gunwale to accurately estimate size (and weight).

Three to four people are required to safely carry out the capture on standard fishing tackle, handle the leader, remove the hook(s), and subsequently release medium-large (1.5–3 m total length) pelagic sharks. A team of four is suggested, which includes one to drive the vessel, one to take the leader, one to operate the fishing gear, and the fourth to use the bolt cutters to cut and/or remove the terminal tackle from the shark prior to release.

Step 1

Circle hooks should be used in conjunction with a firm drag setting on the reel, and preferably with the shark swimming away or side on to the vessel to enable the hook to move to the corner of the mouth. This consistently reduces the chances of the hook and bait being swallowed. If J-hooks are used, the shark should be hooked as soon as it takes the bait to reduce the chance of the baited hook being swallowed.

Step 2

When using circle hooks, the bait should be attached ~2 cm under the hook gape using twine or waxed thread. The bait should be constantly monitored because if a shark takes the bait while swimming toward the vessel, it may still swallow the baited circle hook. Alternatively, the shark shouldn’t be presented with baits until it is sighted. This will prevent bycatch of non-target species and increase the chance of a jaw-hooked shark, which is easier to release uninjured.

Step 3

When a hooked shark is boat-side, the driver should steer downwind slowly to keep the animal swimming steadily next to the vessel. This ensures that the gills are being aerated during handling and reduces the likelihood of rapid direction changes by the shark. For jaw-hooked sharks, it is easiest to operate on the side of the vessel that matches the side of the mouth that the hook is located as this allows direct access to the hook. The person taking the leader should slowly lead the shark close to the vessel while passing any slack leader into the water to reduce the risk of entangling themselves or other people onboard. Smooth and steady movements should be used to bring the shark within range of the vessel.

Step 4

Once the shark is tagged near the base of the dorsal fin using a standard tag-pole and applicator (see images below) a reference on the gunwale or a floating measuring tape can be used to estimate the total length. Total length can later be used to estimate fish weight using length-weight curves.

Step 5

In some cases, long-handled bolt-cutters can be used to cut the hook shank or turn the hook out of the jaw by twisting in the same direction as the circle of the hook. Care should be taken to not make contact with the eyes of the shark with the bolt-cutters or other tools. If the hook cannot be safely removed, cable cutters can be used to cut the leader as close as possible to the hook without risking being bitten (~0.5–1 m away from the mouth), which is generally from above the head of the shark and behind the line from the tip of the snout to the pectoral fin.

MEDIA AND COMMUNICATIONS DETAILING THE PROJECT HIGHLIGHTS

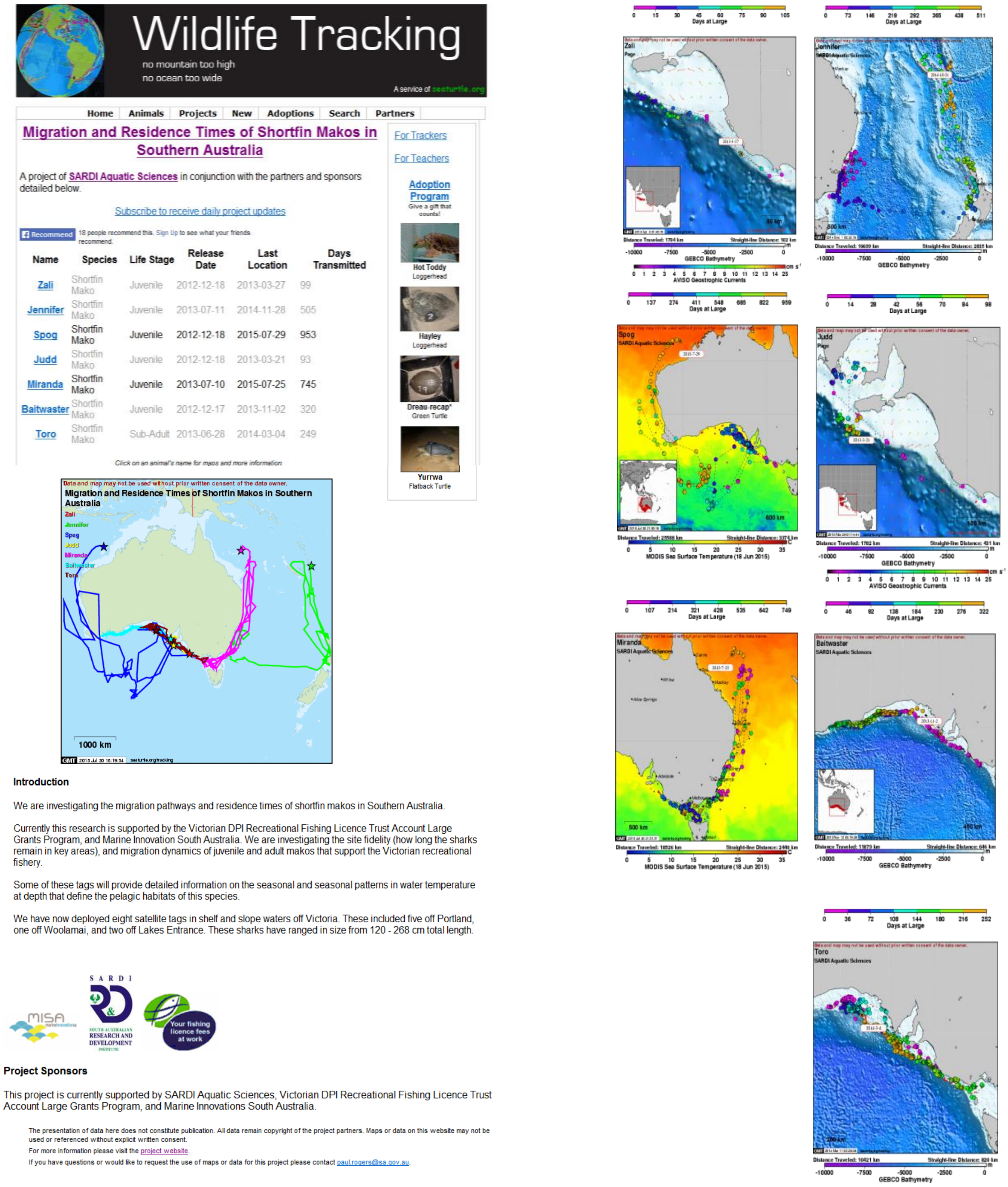
Extension

During the project the Principle Investigator:

- Prepared two articles for Bluewater Boats and Sportfishing magazine that included and an article in the tag-lines section in March-April 2014 (Appendix 2) and a front page feature article in May-June 2013 (Appendix 3.).
- Provided information on the project for Victorian gamefishing club newsletters (Appendix 4).
- Presented at a public forum at Deakin University, Warrnambool, Victoria with Julian Pepperell to provide information about the project and broader pelagic shark research in November 2010 (Appendix 5 and 6).
- Developed project fact-sheets and website information about satellite tagging, types of tags used, and a strategy to follow in the case of the recapture of a satellite tagged shark (Appendix 7 and 8).

Development of tracking web-pages

At the beginning of the project, a series of web-pages were developed through the assistance of the team at wildlifetracking.org using the Satellite Tracking and Analysis Tools (STAT) of Coyne and Godley (2005). These web-pages provide regular daily updates of the Argos satellite tracking data, estimates of distance travelled, time at liberty since tagging, and updated maps overlaying bathymetry (bottom features) and sea-surface temperature from the MODIS weather satellites. The introductory webpage http://www.wildlifetracking.org/index.shtml?project_id=308&dyn=1443749323 and examples of the daily interactive maps for each shortfin mako are shown in Figure 12. The interactive maps can be animated by visitors to the project webpage. The web-page received 87,774 visits up until 30-7-2015 and will continue to be updated until the satellite tags have stopped transmitting signals to the Argos satellites.



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Migration and Residence Times of Shortfin Makos in Southern Australia

A project of SARDI Aquatic Sciences in conjunction with the partners and sponsors detailed below.

Subscribe to receive daily project updates

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Name	Species	Life Stage	Release Date	Last Location	Days Transmitted
Zali	Shortfin Mako	Juvenile	2012-12-18	2013-03-27	99
Jennifer	Shortfin Mako	Juvenile	2013-07-11	2014-11-28	505
Spog	Shortfin Mako	Juvenile	2012-12-18	2015-07-29	953
Judd	Shortfin Mako	Juvenile	2012-12-18	2013-03-21	93
Miranda	Shortfin Mako	Juvenile	2013-07-10	2015-07-25	745
Baitwaster	Shortfin Mako	Juvenile	2012-12-17	2013-11-02	320
Toro	Shortfin Mako	Sub-Adult	2013-06-28	2014-03-04	249

Click on an animal's name for maps and more information.

For Trackers
For Teachers
Adoption Program
Give a gift that counts!
Hot Toddy
Loggerhead
Hayley
Loggerhead
Dreau-recap*
Green Turtle
Yurrwa
Flatback Turtle

Introduction

We are investigating the migration pathways and residence times of shortfin makos in Southern Australia.

Currently this research is supported by the Victorian DPI Recreational Fishing Licence Trust Account Large Grants Program, and Marine Innovation South Australia. We are investigating the site fidelity (how long the sharks remain in key areas), and migration dynamics of juvenile and adult makos that support the Victorian recreational fishery.

Some of these tags will provide detailed information on the seasonal and seasonal patterns in water temperature at depth that define the pelagic habitats of this species.

We have now deployed eight satellite tags in shelf and slope waters off Victoria. These included five off Portland, one off Woolamai, and two off Lakes Entrance. These sharks have ranged in size from 120 - 268 cm total length.

Project Sponsors

This project is currently supported by SARDI Aquatic Sciences, Victorian DPI Recreational Fishing Licence Trust Account Large Grants Program, and Marine Innovations South Australia.

The presentation of data here does not constitute publication. All data remain copyright of the project partners. Maps or data on this website may not be used or referenced without explicit written consent.

For more information please visit the project website.

If you have questions or would like to request the use of maps or data for this project please contact paul.rogers@sa.gov.au.

Figure. 12. Project website highlighting the shortfin mako satellite tracking data.

DISCUSSION

We investigated the patterns of movement and residency of shortfin makos targeted in the Victorian recreational and game fishery. Prior to this study, there were significant gaps in the information available to manage recreational and game fisheries that target this species, including the duration that shortfin makos remain in Victorian waters, and the level of connection with other populations and pelagic fishery areas. To address these, we used satellite telemetry as the primary tool to identify the migration paths, and residence times of shortfin makos in the Victorian fishery and adjacent areas. We also provided media detailing the highlights of the project, presented preliminary satellite tagging results on a dedicated series of web-pages, and drew on experiences gained during the study to develop a fishery Code of Practice for safe handling and release of pelagic sharks.

