National Environmental Research Program

MARINE BIODIVERSITY hub

Determining the size and trend of the west coast white shark population

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Theme 2 - Supporting management of marine biodiversity

Project 2.5 - White shark population and abundance trends

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PROJECT SUMMARY

A combination of aerial surveys, integrating local knowledge, satellite tagging of adult white sharks and opportunistic tagging of juveniles failed to identify discrete white shark nursery areas in either South Australian or Western Australian waters.

It is most likely that white sharks in Australia's western population utilise nursery 'regions' (broad geographic areas of the continental shelf and coast) rather than discrete nursery 'areas' as found in eastern Australia. Such nursery regions are common in other populations of white sharks around the world.

It is unlikely that further effort put into searching for suitable and reliable aggregations of small juveniles will be cost-effective across the remote areas of southern Australia unless locations are reliably reported by the fishing industry or found serendipitously through other project activities (including those by other researcher agencies).

The lack of identified discrete nursery areas means that the half-sibling Close-kin Mark-Recapture (CKMR) approach as used in eastern Australia to estimate adult and total population size, cannot be directly applied to the western population because small juveniles are not readily available. However, an emerging option is to look for relationship patterns other than half-sibling pairs that can also be informative for estimating population size – for example 'offspring-father pairs' – a variant of the parent-offspring-pair CKMR analyses used for southern blue-fin tuna. This is likely to suit samples available in the western population of white sharks given the number of (large) juveniles and the larger number of adult males (as opposed to adult females) in the samples amassed to date and which are projected to increase in number. These analyses are a high priority for future work as part of the NESP study.

The project secured over 250 individual tissue samples (up to December 2015) from white sharks and established an on-going sampling strategy to increase this number. At the time of writing this report, the number of tissue samples had reached 400 individual samples. These comprise mainly large juveniles (> 3.0 m) and adults. This number of samples will increase over the course of the follow-on NESP project.

Additional samples from the coordinated tissue sampling program developed during this project will continue to improve the prospects of CKMR analyses undertaken during on-going work. Further samples are expected from SARDI and Flinders University tagging programs (SA), future tagging work by WA Fisheries and any sharks taken as part of the WA Imminent Threat Policy. Opportunistic sampling of white shark bycatch (commercial fisheries) is undertaken as available by State Agencies and provided to this tissue sampling base.

An emerging priority area for further work is to improve estimates of age and growth in white sharks. Techniques such as estimating growth parameters from stereo BRUV monitoring, DNA-aging and radio-bomb carbon dating of vertebrae are possible options. Chemical marking of vertebrae (when tagging) using either oxytetracycline

or calcein is a good option for juvenile white sharks in eastern Australia where the likelihood of capture is higher (e.g. from shark control programs in NSW and Qld) and this is recommended as a standard practice.

Electronic tagging to assess movements and survival remains a valuable tool. However, for the west, long-term acoustic tagging requires additional acoustic receiver deployments (for example as curtains either side of the GAB). Currently such infrastructure across southern Australia is not sufficient to provide adequate results. Long-term acoustic tagging is more effective when tags are internally placed which in most tagging operations on larger sharks is not the case – particularly in South Australia.

1. PROJECT ACHIEVEMENTS/OUTPUTS

This project provides vital prerequisite information required to identify options for estimating white shark abundance and trends in Australia's western population. It is designed to guide a follow-up project within the National Environmental Science Program (NESP). The current project does not, by itself, provide such an estimate of population size or trends for the west and doing so was specifically identified as being out of the project's scope, but its goal is to identify a strategy for doing so.

The project's objectives were to see if nursery areas for white sharks could be identified in waters west of Bass Strait, to secure existing tissue samples and to establish an ongoing shark tissue sampling program for future Close-Kin Mark-Recapture based estimates of population size.

Finding discrete nursery areas would allow techniques developed in eastern Australia for estimating population size of white sharks to be directly applied to the western population. A lack of defined nursery areas would require a modified approach to achieve this goal.

