Marine Biodiversity Hub

National Environmental Science Programme

Final Report

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Project A14 - Identification of near-shore habitats of juvenile white sharks in south-western Australia

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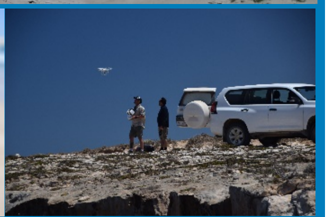
Milestone 9 – Research Plan v5 (2019)



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EXECUTIVE SUMMARY

CSIRO, the Department for Environment and Water, South Australia and the South Australian Research and Development Institute would like to acknowledge the Far West Coast peoples, the traditional owners of the land on which we conducted this research and pay our respects to their Elders past and present.

Understanding the spatial dynamics and behaviour of the juvenile life stage of the white shark, *Carcharodon carcharias*, from the southern-western Australian (SWA) population is crucial to deriving a total abundance estimate and informing future management plans.

The National Environmental Science Program (NESP) Project A14 (Identification of near-shore habitats of juvenile white sharks in Southwestern Australia) investigated credible anecdotal evidence of juvenile white sharks using near-shore habitats in the upper reaches of the Great Australian Bight within the Nuyts Archipelago Marine Park and surrounds.

Initially designed to include unmanned aerial vehicle (UAV) surveys and targeted on-water fishing activities, funding was only available for the UAV component, which would then inform future project design. Funding was provided through the NESP, with matching funding by the CSIRO, and additional funding through Parks Australia and the Department for Environment and Water, South Australia.

To support the anecdotal evidence of juvenile white shark presence in the near-shore environment at the head of the Great Australian Bight, the project team undertook a review of other potential sources of evidence, including combing through the extensive photographic archive from the aerial surveys of the south-western sub population of southern right whale (SRW) (NESP A7 and NESP A13) as well as SRW cliff-top survey data.

A total of 35 UAV flights were completed in 2018 and 2019, covering approx. 7.5 km^2. A range of marine species and shorebirds were observed; however, no white sharks were identified in the video footage. One unidentified species of shark was observed in complex reef habitat at Cabbots Beach.

The marine species observed in the UAV video footage included mullet (*Mugil cephalus*), eagle ray (*Myliobatis australis*), smooth ray (*Dasyatis brevicaudata*), and Australian salmon (*Arripis truttaceus*).

Additional evidence of the importance of the near-shore environments of the Great Australian Bight was collected from several scientific surveys conducted in the region. A total of 136 white sharks were identified in these datasets, with most white sharks being observed at the Head of Bight.

Engagement with the Traditional Owners of Country was through the Yalata Land Management (YLM) Indigenous Ranger team. The YLM team were consulted during all phases of the project and provided with opportunities to join the researchers during UAV survey periods. The project team also visited the Yalata Anangu community school to present to a science class.

The Head of the Great Australian Bight, including several marine parks – Great Australian Bight, Murat, Western Eyre (Commonwealth) and Nuyts Archipelago (State) Marine Parks, appear to be important habitat for white sharks of all life stages. However, further on-water activity and an expansion of the UAV survey into waters west of the Head of Bight would assist with characterising the diversity of this region and provide greater opportunity for deeper engagement with the Traditional Owners of Country. Although difficult to establish effective offshore monitoring, targeted surveys of the Murat (e.g. around Yatala Reef) and Western Eyre Marine Parks would also increase our understanding of white shark distribution as well as biodiversity in the GAB.

1. INTRODUCTION

The white shark, *Carcharodon carcharias*, is a large, circum-globally distributed marine apex predator that inhabits temperate and sub-tropical waters (Compagno 2001). In common with many other elasmobranchs, white sharks display several K-selected life history traits that when combined, characterise populations as potentially sensitive to the impacts of some marine activities, including incidental bycatch in fisheries, trophy hunting to remove body parts (e.g. jaws and teeth), as well as ecosystem-level impacts on key prey and habitats, e.g. potential changes of vertical and horizontal thermal habitats driven by climate change.

Historical declines in white shark abundance resulted in the introduction of protection measures for the species under various international (Appendix II of Convention on International Trade in Endangered Species (CITES) [2005] and Appendix I and II of the Convention on the Conservation of Migratory Species (CMS) [2010]) and national legal instruments (e.g. *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), Australia). In Australia, the species is listed as 'vulnerable' under the Australian *EPBC Act* (1999), and as such, is subject to a recovery plan aimed at rebuilding the population. The species is also protected by State fisheries legislation across its Australian distribution.