Migration pathways

Our study provided evidence that areas used by the Victorian recreational and game fishery represented a relatively small proportion of the overall migration pathway for the animals tracked, perhaps reflecting the seasonal prey availability in that area and the high metabolic requirements of this species. Shortfin makos are highly migratory and undertake seasonal movements to oceanic, mid-outer continental shelf and slope habitats. This was consistent with a previous study that mostly focused on juveniles tagged in the GAB (Rogers *et al.* 2015a). Some individuals undertook large-scale oceanic migrations to tropical waters of the North-east Indian Ocean and Coral Sea during winter and spring, whilst others remained in offshore shelf waters; consistent with the previous study of juveniles (Rogers *et al.* 2015a). Our findings were generally consistent with those of previous studies of shortfin makos in the North-east Pacific Ocean, where fidelity to areas tended to be reduced in oceanic areas (Block *et al.*, 2011). The south-facing continental shelf in our study area is, however, considerably broader than in the North-east Pacific, providing sharks with a broader geographical area to explore while searching for prey aggregations. In the eastern boundary current system in the south-east Indian Ocean off Western Australia, we have found that neritic-focused movements by shortfin makos were rare (Fig. 13A and B), and migrations in adjacent tropical oceanic areas occurred during winter and spring. This is consistent with behaviours of juvenile shortfin makos tagged in the GAB between 2008 and 2010 (Rogers *et al.* 2015a and summarised in Figure 13A). The roles of bathymetric features as navigation reference points during migratory movements, and as foraging habitats, warrant further investigation for this highly migratory species. Evidence from biennial tracks showed multiple-instance usage of seamounts, mid-ocean ridges and submarine canyons by the same individuals in the SW Pacific Ocean and Coral Sea, and shared usage of key habitats by multiple individuals over subsequent seasons. Some of the associations with these features may be partly explained by dietary and broader ecological linkages with epipelagic and mesopelagic fauna (Rogers *et al*. 2012).

Residency patterns

Despite several shortfin makos embarking on oceanic migrations, most remained faithful to continental shelf and slope waters off southern and south-eastern Australia, and in the past 7 years of satellite tracking effort, none have been observed to migrate to the Northern Hemisphere, which is consistent with previous research (Rogers *et al.* 2015a, b) (Fig. 13). Over an extended period of several decades, the NSW Gamefish Tagging Program has only reported a single trans-equatorial crossing by a shortfin mako that was recaptured off the Philippines (Rogers *et al.* 2015a). Importantly, this current study provided further evidence that shelf waters of the GAB, Bass Strait and southern Western Australia encompass important habitats for shortfin makos that also travel to oceanic areas of the Indian and Pacific Oceans, and across the Tasman Sea to New Zealand. Switching state-space model fits showed a large percentage of the positions classified as ‘resident’ or ARS occurred in mid-outer continental shelf and slope waters of southern and south-eastern Australia. The shelf areas of the west coast of the North Island, New Zealand and to a lesser extent the offshore oceanic frontal zones of the STF were also identified as being of ecological importance. In contrast, as shortfin makos migrated to offshore oceanic habitats, residency was sparser. The oceanic frontal zone supports populations of pelagic cephalopods (Kojadinovic *et al.* 2011) that are known to be important prey of shortfin makos in the SW Pacific Ocean (Stevens 1984), and in the Bonney Upwelling Region (Rogers *et al*. 2012); an ecological pattern consistent with other temperate boundary current ecosystems including the southern Californian Bight, where jumbo squid (*Dosidicus gigas*) are important prey of shortfin makos (Preti *et al*. 2012).

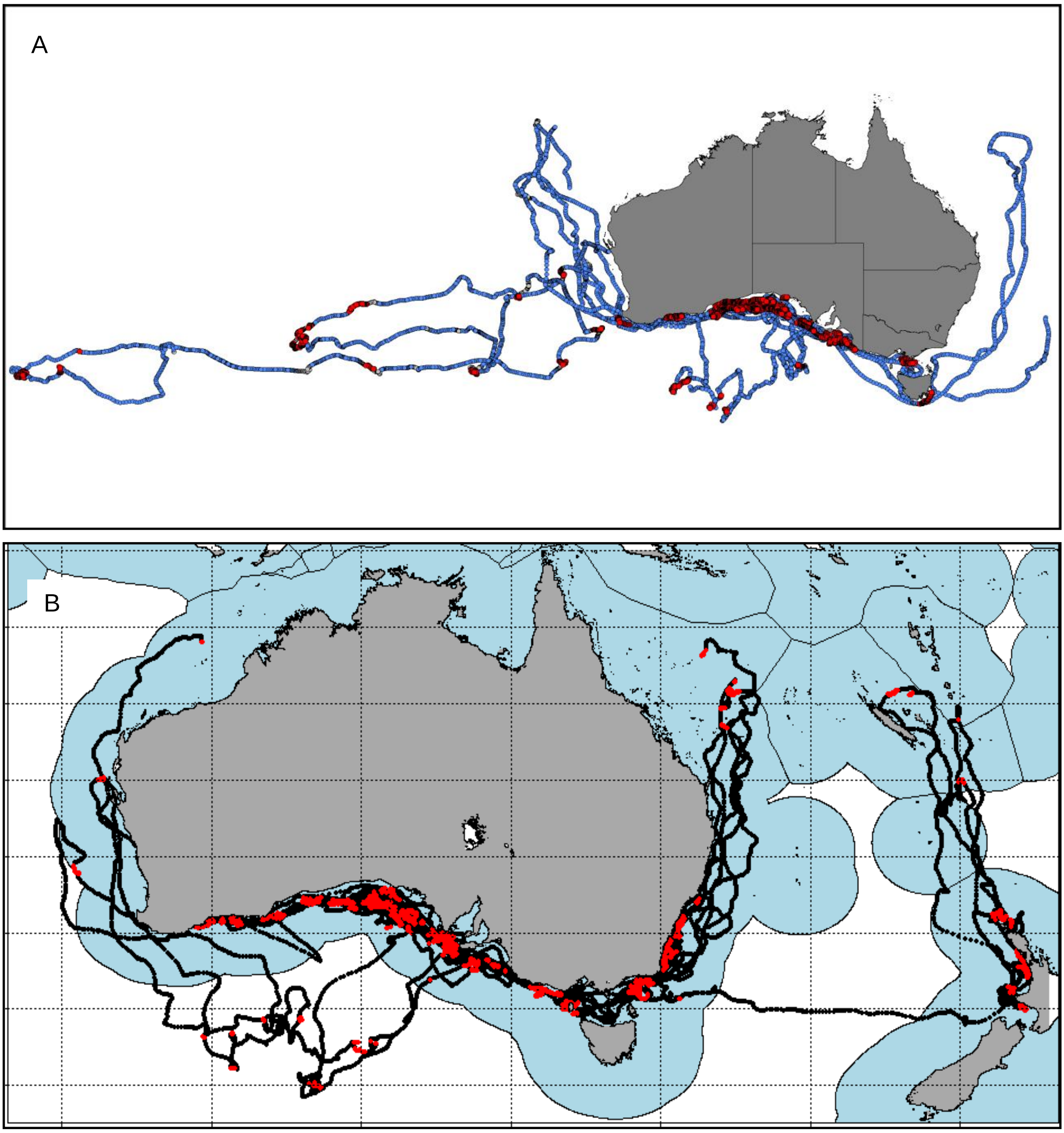

Figure 13. **A.** Migration pathways (blue symbols) and areas classified as ARS (red symbols) for juvenile shortfin makos tagged in GAB shelf waters between 2008 and 2010. **B.** Migration pathways (black symbols) and areas classified as ARS (red symbols) for shortfin makos tagged in Victorian shelf waters in 2012 and 2013.

Guidelines for handling and release

Based on experiences during the project, we suggested a series of steps and identified equipment required to handle and release shortfin makos and other pelagic shark species from recreational and game fishing vessels in a manner that maximises shark survival. The steps were developed to improve the safety of fishers on vessels and optimise the post-release condition of pelagic sharks. The key considerations we suggest will aid in the sustainable fishing of pelagic sharks include the need to:

- Minimise the time the shark is on the fishing line. Reducing the fight time leads to the shark maintaining a vigorous and healthy state when it is released.
- Use non-offset circle hooks that are more likely to result in sharks being hooked in the jaw, or early hook-setting techniques when using J-hooks.
- Use nylon coated leader material to protect the eyes and gills of sharks to be released.
- Move the vessel slowly forward as the line is retrieved prior to tagging/and or release. This aids gill ventilation and reduces the likelihood of rapid and multiple direction changes by the shark during removal of the fishing gear.
- Encourage peers and fishing club members to tag and release large females (>2.6 m) as they produce offspring that will support the sustainability of the fishery in the future.

Media and communications and project extension

During the project, we provided near-real time updates to fishers about the satellite tracking of shortfin makos in Victorian offshore waters. The wildlife tracking project website was visited by 87,774 users during the course of the study, illustrating that considerable community interest and educational benefit was generated by the presentation of these data on-line. Satellite tracking related information was also provided at fishing club and community presentations, presented in fact sheets and summarised in National magazines. The community event at Warrnambool allowed researchers and fishers to communicate about the research and management of a number of pelagic shark species, with special emphasis on shortfin mako, porbeagle and common thresher sharks that are taken in shelf waters off Victoria (Appendices 5 and 6).

Sustainability of fisheries for shortfin makos

The shortfin mako is a HMS that exhibits varying residency in continental shelf and slope waters, and undertakes migrations into offshore oceanic areas where they visit seamount complexes, mid-oceanic ridges and trenches. While using these habitats, shortfin makos are susceptible to several fishing gear types used across multiple management jurisdictions (Bruce 2014). Future management should be responsive to the new information on the broad distribution and stock dynamics of the shortfin mako, and we suggest any new measures would need to be implemented at multi-jurisdictional levels to ensure potential cumulative effects on populations are considered.

This study focused on Commonwealth-managed waters and provided further support that minimal connectivity exists between shortfin mako populations in the Southern and Northern Hemispheres (Rogers *et al.* 2015a, b). Importantly, satellite tagging data shows that the tracked shortfin makos were not likely to be subject to prolonged periods of recreational and game fishing in the areas where they displayed the highest degree of residency, including the western, central and eastern GAB and Bass Strait. The migration pathways of the offshore continental shelf and slope in the central and eastern GAB are rarely fished by recreational and game fishers, with seasonal recreational fishing mostly occurring off SE South Australia, western and central Victoria, Tasmania and the southern and central coasts of New South Wales. In addition, whilst the species is taken as a commercial bycatch in continental shelf and offshore regions (Bruce 2014), there is no target commercial fishery for shortfin makos in Australian waters and current regulations require that live sharks are released in Commonwealth managed fisheries.

The key to future management of the Australasian shortfin mako stock will be the survival of the early juveniles and reproductive-aged and -sized individuals across the broad spatial range that includes Commonwealth and international waters. This should, in part, be facilitated by the encouragement of more recreational and game fishers to use handling and tagging methods that optimise post-release survival. The capture methods we adopted during this study led to a high survival rate of tagged sharks. This is evidenced by the relaying of telemetry data from all sharks that were satellite tagged and is consistent with French *et al.* (2015) who showed that shortfin makos had high (90%) survival following capture, handling and release, and that hooking location was correlated with the use of circle and J-stye hooks.

Research needs

- ***Satellite tracking of adults*** – Further investigations into the extent of movements and connectivity between Australian, South African and New Zealand waters would benefit from the tracking of adult shortfin makos from the SE and SW Indian, and the SW Pacific Ocean regions.

- ***Importance of key nursery and breeding areas*** – Genetic analyses can be used to assess the relative importance and spatial delineation of key nursery and breeding habitats in fishery areas where the species is targeted and/or taken as bycatch.