1.1 Key habitat areas identified for white sharks in southern and western Australian waters

A combination of coastal aerial surveys, targeted as well as opportunistic electronic tagging of adults and juvenile white sharks, combined with accumulated fishers' knowledge continue to point to the western Great Australian Bight (GAB) and the Encounter Bay region of southeast South Australia as key areas for juvenile white sharks. However, the project found no evidence that nursery areas similar to the discrete geographically restricted Port Stephens nursery area in NSW occur west of Bass Strait. Nursery habitat for white sharks in other regions of the world cover broad areas of coast (100s of kilometres) similar to the geographic extent of the south-eastern Victorian nursery area. The areas of the western GAB and Encounter Bay are characterised by a broad continental shelf and this probably provides widespread habitat for juvenile sharks – hence the low frequency of encounter relative to the Port Stephens region. This indicates that directly applying the same technique (i.e. specifically using juvenile half-sibling pairs to identify adult population size and combining these results with estimates of juvenile survival from electronic tagging to populate a demographic model) is not currently feasible as a tool to estimate total population size for the western population and a modified approach is required (see below).

1.2 Strategy to apply population assessment techniques used in eastern Australia established for the western white shark population.

The lower accessibility to juvenile white sharks in the western population, compared to the east is an important finding that determines the future strategy for applying Close-Kin Mark-Recapture (CKMR) techniques for estimating population size for Australia's western white shark population under NESP. CKMR can be applied to any life history stage but the outcomes have different historical timeframes. CKMR analyses of small juveniles (< 3.0 m) provides an estimate of the number of adults currently in the population. CKMR of larger and older individuals (3.0-5.0+ m) may span more than one adult generation and provide an average population estimate across those generations. Without ready access to small juveniles, a strategy to estimate the adult population size of the western population will require analyses of sharks > 3.0 m which can be sampled in far greater numbers in the west than they can in the eastern population. However, this strategy increases the importance of validating age-and growth parameters for these sizes. On a positive side, a change in analysis strategy from small juveniles to larger sharks simplifies the logistics and cost involved as tissue samples can be obtained during projects run independently by partner agencies as opposed to time consuming and expensive field work in remote areas that would have, at best, the ability to sample and tag only low numbers of small juveniles.

There are other options for estimating population size using CKMR and these will be explored in the subsequent NESP project but it will depend on the nature and number of tissue samples that can be collected (including the available size-age of the sharks, their life history status [adult, sub-adult or juvenile], their sex and the geographic distribution of sampling). An emerging option is to look for relationship patterns other than half-sibling pairs that can also be informative for estimating population size – for example 'offspring-father pairs'. The latter are likely to suit samples available in the western population given the number of (large) juveniles and the larger number of adult males (as opposed to adult females) in the samples amassed to date. In short, the larger the number of samples available across the range of shark sizes, the more varied the options will be.

1.3 Initial genome assembly for western population of white sharks established to support population analyses

Samples from the western population have been sequenced and initial analyses have identified related sharks. This indicates that techniques for identifying related pairs of sharks developed in eastern Australia can be applied to the western population, although what relationship factor will be used for the west will depend specifically on what samples are available (see above).

1.4 Analyses of long term (14 year) correlations between white shark distribution and movement in southern Australia

A 14-year data set was used to determine the pattern of use of the Neptune Islands by white sharks (Bruce and Bradford 2015). Analyses revealed a significant difference between males and females indicating sex-specific patterns of movement in southern Australian waters and likely different predatory strategies between sexes. Interannual variability in the relative abundance of white sharks suggest broad-scale environmental processes may drive local abundance. This has potential ramifications for understanding sightings and encounter variability between years. Understanding these patterns will be the focus of future project work.

2. BACKGROUND

Considerable progress has been achieved across several actions in the National Recovery Plan for white sharks with respect to improvements in understanding population structure, various biological parameters, movements, areas of key importance to the species and threats in Australian waters. However, a fundamental impediment to assess the efficacy of both the original (2002) recovery plan and the revised plan, released in 2013, has been the lack of reliable data from which to assess population size and trends. Recent public and political debate, particularly in Western Australia and New South Wales, has highlighted an urgent need to assess population status throughout Australian waters. Doing so on a national scale will help determine effective and defendable recovery and population rebuilding strategies and provide a scientifically sound and evidence-based approach from which to develop policies that balance conservation objectives and public safety.