Close kin mark recapture (CKMR) is a powerful genetic-based approach being used to address seemingly intractable roadblocks to understanding the population dynamics of species of conservation concern, especially those such as the white shark that are wide ranging and present in low to very low densities (Bruce et al. 2018, Hillary et al. 2018). CKMR has now been applied to the eastern Australian grey nurse (*Carcharinus taurus*) shark population (Bradford et al. 2018) and is being applied to several other species of conservation concern (e.g. northern river shark *Glyphis glyphis*, whale shark *Rhincodon typus*).

Using CKMR, the adult component of the southern-western Australian (SWA) white shark population was recently estimated to be approx. 1460 (range 760-2250) individuals (Bruce et al. 2018). However, to accurately assess and monitor the status of the total SWA white shark population we require knowledge of juvenile distribution, connectivity and spatial dynamics as background to aid in collecting data that would underpin estimates of juvenile and sub-adult survival rates.

In eastern Australia, large tagging programs, undertaken by the New South Wales Department of Primary Industries (NSW DPI) and the CSIRO, with both acoustic and satellite telemetry, have led to a relatively well-developed understanding of eastern Australian white shark aggregation sites, juvenile nursery areas and seasonal movements (Bradford et al. 2012, Bruce and Bradford 2012, Bruce et al. 2019). Juvenile sharks were routinely acoustically tagged, and their presence monitored via a broad-scale acoustic array (IMOS-ATF, Bruce et al. 2018, Hillary et al. 2018). By capitalising on the investments of the NSW DPI, CSIRO, and the Australian Government, acoustic detections through time were translated into individual “capture histories”, which were then used to estimate survival rates of the juvenile component of the eastern white shark population (Hillary et al. 2018b).

By contrast, there are several factors that make it challenging to monitor juveniles in the SWA white shark population. These include:

- The area where white sharks occur is remote and logistically difficult to work in due to its distance from ports and population centres. As a result, field-based monitoring is inherently challenging and expensive. By contrast, on Australia’s eastern seaboard, the proximity of nursery areas to large population centres has meant that sharks which are resident for a relatively well-defined season could be readily captured and tagged. Recent tagging has highlighted an expanded footprint of the eastern white shark juvenile aggregation sites along with wide-scale movements over a greater spatial scale than previously documented (Spaet et al. 2020). Very few juvenile white sharks from the SWA population have been tagged, largely due to the focus of tagging effort being on sub-adult and adult white sharks within this population. This represents a key data gap in our understanding of the movement ecology of the SWA white shark population.

- Our understanding of where the juvenile white shark aggregation sites off eastern Australia were located was informed by a large human population base and confirmed through a dedicated electronic tagging program spanning more than a decade. This program, and later work by the NSW DPI (Spaet et al 2020) has provided us with a detailed understanding of juvenile white shark distribution patterns which has assisted further tagging and tissue collection opportunities. However, over the range of the SWA white shark population, the remoteness and relatively sparse human density has meant that sharks (of all size ranges) are encountered less often. This and other factors have restricted tagging programs, which have largely focussed on sub-adult animals in the Neptune Islands Group, South Australia.

- The relatively discrete and defined juvenile white shark nurseries identified within the eastern Australian white shark population range (centred around Port Stephens, NSW and the Ninety-mile beach region of Victoria) may be atypical of white shark nurseries. For example, off the west coast of the United States, the juvenile white shark nursery is distributed across a long stretch of the Southern California Bight and Baja Mexico and extends well offshore beyond the 1000 m isobath (Weng et al. 2007). Despite anecdotal evidence that juvenile white sharks of the SWA population visit near-shore waters, our understanding of their spatial dynamics and behaviour is insufficient to determine the extent of near-shore use.

- A similar level of financial investment as seen in the eastern white shark population has not been made within the juvenile SWA population and has hampered gaining a better understanding of the juvenile component in this population.