- ***Identification of key habitats for other EPBC and CMS listed pelagic shark species*** – This project could be used as a case study on which to base the development of future work to assess and identify the key habitats of other pelagic shark species that are of emerging importance in recreational and game fisheries off southern Australia (e.g. common thresher, school and porbeagle sharks).

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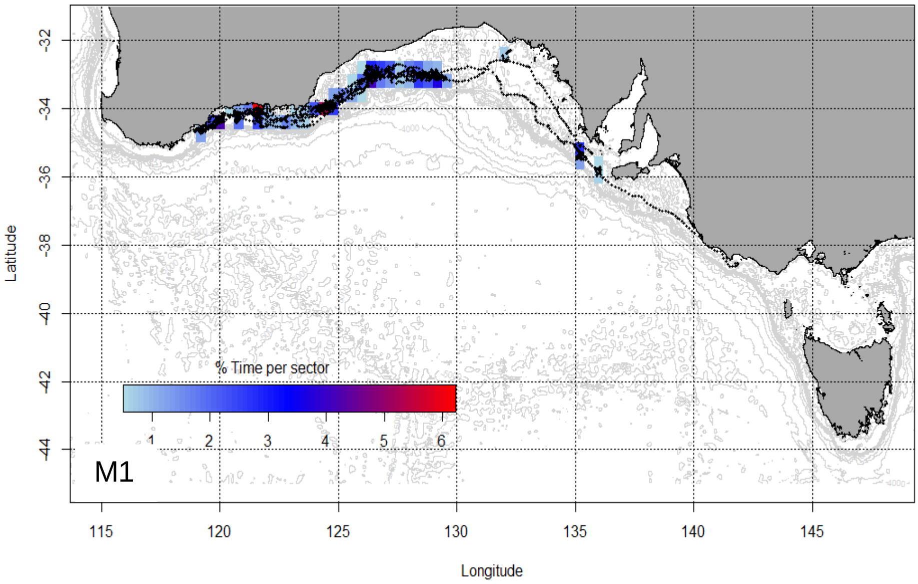
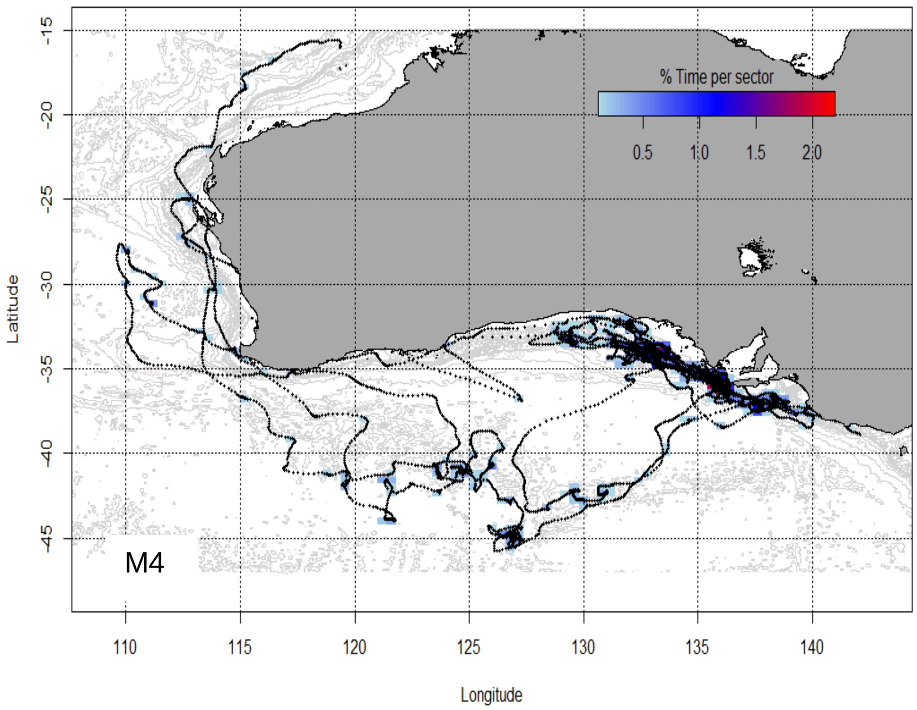
APPENDICES

Appendix 1. Time spent per area with state space model filtered tracks overlaid for each of the five long-term satellite tracks.





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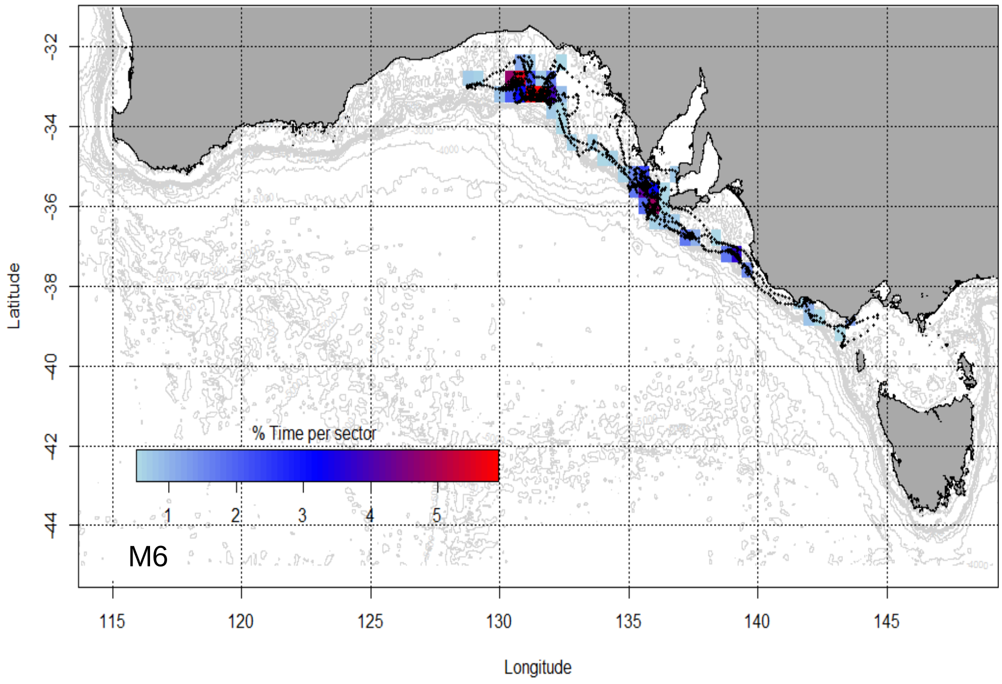

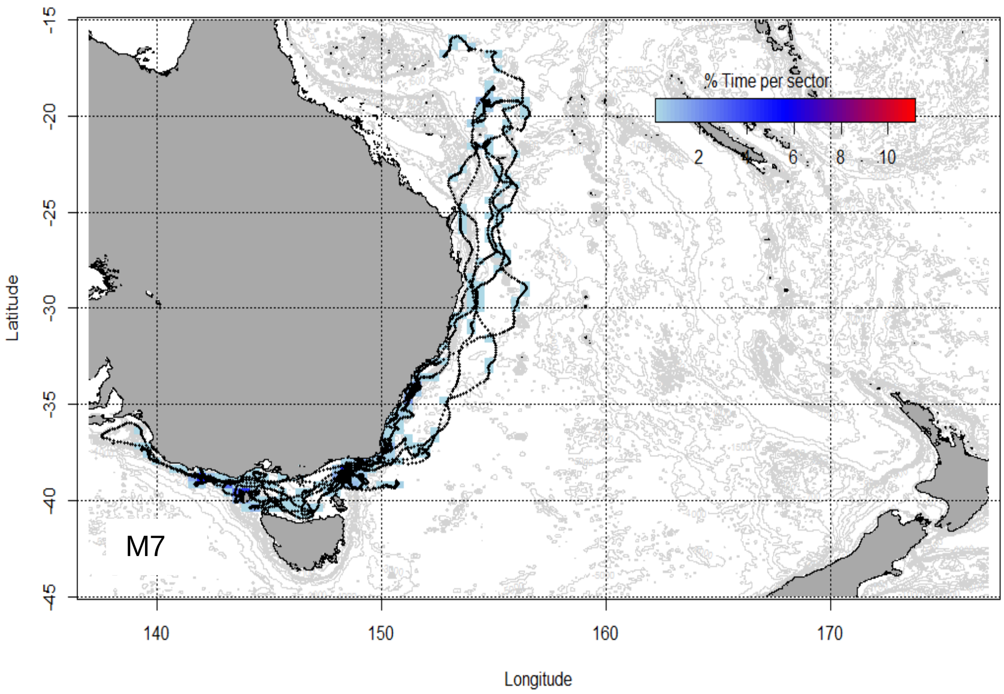

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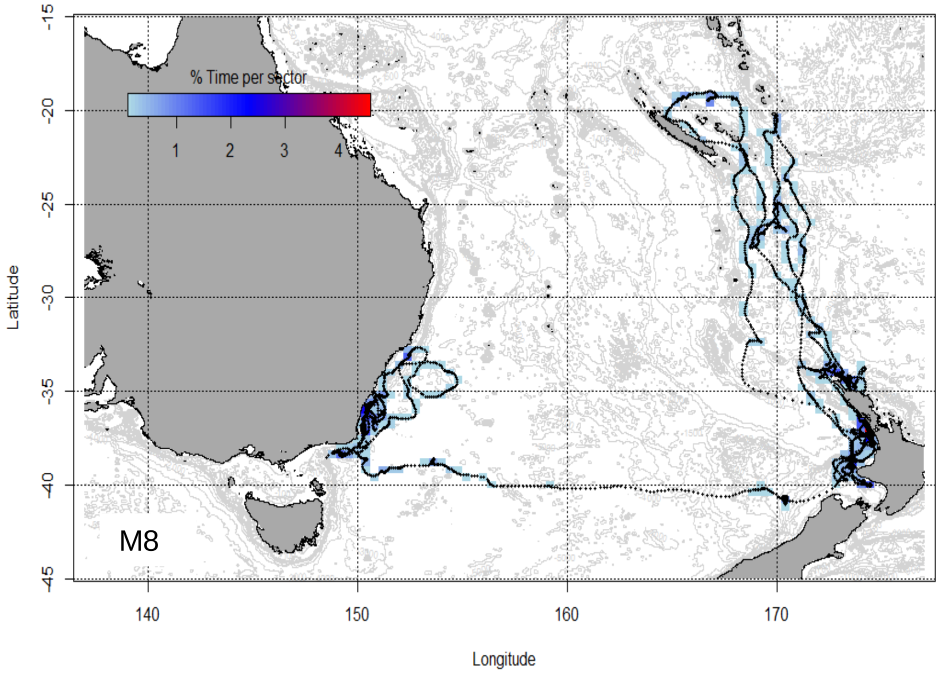


Appendix. 2. Bluewater Boats and Sportfishing. Issue 102. March-April 2014.