Australia has two populations of white sharks separated east and west by Bass Strait. The NERP Marine Biodiversity Hub recently completed the first phase of a project using Close-Kin Mark-Recapture (CKMR) combined with electronic tagging and demographic modelling to provide the first population estimate for Australia's eastern population. This is the first stage in developing a longer term data set and more advanced CKMR analyses for evaluating population trend. The techniques used in the east rely on knowledge of the location of nursery areas for small juvenile white sharks (<3.0 m) for which two are known: one in central New South Wales and the other in southeast Victoria. Sampling and monitoring at these localities is complemented by tissue sampling of juvenile white sharks taken by shark control programs in NSW and Qld, the opportunistic sampling of bycatch from recreational and commercial fishing and samples provided by collaborators in New Zealand waters. CKMR analyses of juveniles specifically provides an estimate of the number of adults (males and females) that produced them (the current population size of adults) and can provide information on adult survival rates and breeding frequency. These data are then combined with estimates of juvenile survival from electronic tag data via demographic modelling to provide estimates of total population size. The ability to genetically sample and monitor juveniles has been the key to the project's success in eastern Australia, hence the focus in this project of locating nursery areas for the western population.

Although Australia's western population of white sharks has been the subject of a significant amount of research dating back to the 1970s, the focus to date has been on sub-adult and adult sharks with no specific research targeting juveniles. As a result, very little is known about the location of nursery areas or the overall distribution and movement patterns of juveniles. Consequently, the novel CKMR-electronic tagging techniques to assess population size, as they are currently applied in eastern Australia, cannot yet be applied to white sharks in the west.

This project partnered the Marine Biodiversity Hub with the Department of Fisheries WA, drawing expertise from SARDI, Flinders University and local knowledge of fishers, in an attempt to locate white shark nursery areas in South Australia and Western Australia. The overall purpose being to lay the ground-work for a subsequent project that would estimate the size and trend of Australia's western white shark population. These projects, combined with existing work in eastern Australia provide a platform for a nationally coordinated assessment of white shark population size and trend. These projects address the highest priority action of Australian's Recovery Plan for white sharks by addressing the key objective of the plan: developing and implementing a monitoring program to assess the recovery of the white shark in Australian waters. In doing so, these projects also address high profile community interest in the status of white sharks and provide a platform for policy decisions on balancing conservation objectives and public safety.

3. PROJECT OBJECTIVES

This is one of several coordinated projects under the Marine Biodiversity Hub with the overarching goal of developing a national-scale population assessment of white sharks in Australian waters. An assessment is necessary to understand whether the species is recovering and hence whether conservation actions under the National Recovery Plan for the species are producing tangible benefit. Specifically, the objectives of this project were to identify the location of nursery areas for white sharks in South Australia and Western Australia, assess the practicality of sampling and monitoring juveniles to estimate adult population size similar to the program of work in eastern Australia, provide an initial genome analysis for white sharks in the western population and develop, with partners and collaborating agencies, an on-going tissue sampling program throughout the region. The completion of these actions lay the ground-work necessary to plan a subsequent project to estimate population size and trend.

The project had four main components:

1. Aerial surveys of selected coastal waters in South Australia and Western Australia to search for aggregations of small juvenile white sharks (< 3.0 m) that would signify the sites of possible nursery areas.

2. Satellite tracking of adult white sharks to identify overall movements including to inshore habitats that may point to the location of potential coastal nursery areas.

3. Tagging of small juveniles (< 3.0 m) with acoustic and/or satellite tags to identify areas of residency that may further signify the location of nursery areas, and

4. A genetics-based component to secure existing tissue from sharks sampled from the western population, undertake initial genome analyses of them and to establish on-going tissue sampling of white sharks west of Bass Strait to build a sample base for CKMR analyses.

These components and their outputs are presented below.

4. AERIAL SURVEYS

Aerial surveys were conducted in areas of Western Australia and South Australia where commercial fishers had reported previous captures of juvenile white sharks. Two broad regions with a history of previous captures were surveyed: the western Great Australian Bight – specifically the area of Israelite Bay and the Encounter Bay region of southeast South Australia.

Seven aerial surveys were conducted in total between December 2014 and November 2015 focussing on spring-early summer and autumn periods when juvenile white sharks are primarily resident in east coast nursery areas. Four aerial surveys were conducted between Esperance and Eucla by the Department of Fisheries, WA; three surveys of Encounter Bay, SA were conducted by CSIRO with assistance from SARDI (Figure 1).