As a result of these key gaps in the understanding of the SWA white shark population, no juvenile mortality estimate is available and hence no total abundance estimate could be calculated. Additionally, the estimate of adult SWA white shark abundance produced by Bruce et al. (2018) included trend (essentially zero or slightly negative). However, it was noted that to confirm the trend at the current rate of sampling and lack of samples from the juvenile life-stage, a further decade of sampling would be required. However, a key result of this analysis was that this time could be halved if we were able to identify and sample at near-shore aggregation sites (e.g. nurseries) of juvenile white sharks. Knowing that juveniles could be readily accessed for tagging and tissue sampling would yield both insights into the adult population (as juveniles carry the genetic mark of their parents – which is the basis for CKMR) and potentially allow tagging to estimate survival rates. Additionally, understanding the spatial distribution and how this may change seasonally and ontogenetically would differentiate between mortality and movement.

To begin thinking about how research may fill some of these key gaps in our understanding of the SWA population, this pilot project investigated credible anecdotal evidence of the presence of juvenile white sharks using near-shore habitat at the head of the Great Australian Bight. Given that the project was only in a pilot phase and had limited funding to cover a very large area of coast, the project included both coastal field surveys by project staff, and an examination of ancillary data from other large marine megafaunal surveys, which were not aimed at detecting white sharks, but that noted their presence. These included coastal cliff top/land based and aerial surveys of southern right whales (SRW). Additionally, the project team worked closely with the Yalata Land Management (YLM) Indigenous Ranger team that works within the Head of Bight (HoB) to Fowlers Bay region. The pilot project included communication with the YLM team, collaboration during preliminary site assessments at Fowlers Bay, a presentation to the Yalata Anangu community school, and discussions about future opportunities for capacity building.

2. METHODS & RESULTS

2.1 Study area

Several lines of evidence (including local recreational fishers, commercial fishers, and marine mammal surveys) were used to identify the region between the head of the Great Australian Bight (HoB) and the eastern end of Fowlers Bay, South Australia to be habitat frequented by white sharks (Figure 1). Members of YLM team have reported captures of juvenile white sharks at the western end of Fowlers Beach and Scott Beach further to the west, as well as during on-site recreational fishing surveys in the Yalata Indigenous Protected Area (IPA) (Rogers et al. 2014). Near-shore habitat in these regions is characterised by white sandy bottom, occasional rocky reef outcrops (e.g. at Windmills), and seagrass beds. The region also provides habitat for several marine species, including:

- several shark species including gummy shark (*Mustelus antarcticus*), school shark (*Galeorhinus galeus*), shortfin makos (*Isurus oxyrinchus*), bronze whalers (*Carcharhinus brachyurus*), and smooth hammerhead (*Sphyrna zygaena*).

- Various schooling teleosts including Australian salmon (*Arripis truttaceus*), snapper (*Pagrus* spp.), and mulloway (*Argyrosomus japonicus*) (Barnes et al. 2019; Steer et al. 2018)

- Several land-based and migratory iconic species of marine predators, including cetaceans, pinnipeds, and seabirds (Evans et al. 2017; Goldsworthy et al. 2017)

The Great Australian Bight (GAB) is a unique habitat, both globally and within Australia. The GAB forms the largest southern-facing coastal landform in the southern hemisphere (Edyvane 1999) and includes a diverse array of habitat types. The Head of the GAB encompasses the Murat (Fowlers Bay to Streaky Bay) and Eucla (Nullarbor to Wahgunyah) bioregions (Rogers et al. 2013). Project A14 was focussed within the Nuyts Archipelago Marine Park, and covered areas within General Management Use Zones (Scott Bay to Mexican Hat), Habitat Protection Zones (Fowlers Bay, western end), and Sanctuary Zones (Cabbots Beach). The Nuyts Archipelago Marine Park adjoins the offshore Great Australian Bight Marine Park, managed by Parks Australia.

The central GAB region has seen an increase in research within off-shore waters (Rogers et al. 2013, Evans et al. 2017), but there remain gaps in our knowledge of the ecology of the remote coastal regions, especially those of sandy and soft-bottom habitat (Edyvane 1999). The Murat bioregion is composed of approx. 22% sandy habitat, 17% reef, and 61% seagrass (Edyvane 1999). While the Eucla bioregion is dominated by sandy (89%) and reef (11%) habitats (Edyvane 1999).

2.2 Prior evidence of white shark presence in the study region

The GAB region is known habitat for white sharks (Last and Stevens 2009). The Neptune Islands Group, in the south east of the GAB (~650 km SE of HoB), host Australia's only shark cage dive operations for the viewing of white sharks. Tagging studies have tracked sub-adult and adult white sharks throughout the GAB (Bradford et al. *under review*; Bruce et al. 2006; Rogers and Drew 2018), and sightings of white sharks have been reported by a variety of ocean users from the surfing community, recreational and commercial fishers (Figure 1), whale watching ventures, and scientific surveys of the region.