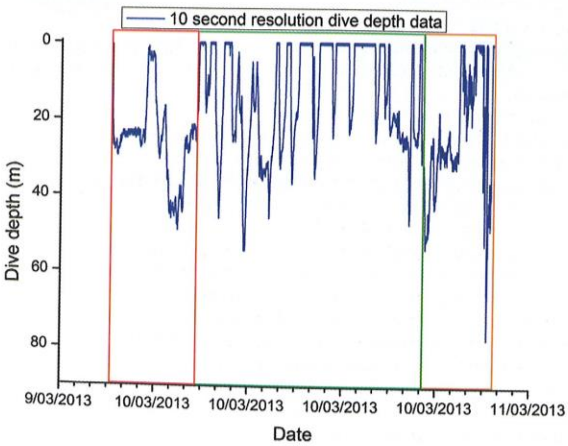
Shortfin mako research in Victoria

Vith the assistance of gamefishermen, cientists from the Southern Shark cology Group (SSEG) at the South ustralian Research and Development nstitute (SARDI) have released number of shortfin mako sharks vith satellite tags to study heir movements.

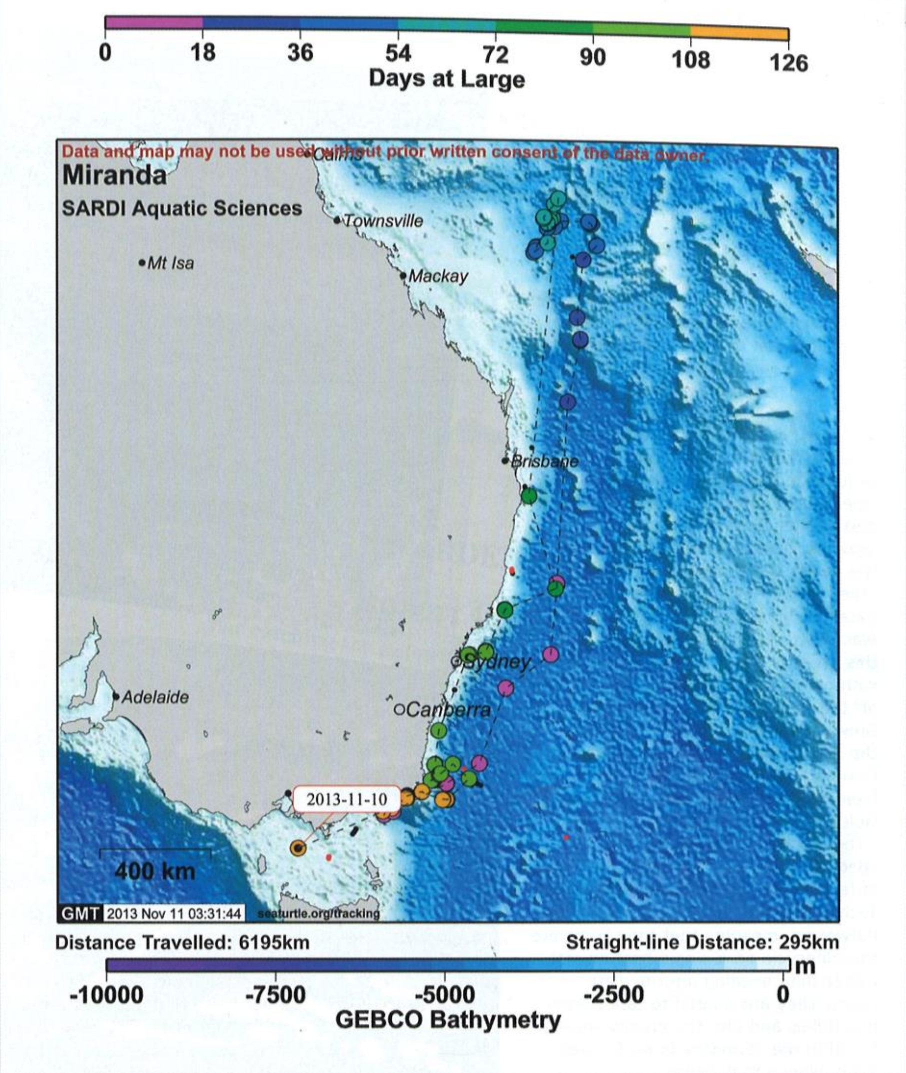
The project has been funded by the Victorian Government using recreational fishing licence fees. It seeks to answer questions such as how long shortfin makos remain in Victorian waters. It will also examine if makos in Victoria are vulnerable to fisheries in other regions, and whether they have links to other populations via their movements.

The data from the project will be used to estimate residence times of shortfin makos in the recreational fishery, as well as identify important habitats for this iconic gamefish, which is among the world's top ocean predators. To help measure the scale of connections between different regions, these findings will be combined with a study of global mako population genetics.

Last March, members of the SSEG spent two days targeting shortfin makos off Victoria's Mornington Peninsula. On the second day, a sub-adult female of around 130kg (250cm) was released with a satellite tag



This chart details the swimming depth of a mako shark over the day following its release with a satellite tag off Victoria. The mako had a relatively short recovery period following its initial capture and release (red box). The green boxed section shows cyclic periods of surface swimming and vertical dives. The end of the orange box shows its recapture the next morning, which involved a dive to 77.5m.



This satellite track shows the northern movement of a 187cm shortfin mako dubbed 'Miranda'. It was tagged in the Bass Canyons, Victoria in July 2013. Over the next 112 days it roamed north into the Coral Sea before returning along the continental shelf of NSW and back down to the Victorian border.

aboard gamefisherman Steve Taranto's vessel *HomeStrait*. Amazingly, it was recaptured less than a day later by another group of anglers. Unsure if the shark would survive, they decided to keep it and recover the satellite tag, which was later returned to the scientists. Having the actual tag recovered meant that the scientists could extract much more detailed data from the tag's computer than is normally available through the summarised reports uploaded to a satellite. The return of the valuable tag also meant it could be redeployed at a later date.

While the recapture was surprising for everyone involved, it has provided extremely useful high-resolution data on the post-release behaviour of this iconic gamefish. Following the recapture, SARDI produced a detailed project fact-sheet on mako satellite tagging. It outlines steps to follow should you capture a mako with a satellite tag. You can download it at *www.dpi.vic.gov.au/fisheries/science/satellite-tagging-of-shortfin-makos*

In late June, the SSEG again teamed up with local anglers and spent three days at sea to deploy satellite tags off Portland in south-western Victoria. From the SARDI vessel *Toro*, they tagged a female mako estimated at 270cm and weighing between 150 to 170kg. In July, two additional satellite tags were deployed on makos in the Bass canyons off Victoria. These sharks were estimated at 1.8 to 1.9m in length and were also released from *HomeStrait*. Since their release, the two makos have travelled across a wide variety of habitats, including the shelf, shelf slope and oceanic waters off New South Wales and Queensland. One of the sharks, dubbed 'Miranda', ventured north to the Coral Sea over winter, before returning down along the NSW coast in October.

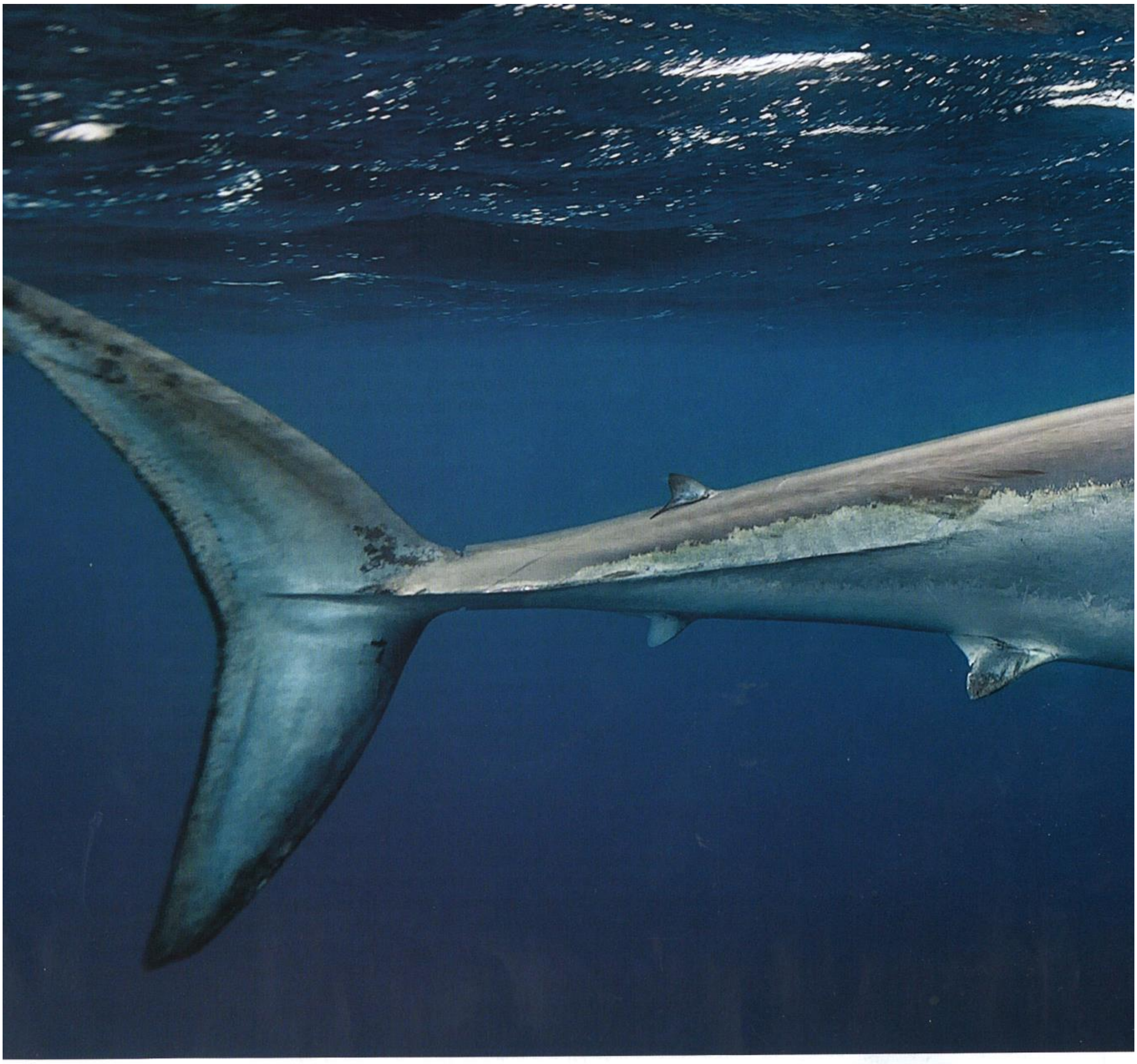
By November, the project had released eight shortfin makos with satellite tags. Four more were to be deployed before the end of 2013 to cover the seasonal and geographical extent of the fishery.

Data and images from the project will contribute to developing a voluntary Code of Practice that will incorporate a set of guidelines for the sustainable fishing, handling and release of line-caught pelagic sharks.

A summary of this project, as well as other related mako research, was detailed in *BlueWater* Issue 97. For more information about this project, visit *www.dpi.vic.gov.au/mako*. You can also follow the movements of tagged shortfin makos online at *www.wildlifetracking.org*.