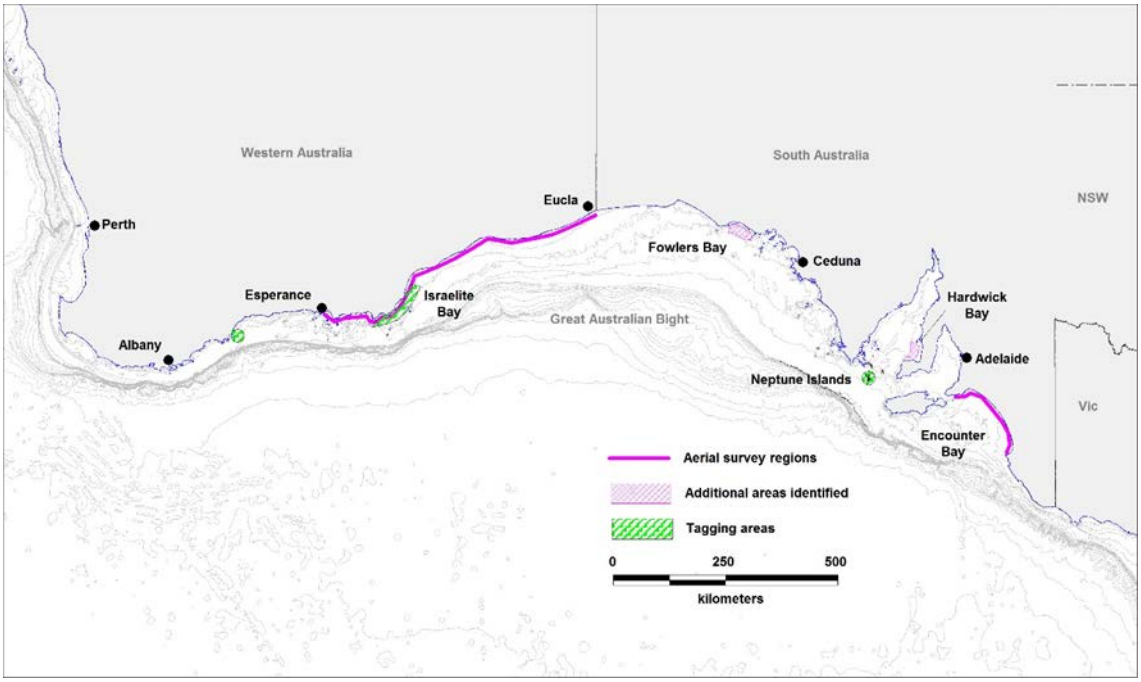

Figure 1: Location of aerial survey zones. Pink hatched zones indicate additional areas where juvenile white sharks were reported by local fishers and SARDI. These will be investigated if opportunities present during subsequent project work. Green hatched zones indicate areas where tagging took place during the project

Aerial surveys covered approximately 1000 km of the southern Australian coastline focussing on habitat similar to where nursery areas are found in eastern Australia (Figure 2 and Figure 3).

Figure 2: Coastal zone habitat – Israelite Bay, WA

Figure 3: Coastal zone habitat – Encounter Bay, SA

Surveys in both areas identified various marine life including schools of Australian salmon, seals and dolphins. Sharks were only observed on the WA surveys and were identified as either tiger (*Galeocerdo cuvier*) or whaler sharks (*Carcharhinus* sp.). No white sharks were sighted and thus although the areas surveyed hold the best promise for locating juvenile white sharks based on historical encounters and captures, nursery areas similar to east coast waters, and specifically similar to the geographically discrete nursery area off Port Stephens, could not be confirmed.

Incidental captures of juvenile white sharks were reported by local recreational and commercial fishers in two areas of South Australia during the project period. These areas will be opportunistically investigated during the course of subsequent projects or via collaborative tagging programs with SARDI.

5. SATELLITE TRACKING OF ADULT WHITE SHARKS

Pop-up satellite archival tags (Wildlife Computers™) were deployed on 11 large white sharks including four adult females (4.8 – 5.2 m total length, TL), four adult males (3.6 – 4.2 m TL) and three sub adult females (3.8 – 4.6 m L) – Table 1. All tags were deployed at the Neptune Islands in South Australia from April 2014 to February 2016.

Despite a number of premature releases and two tag failures, significant data sets were recorded for several tagged sharks. Tagged sharks showed extensive use of shelf edge/slope waters off South Australia and over the Great Australian Bight (Figures 4 to 7). Significant offshore excursions were recorded, including the movement of a 4.6 m TL female white shark into international waters of the Southern Ocean approximately 1800 km southwest of WA (Figure 6). This is the furthest recorded offshore movement of a white shark tagged in either South Australia or Western Australia.