Figure 1. White sharks caught by recreational fishers at Yalata, 2018.

Tagging programs within the SWA white shark population have largely been centred around the Neptune Islands, South Australia, where reliable numbers of sharks can be found. These programs have focussed on sub-adult and adult white sharks. The sharks tagged in this region disperse widely throughout the GAB but show some affinity for the shelf region (Rogers and Drew 2018; Bradford et al. *under review*), including the HoB (Figures 2-4).

The NESP-funded projects “Project A7 - Monitoring population dynamics of ‘western’ right whales off southern Australia” (Smith et al. 2019) and “Project A13 - Estimation of population abundance and mixing of southern right whales in the Australian and New Zealand regions” provided imagery of sharks observed during the annual southern right whale aerial surveys stretching back to 2003. These surveys were typically conducted in August/September and covered the region between Cape Leeuwin, WA and Ceduna, SA. An estimation of the location of sightings was taken from the original field sheets. Figure 3 is a white shark observed near the Head of the Great Australian Bight (~31.52 °S, 131.07 °E) in 2012. Additional survey data were obtained from the cliff-top whale survey at the HoB (pers comm. C. Charlton & S. Burnell) and surveillance flights by the Department of Environment and Water (DEW), South Australia (Figure 4. pers comm. D. Holman). All estimated positions were tabulated and plotted using MapInfo software (ver. 7.5).

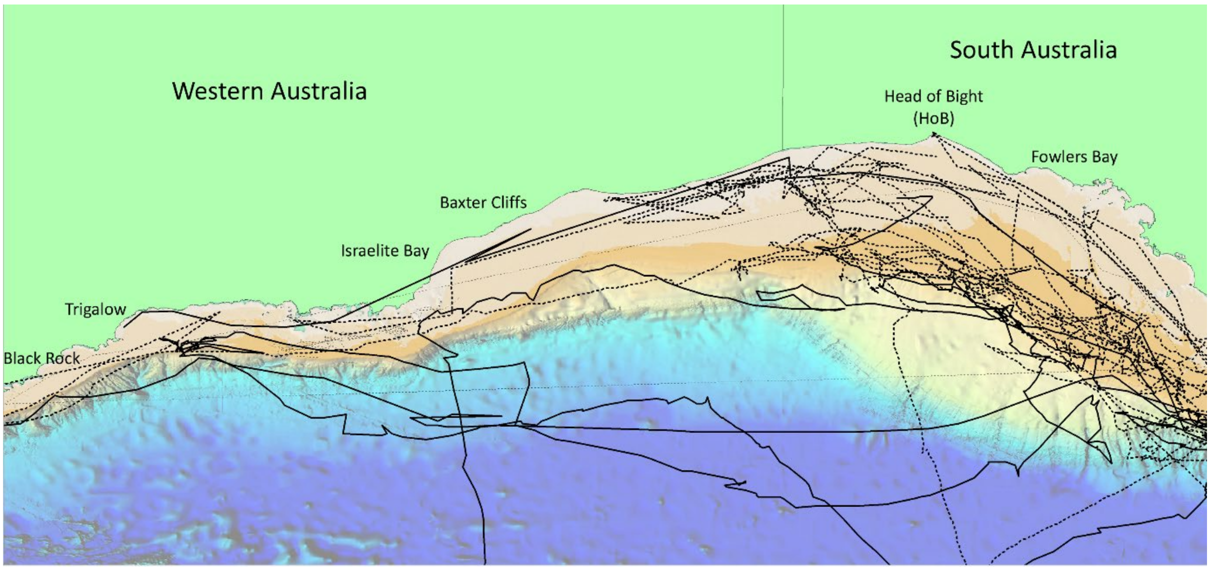

Figure 2: Tracks within the Great Australian Bight of satellite-tagged white sharks (female = solid line; male = dotted line).

Figure 3: White shark with distinctive damage to the left pectoral fin captured on camera during the 2012 aerial survey for southern Right whales (courtesy of Smith et al. 2019); survey altitude ~305 m.

The aerial surveys by NESP A7 and DEW, SA coupled with the cliff-top survey at the HoB provided the bulk of reliable sightings of white sharks in the GAB. In excess of 65,000 images from the annual whale survey, spanning 2003 to 2019 (inclusive) were archived. These images and associated daily record sheets were examined for sharks. Forty individual sharks were identified, and approximate positions obtained from the data sheets.