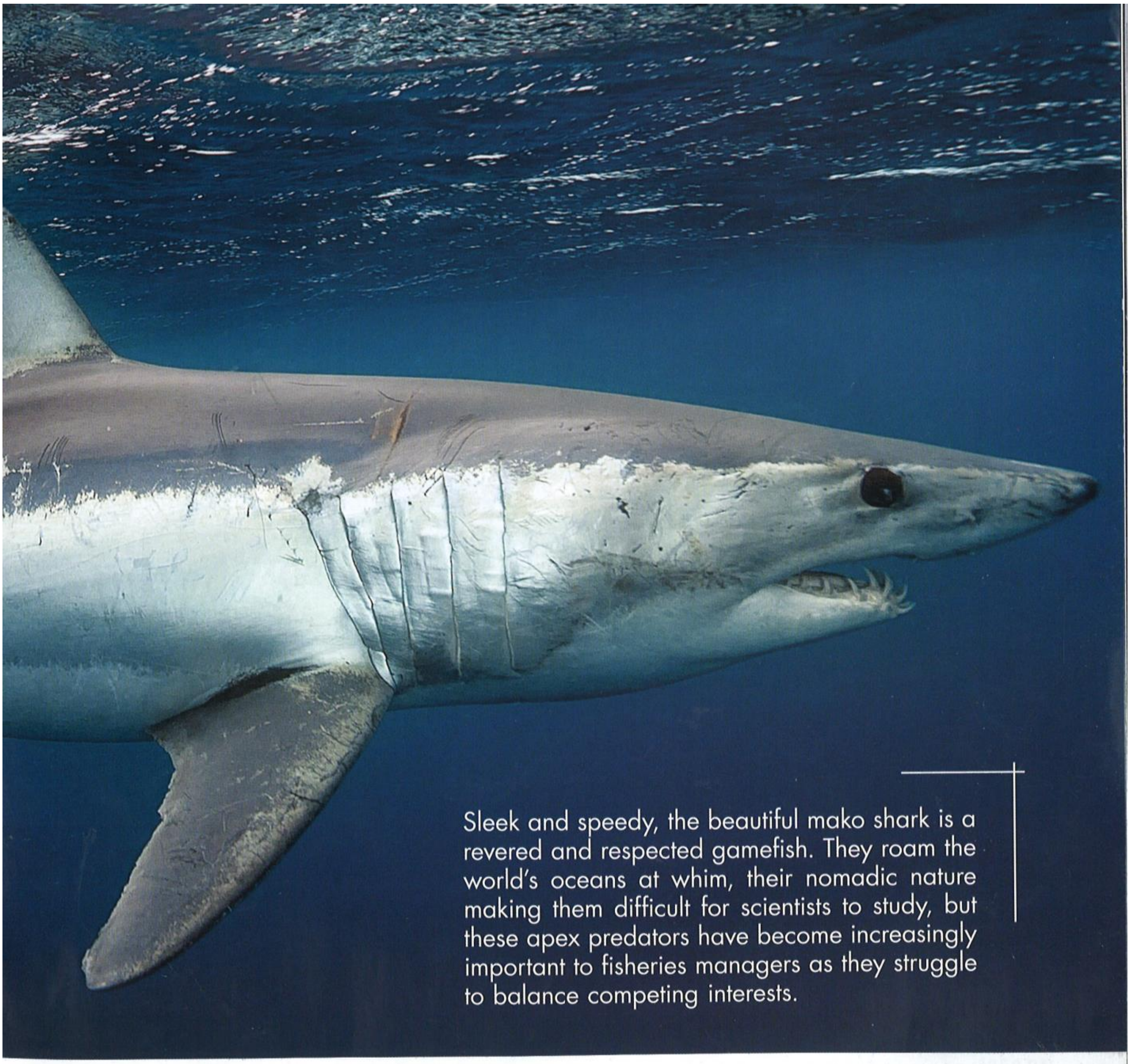
– Dr Paul Rogers

Appendix 3. Bluewater Boats and Sportfishing. Issue 97. May-June 2013.



AUTHORS: **DR PAUL ROGERS, DR JULIAN PEPPERELL, DR SHANNON CORRIGAN AND ROB FRENCH**
PHOTOGRAPHY: **SAM CAHIR; DOUG PERRINE; PAUL ROGERS; SHANE SANDERS**

The magnificent SHORTFIN MAKO – a new perspective



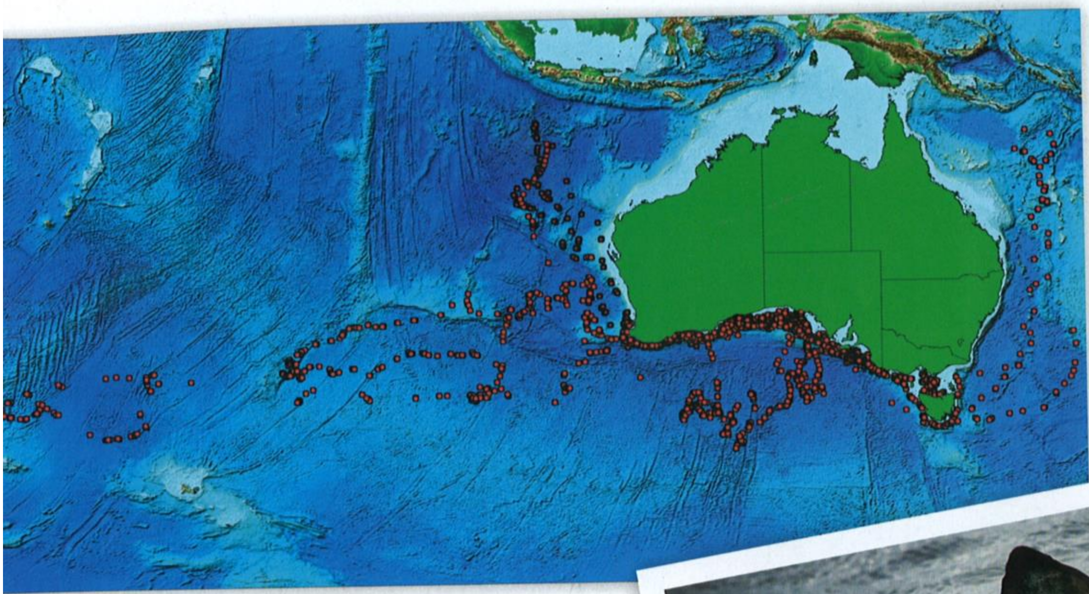
Staring into the inky blue water of the southwest Pacific Ocean, the fisherman's senses tell him he is not alone. Seconds later, a large shortfin mako glides into view. The shark's stiff body and huge tail effortlessly propel it around the boat.

A month later off Sydney, a reel screams and the big mako jumps six metres into the air, does two back-flips and breaks the line. She glides off into the gloom with two hooks in the corner of her mouth.

Nine months later off Madagascar, a tribesman gently steers his boat to the drop-off. Today he hopes for a shark as one kilogram of fins can fetch as much as US$100. The same mako glides into view and chews on his freshly painted outrigger canoe with a crunch of wet splinters. The man stumbles and nearly falls overboard. She sprays him with her tail and disappears into the blue depths.

Three months later and about 200 nautical miles to the south, the deckhand of a longline vessel hears the line on the winch drum start to crackle under some serious weight. The line cuts deep, slicing the surface like a hot knife. The weight on the line and lack of circling tells him this is not a tuna. He sees colour down deep – the blue back of a big mako. With the circle hook pinned in the corner of its mouth the mono leader is safe from those menacing, line-cutting teeth. The deckhand cuts the line and she swims off tired, with another hook and a metre of mono to add to her growing collection of 'man-made mouth bling'.

"This warm-blooded predator has evolved under conditions of very low natural mortality."



Makos are highly migratory, as demonstrated by these tracks recorded for 10 shortfin makos after they were agged with satellite transmitters in the Great Australian Bight.

She is starting to look like a battle-scarred blue warship, but she pushes on. That was the first fishing gear she had come across for some time and it could easily have ended her journey; a journey that has now spanned the equivalent of dozens of trips around our planet.

MAKO IS A MĀORI WORD

Mako is a Māori word for shark and is correctly pronounced 'Marko'. Ancestors of the shortfin mako (*Isurus oxyrinchus*) survived the oceans of this planet for more than 100 million years, but now, since industrial pelagic longline fishing began about 50 years ago, the modern version of the species has been heavily impacted in some of the Earth's northern seas and oceans.

This warm-blooded, highly mobile predator has evolved under conditions of very low natural mortality to be one of three oceanic top dogs. Female shortfin makos have to reach a large size before they become sexually mature and they only have small litters of pups. For this reason, their population sizes are naturally lower than those of the bony fish species that comprise much of their prey.

This article aims to provide an overview of the research into the biology and ecology of the shortfin mako in the past five years, as well as to provide summaries of national workshops on improving the sustainable management of the Australasian fisheries from which makos are taken.

hortfin makos travel at least 10,000km per year, and dive to depths of between 200 and 800m."

THE MAKO DEBATE

To give this research on shortfin makos in Australian waters a political context, from January 29, 2010, shortfin makos, longfin makos and porbeagle sharks were listed under the Environmental Protection Biodiversity and Conservation (EPBC) Act (1999), in response to listings in Appendix II of the Convention on Migratory Species. With this inclusion came protection measures for each of these species in Australian State (out to three nautical miles) and Commonwealth waters.

These restrictions were hotly contested by the Australian fishing community. This led to an unprecedented amendment to the EPBC Act that allowed recreational anglers to continue to target shortfin makos. Two points of contention at that time were that there was limited genetic, tagging or satellite tracking information available regarding the links between Australian shortfin mako populations and heavily exploited stocks in the northern hemisphere; and that there was limited information on the movement and mixing of the shortfin makos that support the Victorian recreational fishery and other regions of Australia.

This situation provided an immediate challenge for Australian shark research scientists who were directed to work together with fishery managers to address some of the key data gaps for this species.

MAKO MANAGEMENT FORUM

Australia's National Recreational Mako Shark Fishery Management Forum hosted in Melbourne in May 2010 by the Victorian Department for Primary Industries highlighted the need to ensure that recreational fishing for shortfin makos is sustainable, and to recognise the importance of pelagic sharks in recreational fisheries.

Participants, including recreational gamefishing representatives, expressed the need to promote and adopt 'world's best' fishing practices with respect to pelagic sharks. Participants also agreed to support the development of a 'desk-top' study to identify and propose a cost-effective way to address gaps in our knowledge about shortfin mako, and porbeagle and thresher sharks.

Other important issues that were raised included a need for further information on the biology and stock

status for these species; the level of fishing activity by all relevant sectors; current recreational fishing practices; and levels of post-release survival.

AUSTRALASIAN MAKO WORKSHOP

The Australasian Mako Workshop was funded by the Fisheries Research and Development Corporation (FRDC) to identify gaps in our knowledge of shortfin makos. The workshop was run in February 2012 in Hobart by Barry Bruce of the CSIRO.

Participants included scientists from the CSIRO and the Fisheries Departments of Tasmania, Victoria, New South Wales, Queensland, South Australia and Western Australia, as well as experts from New Zealand, the USA and the Secretariat of Pacific Community (SPC). Officials from the Australian Fisheries Management Authority and the Department of Environment also attended, as did representatives from the World Wide Fund for Nature and Humane Society International. The gamefishing sector was represented by Brett Cleary (now GFAA President) and President of the (Tasmanian) Southern Game Fishing Club, Mr John Brooker.

Large fish and squids were dominant in the diets."

An internationally collaborative genetic study by Dr Shannon Corrigan at the College of Charleston in South Carolina (formerly Flinders University) was a key presentation, and the continuation of this study was supported soon after through an FRDC tactical research grant.