Table 1: Details of large sharks (including adults) tagged with pop-up satellite tags

PTT	TL (m)	Sex	Latitude	Longitude	Deployment Date
131885	5.2	F	-35.281	136.054	19/04/2014
131887	5.0	F	-35.327	136.116	15/07/2014
131886	5.2	F	-35.281	136.054	15/07/2014
151748	3.8	F	-34.691	136.077	23/07/2015
151885	4.3	F	-35.335	136.121	25/07/2015
151886	4.0	M	-35.335	136.121	25/07/2015
151749	4.6	F	-34.656	136.063	06/08/2015
153620	3.6	M	-35.231	136.072	17/12/2015
33956	3.8	M	-35.226	136.074	31/12/2015
151887	4.2	M	-36.670	139.229	25/01/2016
131889	4.8	F	-35.249	136.100	07/02/2016

Two females showed extensive use of shelf edge habitats off Encounter Bay including a 5.0 m female whose tag popped up in Encounter Bay during late winter prior to the nominal spring pupping period assumed for the species (Figure 4).

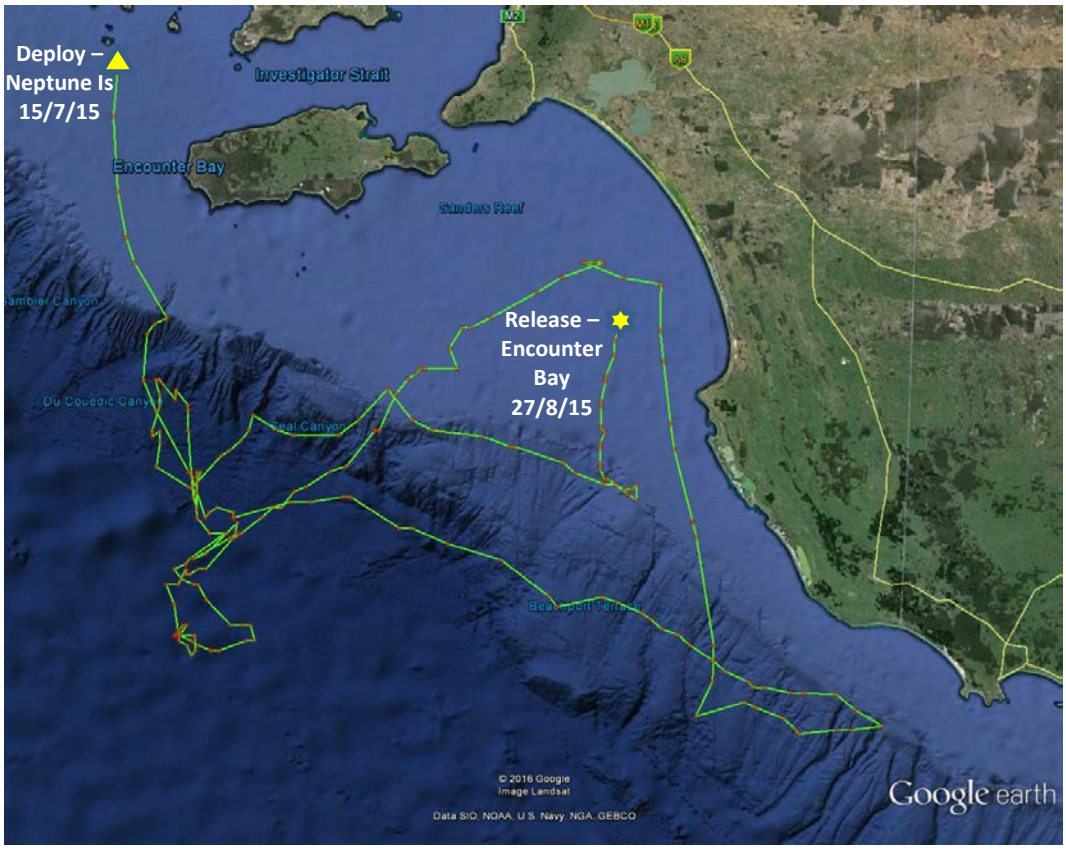

Figure 4: Track of a 5.0 m TL adult female white shark tagged at the Neptune Islands, SA