A total of 90 white sharks were recorded during the cliff-top surveys at the HoB from 1994 to 2017. A further six white sharks were observed during compliance flights by DEW from 2014 to 2019. Sightings were distributed from Black Rock, WA (-34.93, 118.22) to St Francis Island, SA (-32.51, 133.28) (Figure 5). Of the 136 recorded sightings, 14 (10%) were from the Israelite Bay, WA region, with 101 (74%) sightings in the HoB, SA region (Table 1). The highest densities of sightings were recorded adjacent to easterly-facing landforms. The timing of the surveys skews the temporal distribution of the sightings. None-the-less, sightings peaked in August and were recorded from July to October.

Figure 4: White shark observed near the Head of the Great Australian Bight in December 2019 during a Department of Environment and Water, South Australia compliance flight (courtesy of DEW).

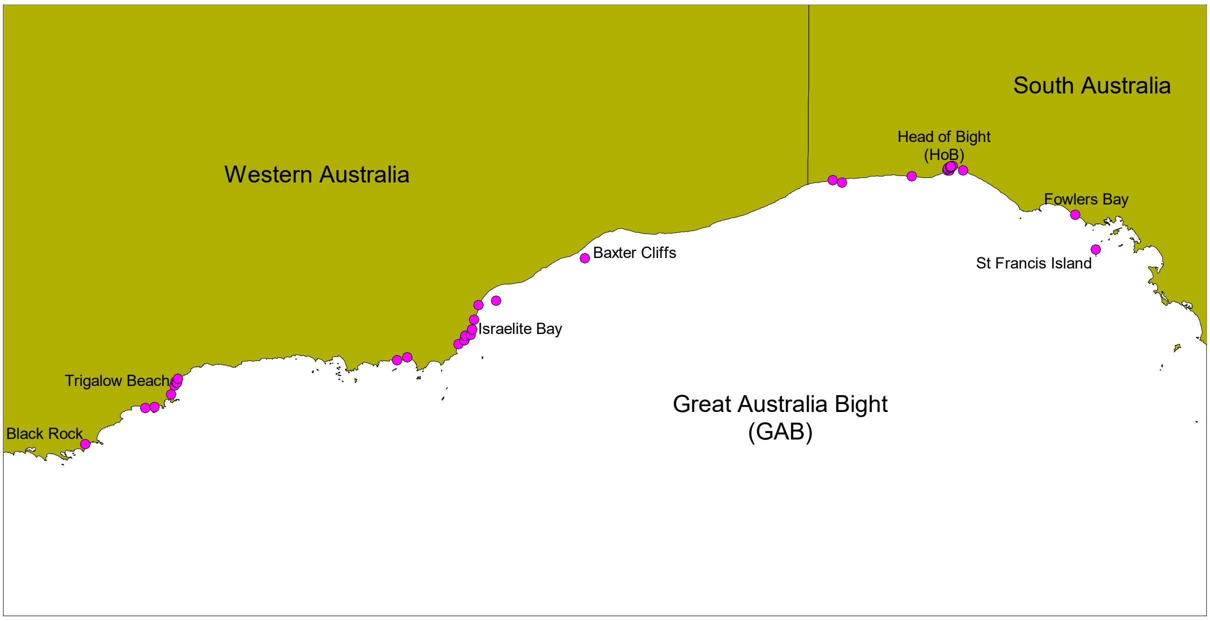

Figure 5: Distribution of white shark sightings recorded by the annual Southern right whale survey (NESP A7, Smith et al. 2019), annual cliff-top survey (courtesy of C. Charlton & S. Burnell), and Department of Environment and Water, South Australia compliance flights (courtesy of D. Holman).

Table 1: Total number of white shark sightings recorded by the annual Southern right whale survey (NESP A7, Smith et al. 2019), annual cliff-top survey (courtesy of C. Charlton & S. Burnell), and Department for Environment and Water, South Australia compliance flights (courtesy of D. Holman), grouped in general regions. Regions are sorted from the most westerly (Black Rocks) to the most easterly (St Francis Island).