Other issues identified to be of highest importance for shortfin makos included: the need for more movement information; a review of previous and current studies of their ageing; the identification of pupping grounds; the identification of recreational and commercial post-release mortality levels; and the improved collection and collation of catch information from both the recreational (non-club) and commercial sectors.

OCEANIC MIGRANTS

Satellite tagging conducted by the Southern Shark Ecology Group at the South Australian Research and Development Institute (SARDI) Aquatic Sciences Division has recently shown that Australian-managed waters are just one of many stop-off points for shortfin makos. Between 2008 and 2012, 14 shortfin makos have been tracked using dorsal-fin-mounted satellite tags. The predominantly juvenile sharks were up to 2.8m in total length and were tagged from commercial and recreational fishing vessels in the Great Australian Bight, off Port MacDonnell in South Australia, and more recently, off Portland in Victoria.

Tracking data for the first 10 tags has now been analysed in detail after providing 8326 GPS positions and 145,951km of tracking data. Estimates of distances travelled by individuals ranged from 1342km in 49 days to 25,550km in 551 days. Three of the tracks provided valuable new insights into the highly migratory nature of this species: one travelled 21,229km in 482 days, another 22,804km in 469 days, and the third 25,550km in 551 days. One shortfin mako was tagged with the assistance of anglers Dennis and Kerry Heineke aboard *Shaka-Zura* off Port MacDonnell. This shark migrated 25,550km – including a trans-oceanic movement across the Indian Ocean towards Madagascar, Africa.

Some shortfin makos, such as one we tagged from *Home Strait*, spent several months in shelf waters of the Great Australian Bight and travelled south to an area known as the Sub-Tropical Front. Prior to our study, it would have been hard to imagine that shortfin makos travel at least 10,000km per year, and even further if we account for the dives that they make to depths of between 200 and 800m.

The shortfin makos we tagged did not mix or migrate any further north than the Coral Sea and there was mited mixing between sharks off southern and those ff eastern Australia. This first major Australian satellite racking study of shortfin makos has gone a long way o uncovering the secret lives of this species. It has aught us a lot about their mobility and habitat use, and ighlighted that their highly migratory behaviour can otentially render them vulnerable to a range of target nd non-target fishery gear-types over their lifespan.

Our previous and current satellite tracking data an be viewed at: www.wildlifetracking.org/index.html?project_id=308

WHAT DO THEY EAT?

Our recent study of the diet of shortfin makos was based on the stomach contents of sharks collected during gamefishing competitions at Port MacDonnell in South Australia and Portland in Victoria between 2008 and 2010. Large fish and squids were dominant in he diets. These included barracouta, arrow squid and small tunas. A male short-beaked common dolphin was also identified in the stomach of one shark, and even a small juvenile mako was found in the stomach of a large adult caught in eastern Victoria. Consumption of squids was often indicated by the presence of their beaks in stomachs and sucker scarring on the skin surfaces around the gill slits and mouth.

This information is currently being combined with similar information for marine mammal, seabird, fish and shark species to assist with ecosystem-based fisheries management.

VICTORIAN INITIATIVES

Shortfin makos are an important recreational species in Australia, with the key centres of activity in New South Wales, Victoria, Tasmania and South Australia. Those shark researchers at SARDI recently obtained funding from the Victorian Department of Primary Industries Recreational Fishing Licence Trust Account to undertake a project titled *Innovative ways to ensure the future sustainability of the recreational fishery for shortfin makos in Victoria*. This projects aims to better understand the movement dynamics and residency of juvenile and adult shortfin makos that form a valuable component of the Victorian recreational fishery.

It is not known how long shortfin makos remain in Victorian waters, or whether they are vulnerable to fishing in other regions. The project also aims to provide practical information, including a Code of Practice for sustainable handling and release practices for pelagic sharks that will be developed with dedicated recreational anglers during satellite tagging trips.

This project forms part of a national approach by shark scientists in South Australia, Tasmania and New South Wales to develop regionally important research projects on shortfin mako recreational fisheries in Australia. More broadly, the project will have flow-on benefits to local businesses and the wider community whose seasonal prosperity is partially reliant on having sustainable recreational fisheries for large pelagic fishes and sharks.

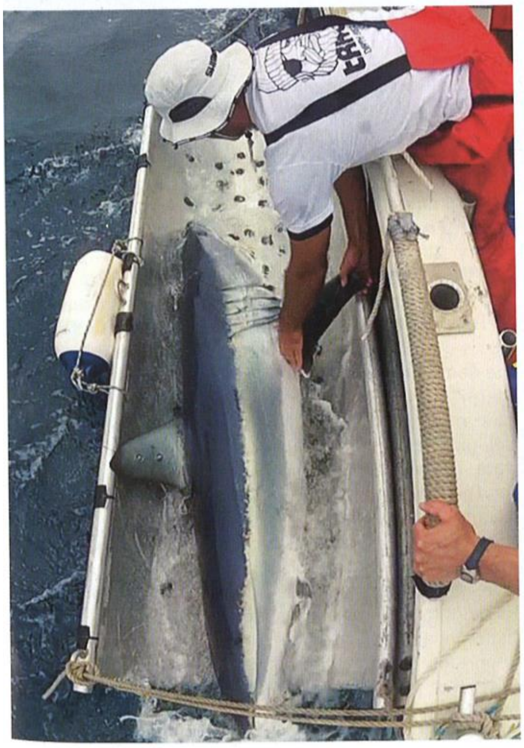
In late December 2012, four shortfin makos ranging in sizes from 1.2 to 2.6m were satellite tagged off Portland with the assistance of Shane Sanders and Brody Carter aboard *Baitwaster* from the Portland Sport and Gamefishing Club. The sharks were hooked on gamefishing tackle and then transferred across to the research vessel for tagging. Four more tags were scheduled to be deployed off Bass Strait and Warrnambool in the summer and autumn of 2013. If you think you could assist with this project, please contact Paul Rogers on: 0428 113 236 or +61 (08) 8207 5487, or send him an email at: paul.rogers@sa.gov.au. Paul is also keen to visit Victorian fishing clubs to talk about shortfin mako research this season.

"SPAT tags are designed to determine if sharks die after being caught and released."

MIXING AND BREEDING

It is unknown how much mixing and breeding occurs between shortfin makos during their long migrations. Currently we are combining our satellite tagging data with genetic profiles of individual shortfin makos to provide information to governments and regional fishery management authorities in the Pacific and Indo-Pacific regions about the size of area to be considered to better manage fishing and bycatch of shortfin makos.

This work is being conducted by the aforementioned Dr Shannon Corrigan at the College of Charleston in South Carolina, in collaboration with National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries) in California.



Left: A mako is held in a cradle beside *Baitwaster* while scientists prepare to release it with a satellite transmitter.

Below: Scientists drill holes in a mako's dorsal fin to bolt-on a transmitter that will beam data to orbiting satellites whenever the device's aerial is above the water.

"There are few reliable ways to estimate how many shortfin makos inhabit our oceans."

The project is using tissue samples collected from commercial fisheries and at gamefishing competitions over the past two decades by Dr Julian Pepperell and his team; Lindsay Marshall, WA Fisheries, CSIRO; and researchers in Europe, South Africa, Mexico, New Zealand, Japan, the USA and South America.

A number of dedicated gamefishermen have also taken time to collect samples, including Greg Barea from Shellharbour and Ashley Dance from Warrnambool. This study, in particular the analysis of Australian shortfin makos, was supported during the Australasian Mako Workshop and is currently funded by the Australian Government via a FRDC Tactical Research Fund grant titled: *Shark Futures – Using molecular techniques to improve the ecologically sustainable fisheries management of shortfin makos* (Isurus oxyrinchus) *in the Australasian region*.

So far, Shannon's work shows that the Australian Exclusive Economic Zone (EEZ) seems to have one population of shortfin makos that is likely part of a larger southwestern Pacific stock that shares connections with New Zealand. Some mixing may also occur across the Indian Ocean with Africa, Mauritius, etc, however, further analysis is required to resolve this question. So far there is minimal evidence of cross-equatorial mixing, according to the Australasian component of the genetic study, however, this too will be further investigated in the near future.

Our satellite tagging data agrees, in part, with the genetics, showing that when makos from the south reach the higher tropical latitudes they tend to turn around and head back to the south again. Shannon is currently filling in the final gaps in her sampling in the Indian Ocean off Western Australia and aims to complete the project in June 2013.

POST-RELEASE MORTALITY

PhD student Robert French of the Fisheries, Aquaculture and Coasts Centre at the University of Tasmania's Institute for Marine and Antarctic Studies plans to tag 30 shortfin makos with new survival pop-up archival tags (SPAT). This will include 10 tags in each of three States: Tasmania, Victoria and New South Wales. The tags are specifically designed to determine if sharks die or survive after they have been caught and released.

Before release, these SPATs take a blood sample that's used to look for signs of physiological stress to explain how much the shark exerted itself before it was landed, and why a shark has not survived if it is found to die after release.

The results will be used to discover which fishing gears and practices are more beneficial for the survival of the released sharks, and will be compiled into an educational 'best practices' tool for gamefishermen. This project is supported by both the Fishwise Tasmanian Recreational Fishing Trust and the project led by Paul – funded by a Victorian Recreational Fishing Grant.

In 2012, Rob deployed 12 SPATs off Sydney and Shellharbour in NSW, Eagle Hawk Neck in Tasmania and Port MacDonnell in South Australia with the help of recreational anglers. A video detailing Rob's research project can be found at: www.youtube.com/watch?v=XisKJKJi9fI

To complement his work on stress and post-release survival, Rob is also conducting an angler survey to learn more about Australian mako anglers, and how beliefs and practices vary between States. This study is a great opportunity for anglers to give their personal opinions on fisheries research and management.

Surveys like this are a vital tool for the communication of views and needs between game anglers and researchers. As a final component, Rob is also collecting tissue samples and analysing stable isotopes to compare findings to diet studies that have used other methods. Rob has been working closely with the gamefishing community, and if you think you could assist with some of the satellite tag deployments, you can call him on 0414 386 474, or send him an email at: Robert.French@utas.edu.au

HOW MANY MAKOS ARE THERE?

The most common question we get asked as researchers is "How many shortfin makos are out there?". Of course this is a great question, and it is sometimes followed by the same person answering with, "There's heaps, isn't there?". There are very few reliable ways to estimate how many shortfin makos or other highly migratory pelagic sharks inhabit our oceans, and there is minimal data on catch, fishing effort and bycatch available for this species in High Seas jurisdictions adjacent to Australian waters.

We currently do not have modern estimates of relative or absolute numbers of shortfin makos in Australian waters; however, fisheries scientists are currently seeking funding to assess their abundance and that of other highly migratory shark species. These are all the more important, as potential threats to our shark stocks across their vast geographical range require us to continue to work together to achieve sustainable management practices for these magnificent pelagic fish.

Appendix 4. VR Fish Newsletter update August 2013. Provided to Bass St GFC and Warrnambool Offshore GFC.

Your fishing licence fees at work

Mako Research in Victorian shelf waters

The Victorian Government is using recreational fishing license fees to help South Australian fisheries scientists from SARDI Aquatic Sciences deploy satellite tags on shortfin makos with the assistance of recreational and game fishers to answer several important research questions:

- How long do they remain in Victorian waters?
- Are they linked to other mako populations via their movements?
- Are makos in Victoria vulnerable to fisheries in other regions?