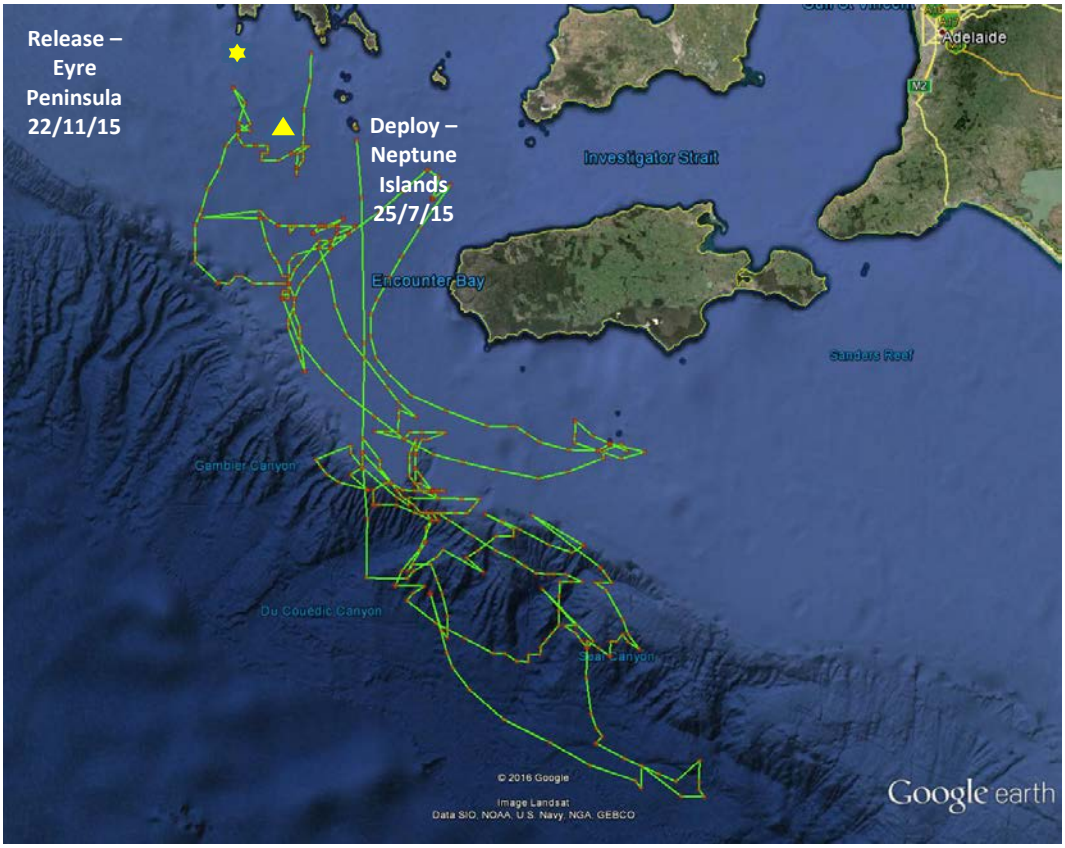

Figure 5: Track of a 4.3 m TL sub-adult female white tagged at the Neptune Islands, SA