Region	State	Number of sharks
Black Rock	Western Australia	1
Reef Beach	Western Australia	1
Dillon Bay	Western Australia	1
Trigalow Beach	Western Australia	4
Point Ann	Western Australia	3
Point Charles	Western Australia	1
Alexander Point	Western Australia	1
Yokinup Bay	Western Australia	1
Israelite Bay	Western Australia	14
Wattle Camp	Western Australia	3
Baxter Cliffs	Western Australia	1
Eucla	Western Australia	1
Wigunda Caves	South Australia	1
Head of Bight (HoB)	South Australia	101
Point Sinclair	South Australia	1
St Francis Island	South Australia	1

2.3 Unmanned aerial survey technique

The primary objective of this project was to carry out unmanned aerial vehicle (UAV) surveys of the Fowlers Bay region. Transects were surveyed using a DJI Phantom Pro 4 vertical take-off and landing (VTOL) quadcopter. The Phantom 4 Pro uses a camera system with a 1-inch CMOS sensor to capture either video up to 4096 x 2160p at 60 fps or 20 megapixels still images. For this project, video imagery was preferred, as an early trial transect using photographs was unsuccessful in gathering useful data. The DJI Ground Station Pro app was used as the flight operating system. Five locations were surveyed using pre-programmed parameters in October-November 2018 and November 2019, with a further seven locations surveyed on an ad-hoc basis (Table 2). The total surveyed area equated to approximately 7.5

km^2 over approx. 750 minutes flight time. The ad-hoc surveys covered more complicated bathymetry and dynamic surf conditions, so pre-programmed transects were unsuitable as flight paths. For these flights the DJI Go app was used, and flights were undertaken in survey areas behind the surf line in water < ~10 m deep to ensure maximum chance of observing animals within the water column. The area surveyed was calculated using an online image footprint calculator (https://www.xdrones.es/aerial-camera-ground-footprint-calculator/). An independent contractor (Rod Lednor, Global Unmanned Systems) was used to verify the results obtained via the online calculator.

For each survey, three members of the team independently viewed each transect file (at least once) to identify marine animals, focussing on sharks. The results were compared, and discrepancies verified through additional viewing of targeted segments of the video files. The verified observations are presented in Table 3.

Table 2: Unmanned Aerial Survey locations within the Nuyts Archipelago and Head of Bight region of South Australia.

Station Name	Type	Number Surveys	Start Latitude	Start Longitude	Area (m^2) Surveyed
Mission 4	Programmed	10	-31.9793	132.4431	1 753 352.95
Mission 5	Programmed	2	-32.0064	132.4292	287 729.41
Mission 6	Programmed	9	-31.9705	132.4483	2 000 230.44
Mission 7	Programmed	1	-31.9583	132.4606	228 560.72
Mission 15	Programmed	5	-31.9855	132.4404	1 064 625.82
Windmills	Free-flight	2	-31.9402	132.5026	397 612 .46
Cabbots Beach	Free-flight	2	-32.0254	132.2311	377 394.78
Scott-west	Free-flight	2	-32.0069	132.3875	405 591.58
Scott-east	Free-flight	1	-32.0068	132.4314	199 595.34
Scott-middle	Free-flight	1	-32.0032	132.4263	161 483.31
Mexican Hat	Free-flight	1	-32.0173	132.3402	194 520.39
Boat Launch	Free-flight	1	-32.0189	132.1828	55 120.47
Total Area Surveyed (m^2)					**7 125 817.67**

Table 3: Unmanned Aerial Vehicle mission observations.

Date	Mission	Shark	Ray	Fish	Other	Note
25/10/2018	M4_1			2		Mullet
25/10/2018	Scott-East			1		Mullet
30/11/2018	M4_1			1		Mullet
30/11/2018	M4_2			3		Mullet
30/11/2018	M6_1					
30/11/2018	M6_2					
30/11/2018	M7_1					
12/11/2019	M4_1		1			Eagle ray
12/11/2019	M4_2		1			Eagle ray
12/11/2019	M6_1					
13/11/2019	Cabbots_1					
13/11/2019	M4_1					
13/11/2019	M4_2					
13/11/2019	M4_3		1			Smooth ray
13/11/2019	M6_1					
13/11/2019	M6_2			1		Mullet
13/11/2019	M6_3					
13/11/2019	M15_1					Low relief reef
13/11/2019	M15_2					Low relief reef
13/11/2019	Scott-West		2			Eagle ray
13/11/2019	Windmills_1					
14/11/2019	M4_1			1		Mullet (elongate)
14/11/2019	M5_1					
14/11/2019	M6_1 (*)					
14/11/2019	M6_2					
14/11/2019	M6_3					
14/11/2019	M15_1			2		Mullet (1 x elongate; 1 x clustered)
14/11/2019	M15_2		1	1		Eagle ray, mullet (elongate)
14/11/2019	M15_3		1	1		Smooth ray, mullet (elongate)
14/11/2019	Scott-East		11			Eagle ray
14/11/2019	Scott-Mid					
14/11/2019	Scott-Mid2					
15/11/2019	Cabbots	1 (3:13-3:44)				Low relief reef
15/11/2019	Mexican Hat					Broad sandy expanse fringed with low reef
15/11/2019	Boat Launch			'000s		Single school salmon