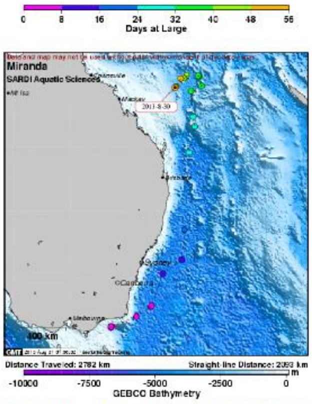
The data from this project will be used to estimate residence times of makos in the recreational fishery and identify important habitats for this iconic sport-fishing species and top predator in the world's oceans. Findings will also be combined with those of a directly related study of global mako population genetics to help describe the scale of connections between different regions.

Project update

In December 2012, the researchers spent a week targeting makos to deploy satellite tags in shelf waters off Portland in SW Victoria. Small juvenile and adult shortfin makos were reportedly abundant in this region between December and February. They teamed up with local recreational/game fishers Shane Sanders, and Brodie Carter who have considerable expertise in tag and release of makos. The group transferred sharks between the research and recreational vessels and successfully deployed four satellite tags on makos that included two small juveniles of 120 and 130 cm, a mature sized male (200 cm), and a sub-adult female of 260 cm. This year in June, they returned to Portland and managed to satellite tag the largest shark so far, a 2.7 m female that travelled straight to several seal colonies before heading into the middle of the Great Australian Bight. In July, two additional satellite tags were deployed on makos of 1.8-1.9 m in the Bass canyons during two nights on Steve Toranto's vessel *Home Strait*. These two sharks are currently in oceanic waters of the Coral Sea and the area south of Sydney.

The project has largely used circle hooks and is trying to encourage fishers to adopt the same practice, as they have been shown in previous studies to improve survival rates. Data and images from the project will contribute to developing a voluntary Code of Practice that will incorporate a set of guidelines for the sustainable fishing, handling and release of line caught pelagic sharks.

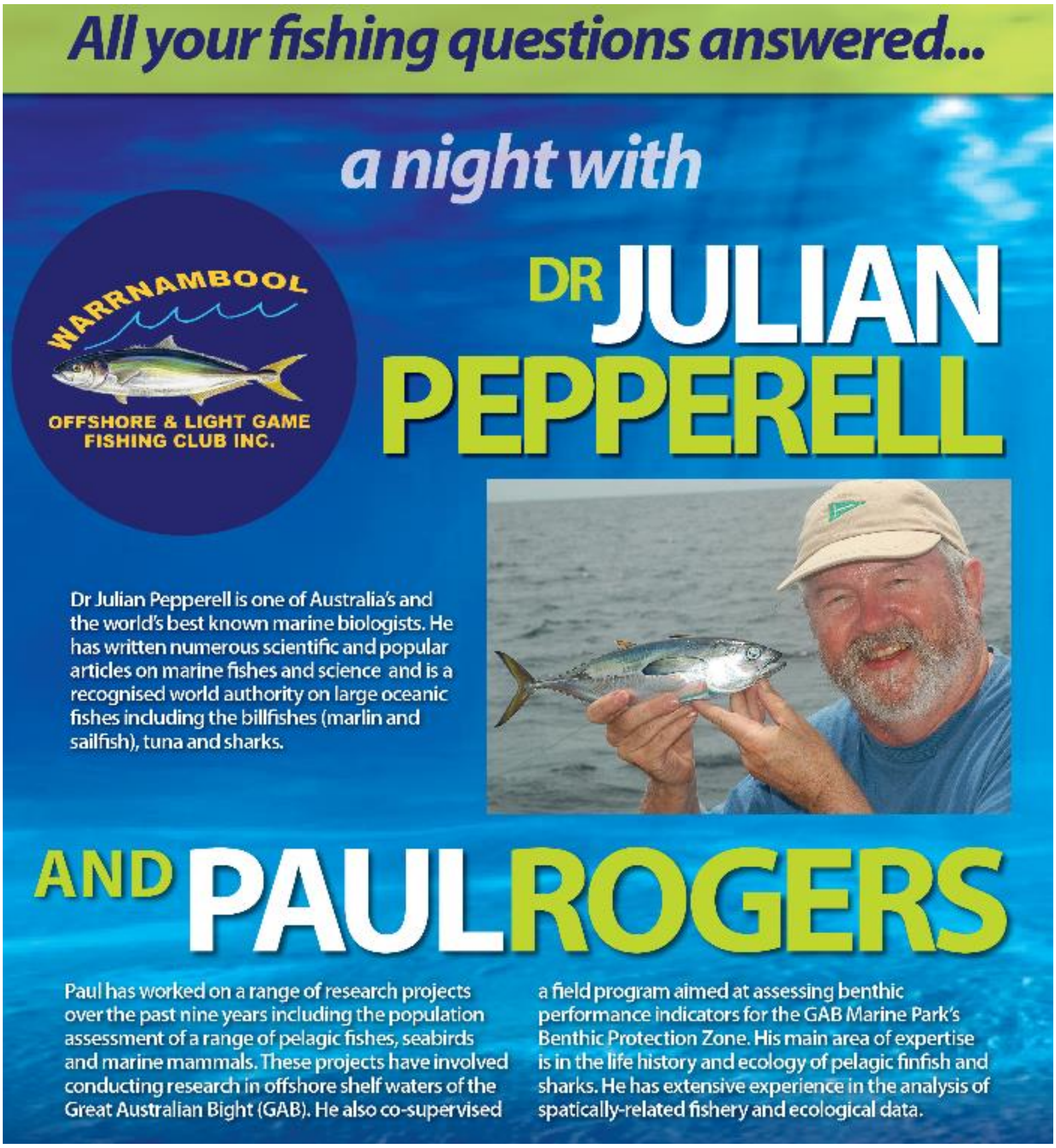
You can follow the movements of tagged makos online at www.wildlifetracking.org or visit www.dpi.vic.gov.au/mako for more information about this project. A summary of the project and related mako research is provided in Bluewater Boats and Sportfishing, Issue 97.



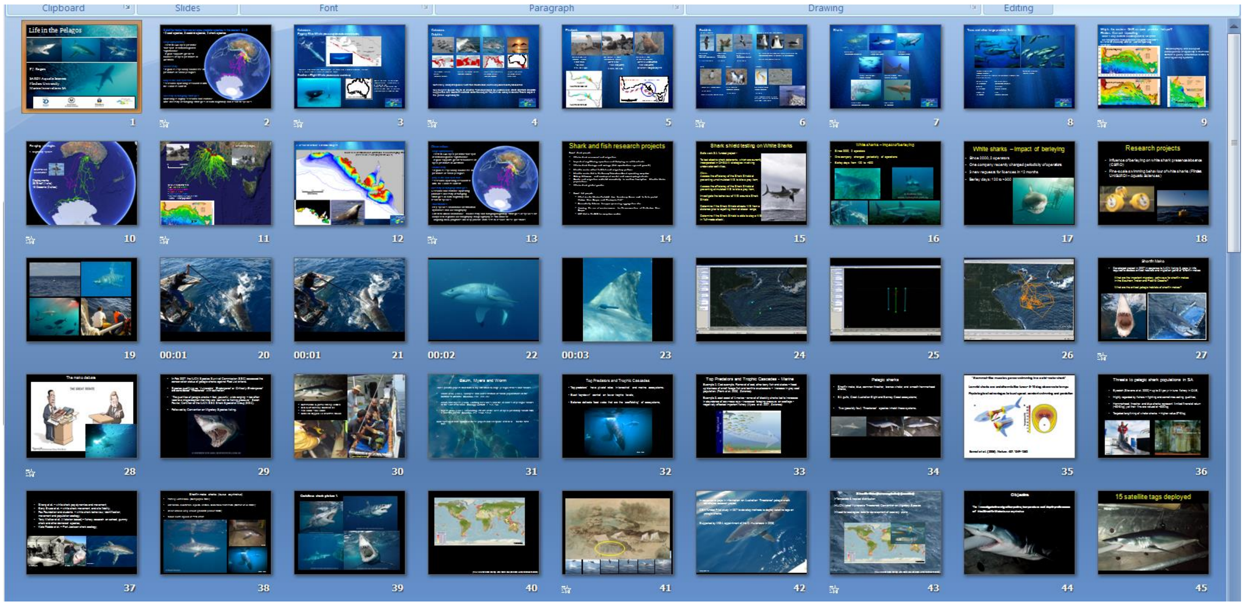
Map showing the track of a mako that was satellite tagged from FV *Bass Strait* near the canyons in eastern Bass Strait in winter 2013.

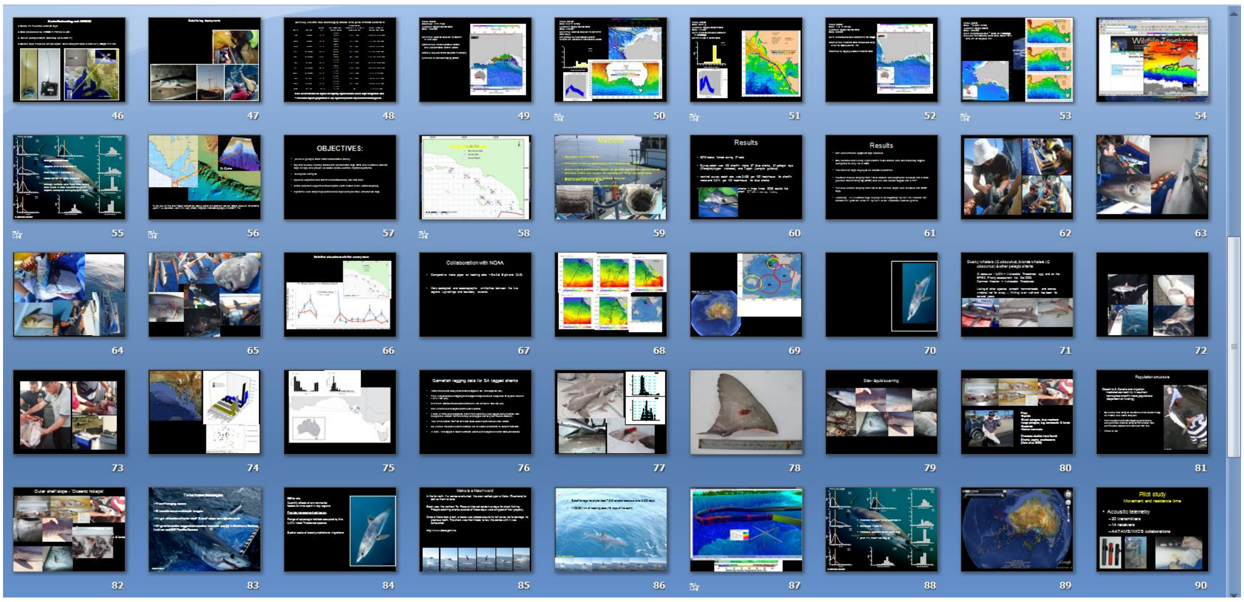
Researchers attaching a satellite tag to a mako at Portland in December 2012.

Appendix 5. Public presentation flyer at Deakin University, Warrnambool, Victoria.



Appendix 6. Power-point presentation given by PI at public presentation at Deakin University, Warrnambool, Victoria.