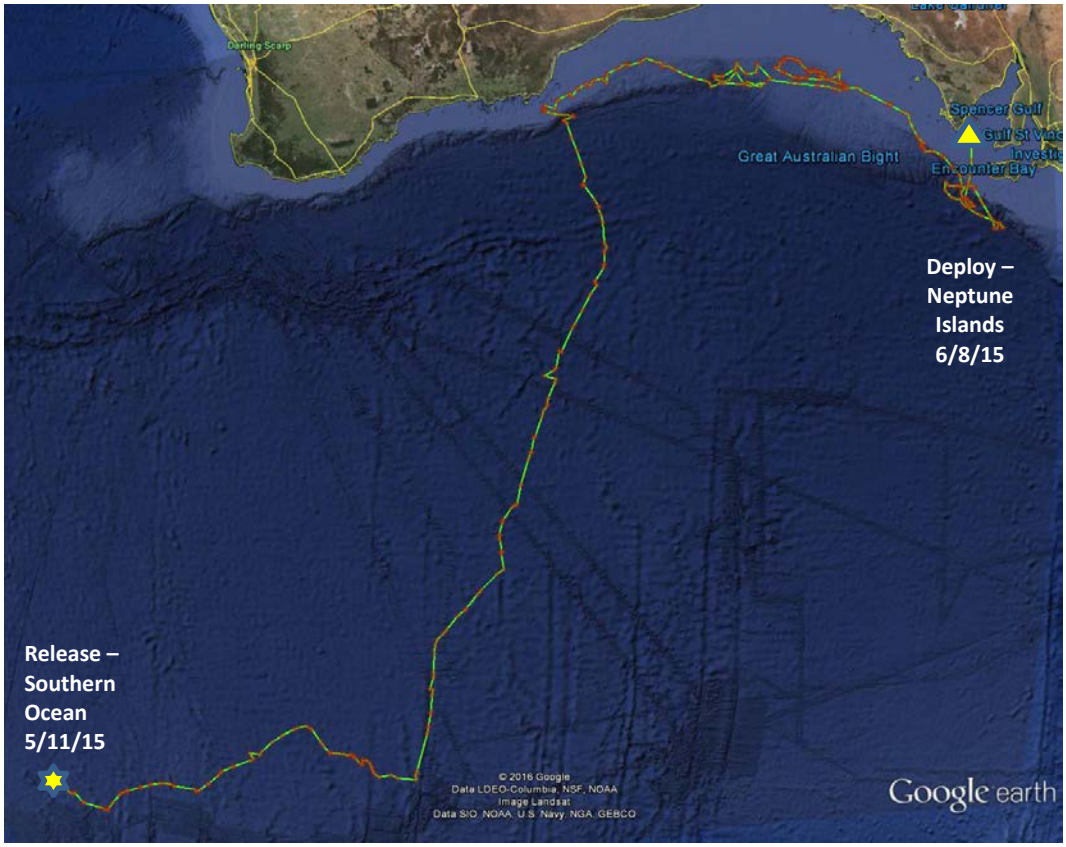

Figure 6: Track of a 4.6 m TL sub-adult female white tagged at the Neptune Islands, SA