2.4 Engagement with the Yalata Indigenous Community

The initial stages of the project were guided by the collective knowledge of the Yalata Land Management team (YLM). The YLM confirmed sightings of juvenile white sharks in the region and provided access to country managed by the YLM to carry out land-based UAV surveys. The YLM team was consulted at all times and accompanied the team to several locations to assess sites during the survey.

The project team visited the Yalata Aboriginal community and met with a science class at the Yalata Anangu School to talk about the project. Prior to our visit, the teacher and students undertook a field trip to the local community beach to start the conversation on what is in the marine environment in their region.

3. DISCUSSION/CONCLUSION

Surveying remote regions, such as those of the far-west coast of South Australia and the GAB, is logistically challenging and expensive. This project (NESP A14) demonstrated that land-based UAV surveys of remote and difficult to access coastline are feasible with the support of the Traditional Owners of Country, state, regional and Commonwealth management agencies. Through a collaborative framework, this project was able to gain access to regions of the Fowlers Bay coastline, and areas towards the Head of the Great Australian Bight, where credible evidence existed of the presence of juvenile white sharks. The YLM team and DEW provided local knowledge of backroad access as well as up-to-date information on suitable weather conditions to survey and access particular areas; ultimately reducing project costs and improving our understanding of the region.

A total of 35 UAV flights, surveying an area of approx. 7.5 km^2 (over approx. 750 minutes flight time) in total, were undertaken between October 2018 and November 2019. Mullet (*Mugil cephalus*) were commonly observed in the video files, with smooth ray (*Dasyatis brevicaudata*), eagle ray (*Myliobatis australis*) and Australian salmon (*Arripis truttaceus*) also featuring in several files. A single shark was observed at Cabbotts; although the species could not be determined from the imagery, we were able to rule out any positive identification of a white shark. It is recommended that UAV surveys be continued at targeted areas to increase the potential for identifying juvenile white shark nursery grounds in addition to improving our understanding of regional biodiversity.

This project built upon the existing relationships with the YLM team and demonstrated a strong desire within the Yalata Community for greater engagement with the research team. The visit to the Yalata Anangu school was a great success and should be followed up with future visits and the provision of relevant educational material, such as posters of park features and the animals to be found within the region.

The total area surveyed by UAV was small in comparison to the potential juvenile white shark habitat. The various lines of evidence detailed above, however, indicate that the surveyed region, the HoB, and inshore waters extending west to Israelite Bay remain key target areas for identifying juvenile white shark aggregations. The southern right whale surveys, HoB cliff-top surveys and flights by DEW have all observed large white sharks in these regions, many within the size range of mature female white sharks. Targeted pop-up satellite archival (PSAT) tagging of large white sharks in these regions may lead us to critical habitat associated with pupping. The data collected from larger individuals will also provide a greater understanding of white shark movements throughout southern Australia.

In addition to targeted PSAT tagging, the use of Baited Remote Underwater Video (BRUV) coupled with active fishing may also assist with identifying young-of-year and juvenile nursery grounds. BRUVs have been used very successfully in the Port Stephens region of NSW to observe, identify and measure individual white sharks (Harasti et al. 2016; Harasti et al. 2019).

By combining all of these techniques we would be able to survey a much greater area at a higher resolution than by UAV alone.

A combination of techniques also expands opportunities for engagement with Traditional Owners (e.g. Indigenous cadetships/training opportunities) and other regional management agencies (e.g. Department of Primary Industries and Regional Development, WA); thus, building a collaborative economy of scale allowing for a diverse range of approaches to tackle the gaps in our understanding of white shark distribution. It would also allow for an ecosystem/biodiversity-based approach to inform management on a range of species within this poorly studied region.