Appendix 7. VICDPI Project Fact Sheet.

Your fishing licence fees at work

Your fishing licence fees at work

Satellite tagging of shortfin makos

The Victorian Government is using recreational fishing licence fees to help South Australian fisheries scientists tag shortfin mako sharks and answer several important research questions:

- how long do they remain in Victorian waters?
- are they linked to other mako populations via their movements?
- are makos in Victoria vulnerable to fisheries in other regions?

In December 2012, four makos ranging in length from 1.2 to 2.6 metres were satellite tagged off Portland with the assistance of volunteer anglers and the Portland Sport and Gamefishing Club.

The sharks were transferred between vessels using a purpose-built sling, which allowed the capture of makos using conventional gamefishing tackle.

Four additional satellite tags will be deployed between Warrnambool and Bass Strait during 2013.

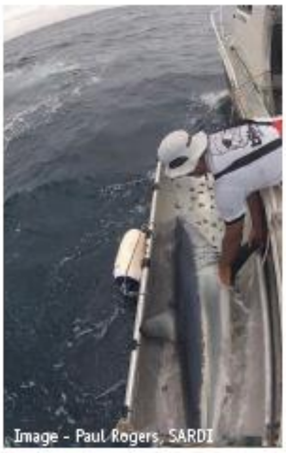
The data from this project will be used to estimate residency of shortfin makos in the fishery and identify important habitats for this iconic shark species.

Data and images will also contribute to a Code of Practice for the sustainable handling and release of pelagic sharks.

You can follow the movements of tagged makos online at www.wildlifetracking.org or visit www.dpi.vic.gov.au/mako for more information about this project.

For more information about the Recreational Fishing Grants Program visit www.dpi.vic.gov.au/fishinggrants

Peter Walsh, Minister for Agriculture (including Fisheries)



State Government Victoria

DEPARTMENT OF PRIMARY INDUSTRIES | fisheries

Appendix 8. Fact-sheet: Satellite tagging of shortfin makos. VicDPI website. 18 March, 2013.

Background Information

The Southern Shark Ecology Group from SARDI Aquatic Sciences in South Australia is currently using two types of satellite tags to answer the following research questions: 1) how long do shortfin makos remain in Victorian waters? 2) are they linked to other shortfin mako populations via their movements?, 3) are shortfin makos in Victoria vulnerable to fisheries in other regions?

This project is funded via the Victorian DPI Recreational Fishing Licence Trust Account Large Grants program and was supported by VR Fish and several gamefishing clubs in Victoria. We recently deployed four satellite tags on shortfin makos off Portland in SW Victoria. Three additional satellite tags will be deployed in 2013. Prior to this project, other satellite tags were deployed in the Central Great Australian Bight and off SE South Australia to investigate the migration patterns and critical habitats of this species.

Satellite and conventional gamefish tagging data has shown that there is mixing of the shortfin mako population between the Southern, Indian and Pacific Oceans. In response to this we have designed this fact-sheet to inform recreational and gamefishing clubs around Australia about the project, the types of tags we are using, and options to follow in the rare case that a satellite tagged shortfin mako is captured.

<u>Important questions fishers may have regarding this study include:</u>

Q1. What do the satellite tags deployed on the shortfin makos look like?

In Victoria, two types of tags are being deployed (see image 1 on page 3). The first type is a slim black SIRTRACK™ tag. These small tags (~40 mm long and 37 g) are fixed to the trailing edge of the first dorsal fin. They are being used to tag shortfin makos of 1-2 m. The second larger tag type is circular and cast in clear resin. These larger tags are attached to the middle of the first dorsal fin. They are being used on shortfin makos >2 m. They have a blue Wildlife Computers™ label embedded inside them with the contact details for the manufacturer. These larger tags store dive and temperature information, and therefore it is important to the study that they are returned if the shark is captured and killed.

**Four other tag types have been used in previous projects on shortfin makos off southern Australia. Therefore, it is possible that fishers may also capture a shortfin mako that has retained one of these tags. We have also added images of these tag types for reference (See image 2 on page 4).

Q2. What should we do if we catch a shortfin mako that has any type of satellite tag attached to it? Ultimately, it is the choice of the fisher as to whether they wish to follow the following options during two different capture scenarios:

Capture Scenario 1*:* A shortfin mako is hooked and the fisher identifies that the shark has a satellite tag attached to its dorsal fin. The shark is jaw hooked, is in lively, healthy condition and has no visible physical injuries other than the hook wound in the corner of its mouth. The fisher makes the decision to release the shark.

Preferred option*:* The leader is cut as close as possible to the mouth of the shark, or the hook is removed with the shark in the water (if the decision is made that it can be done without compromising the safety of anyone on-board i.e. adequate equipment is on-board, e.g. wiring gloves, wire cutters and bolt-cutters). A clear photo of the shark and tag is taken. The fisher can then contact Dr Paul Rogers to report the location and details of the capture on 0400 536150, 08 82075487; email: paul.rogers@sa.gov.au. If PR is not available please contact Mr Paul Irvine on 0404 837211.

Capture Scenario 2: A shortfin mako is hooked and the fisher identifies that the shark has a satellite tag attached to the dorsal fin. The shark is hooked in the gut or throat, is bleeding from the mouth and/or gills and the angler makes the decision to land it.

Preferred option*:* The fisher contacts Dr Paul Rogers as soon as possible on 0400 536150, (08) 82075487 (email: paul.rogers@sa.gov.au) to discuss the capture and recovery of the satellite tag. If PR is not available please contact Mr Paul Irvine on 0404 837211. If the fisher is within phone range and enough people are on-board to manage the situation safely, this can be done while the shortfin mako is on the leader.

Q3. Is it illegal to capture and kill a shortfin mako that has a satellite tag?

Answer: No, it is currently legal for recreational fishers to target, capture and take shortfin makos regardless of whether they have been satellite tagged. However, by reporting the capture of a satellite tagged shortfin mako, the fisher is providing valuable information for our scientific study. If the tag is recovered it can be used to tag another shark.

Q4. Can I follow the tagged shortfin makos online?

Yes, the satellite tagged makos can be followed at:
http://www.wildlifetracking.org/index.shtml?project_id=308

Q5. Where can I get an update about shortfin mako research in Australia? An article about recent shortfin mako research is to be published in the next edition of Bluewater Boats and Sportfishing.

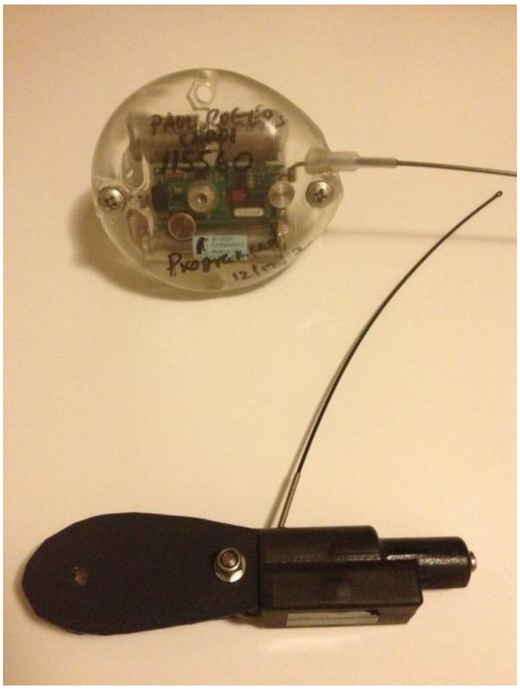


Image 1. Satellite tags that are currently being used to track shortfin makos in Victorian waters.

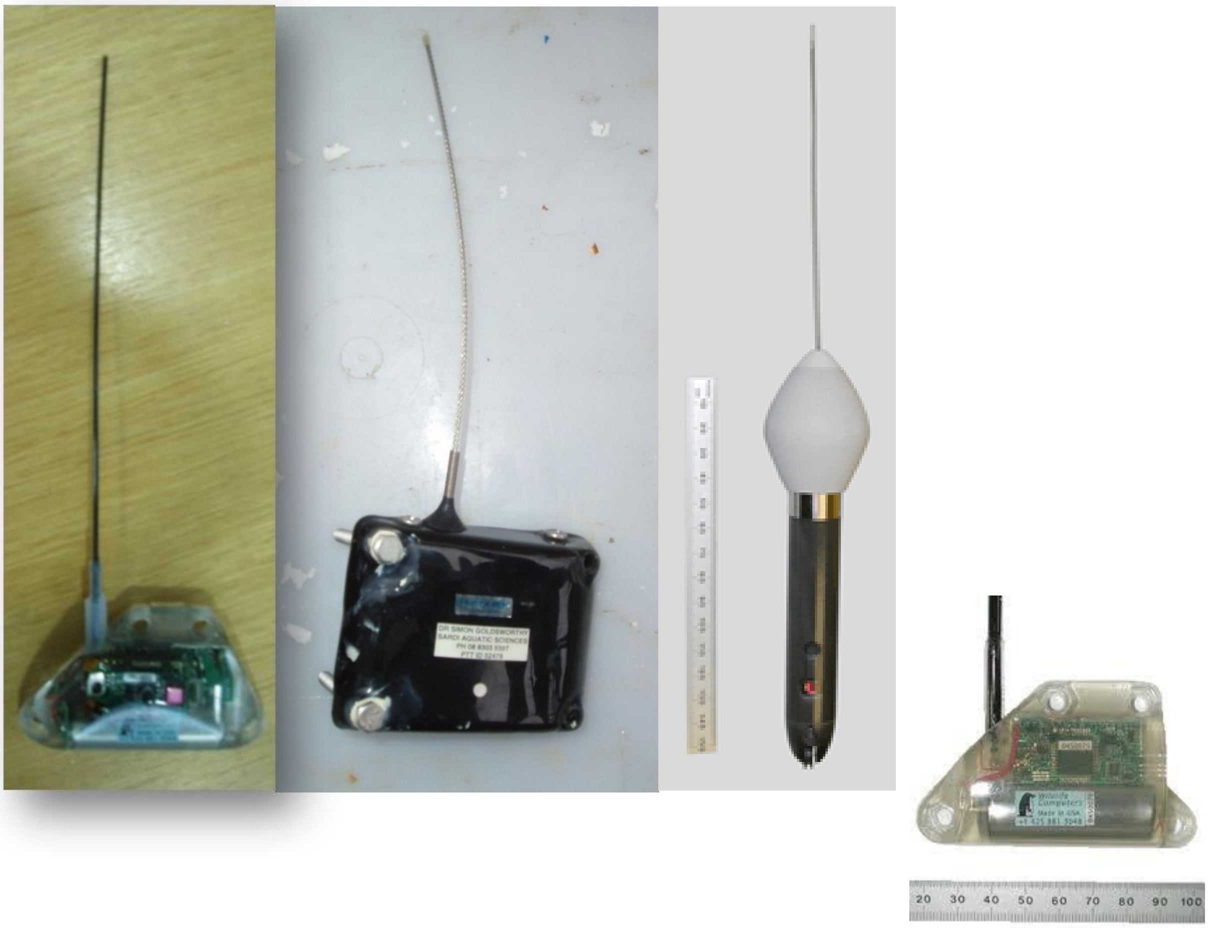


Image 2. Satellite tags that have been used previously to track shortfin makos off southern Australia