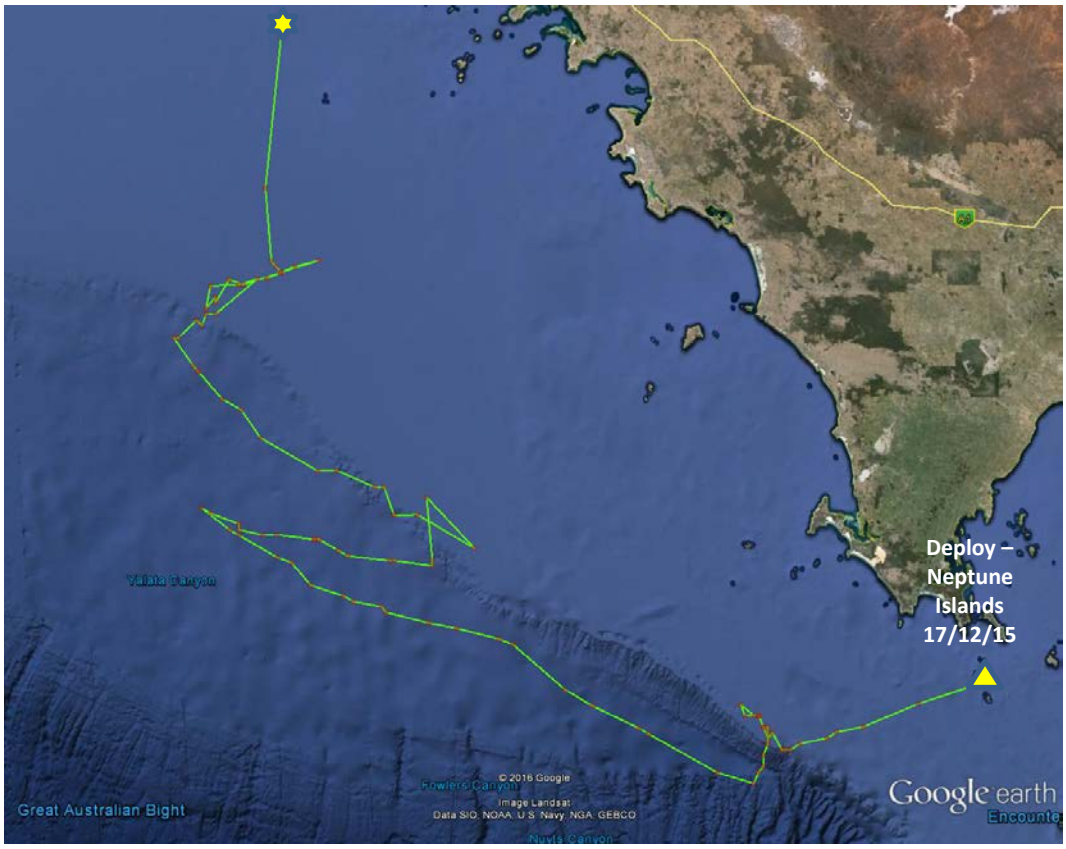

Figure 7: Track of a 3.6 m TL adult male white tagged at the Neptune Islands, SA

6. TAGGING OF JUVENILE SHARKS

Tagging of juvenile sharks was undertaken opportunistically at the Neptune Islands (when they were observed) and during a shark tagging cruises by Fisheries WA taking advantage of vessel logistics used by non-NERP projects. In addition, two tagging surveys was specifically undertaken by Fisheries WA in the Israelite Bay area during November 2014 and April 2015.

6.1 Tagging surveys – Fisheries WA

Two setline surveys were conducted between Cape Arid (34.01°S, 123.15°E) and approximately 50km NNE of Israelite Bay (33.25°S, 124.10°E) from the Department's PV Hamelin between 7 and 27 November 2014 and 7 to 21 April 2015 (the latter to coincide with the first aerial survey). Depending on conditions, area of operation and other constraints, a maximum of 3 individual setlines were deployed at any given time and these were continually monitored to ensure that captured sharks could be tagged and released as quickly as possible. Setlines comprised single 12/0 (J-shaped) broadbill hooks attached via 3.0mm stainless wire snoods to anchored 12mm polypropylene ropes. Hooks were suspended approximately 3m below the surface with a single 100 litre float and were baited with a variety of fresh and frozen Australian salmon (*Arripis truttaceus*) or pink snapper (*Pagrus auratus*). Visual surveillance of nearshore waters were also conducted from the 5.8m aluminium support vessel, RV "Breaksea".

A total of 8 white sharks (2.3 – 4.02 m FL) were captured and tagged with internal Vemco™ acoustic transmitters and Jumbo Rototags (fin tags) during both surveys (Table 2).

Table 2: Details of white sharks tagged during surveys for juveniles

Date	Site	Sex	Fork Length (m FL)
7/11/2014	Israelite	F	3.59
7/11/2014	Israelite	F	3.39
7/11/2014	Israelite	F	2.3
8/11/2014	Israelite	M	3.18
8/11/2014	Israelite	F	2.93
13/11/2014	Israelite	F	2.6
13/11/2014	Israelite	M	2.67
18/04/2015	Cape Arid	F	4.02

To date, no detections of acoustic tagged sharks have been confirmed due primarily to the low number of acoustic receivers deployed in southern Australian waters. Receiver deployments will increase in number over the next 12 months, as a result of SARDI-led projects, which will assist in mapping movement patterns.

6.2 Opportunistic tagging

Three juvenile white sharks (1.9 – 3.2 m TL) were opportunistically tagged with PSAT tags during the course of the project (Table 3). However, tags either failed to record data (1.9 m shark) or were shed from the shark within days of deployment.

Table 3: Details of white sharks opportunistically tagged during the project period

PTT	TL (m)	Sex	Latitude	Longitude	Deployment Date	Site
36495	1.9	M	-34.377	119.572	17/08/2014	Bremer Bay, WA
151889	3.2	M	-35.230	136.071	26/07/2015	Neptune Is, SA
151888	2.7	M	-35.230	136.071	26/07/2015	Neptune Is, SA

7. GENETICS COMPONENT

Historical tissue samples from western Victoria, South Australia and Western Australia were secured and sequenced during the project. To date genetic analyses continue to support the two population model previously determined for Australian waters. Sampling agreements have been established with Fisheries WA, SARDI and Flinders University for the contribution of shark tissue towards future work on estimating population size. To date samples from over 250 white sharks from the western population have been secured and this number continues to rise. These actions present a sound base for future work.

8. PROJECT PUBLICATIONS

Bruce, B. D. and Bradford, R. W. (2015). Segregation or aggregation? Sex-specific patterns in the seasonal occurrence of white sharks at the Neptune Islands, South Australia. Journal of Fish Biology 87: 1355 – 1370.

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