Our understanding of regional biodiversity would be further enhanced by including UAV, BRUV and targeted fishing surveys of some of the offshore reefs and islands. These regions also fall within the Nuyts Archipelago Marine Park, Nuyts Reef and St Francis Sanctuary Zones (SZ-1 and SZ-8), with the Nuyts Reef and St Francis Island group forming focal points for many species within the GAB. There have been surveys of these inshore regions for Australian sea lions (Goldsworthy et al. 2015) as well as a baseline SCUBA and BRUV survey of the St Francis Group. However, to our knowledge there has not been any underwater surveys to assess biodiversity outside of the St Francis Group. For example, targeted surveys within the Murat Marine Park (Yatala Reef) and Western Eyre Marine Park (where island or subsurface features provide a focal point) would improve our understanding of biodiversity within the GAB.

4. ACKNOWLEDGEMENTS

CSIRO, SARDI & DEW would like to acknowledge the Far West Coast peoples, the traditional owners of the land on which we conducted this research and pay our respects to their Elders past and present.

This work was undertaken for the Marine Biodiversity Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Science Program (NESP). NESP Marine Biodiversity Hub partners include the University of Tasmania; CSIRO, Geoscience Australia, Australian Institute of Marine Science, Museum Victoria, Charles Darwin University, the University of Western Australia, Integrated Marine Observing System, NSW Office of Environment and Heritage, NSW Department of Primary Industries.

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Dr Claire Charlton (Curtin University) and Dr Stephen Burnell (Eubalaena Pty Ltd) contributed observation data from the long-term cliff-top survey at the Head of the Great Australian Bight. Natalie Kelly (Australian Antarctic Division) facilitated access to the image repository of the southern right whale surveys of the Great Australian Bight.

Animal Ethics approval was granted through the CSIRO Wildlife, Livestock and Laboratory Animal, Animal Ethics Committee: AEC 2018-31.

Dirk Holman is a registered/approved unmanned aerial survey (drone) pilot: Civil Aviation Safety Authority (CASA) Remote Pilot Licence (RePL) number: 1029935.

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6. APPENDIX A: BIRDS OBSERVED DURING FIELD SURVEYS.

Table A 1: List of birds observed during unmanned aerial vehicle surveys in the Fowlers Bay, South Australia region. Images are retained by the principal investigator using the filename listed (available on request: russ.bradford@csiro.au). Some of the images are reproduced below.

Common name	**Species name**	**Filename**
Australian pelican	*Pelecanus conspicillatus*	DSC _0205.jpg, DSC _0206.jpg
Silver gull	*Chroicocephalus novaehollandiae*	DSC _0200.jpg
Pied oystercatcher	*Haematopus longirostris*	DSC _0261.jpg
Little penguin	*Eudyptula minor*	DSC_0333.jpg, DSC_0334.jpg
Unidentified species		
Sanderling?	*Calidris alba*?	DSC_0194.jpg
Tern (Crested)?	*Thalasseus bergii*?	DSC_0226.jpg
Sandpiper (Curlew)?	Scolapacidae	DSC_0242.jpg, DSC_0243.jpg
Raven (Australian)?	*Corvus coronoides*?	DSC_0298.jpg

Figure A 1: Australian pelican (*Pelecanus conspicillatus*), Fowlers Bay, South Australia.

Figure A 2: Pied oystercatchers (*Haematopus longirostris*), Fowlers Bay, South Australia.

7. APPENDIX B: OUTPUT. ARTICLE FOR THE AUSTRALIAN MARINE PARKS SCIENCE ATLAS.

On the hunt for prime white shark habitat

Summary/Teaser:
Fowlers Bay sits in the Great Australian Bight, immediately adjacent to the Great Australian Bight Marine Park. The bay is characterised by long stretches of wide, white sandy beaches and rocky headlands. To the east, they're backed by towering sand dunes and to the west, immense 90 metre cliffs run for a 170 km stretch. Exposed to south-easterly winds that drive large swells, the region is a popular haunt for the keen surfer and recreational fisherman. It is also known for its white shark population and thought to be prime habitat for juvenile white sharks.

Where:
Great Australian Bight Marine Park, Nuyts Archipelago Marine Park: Fowlers Bay, South Australia to the Head of the Great Australian Bight

Who:
Russell Bradford & Toby Patterson (CSIRO Oceans & Atmosphere), Dirk Holman (DEW, SA), Paul Rogers (SARDI)
When: November-January 2019 & 2020

Why:
The Great Australian Bight provides a home for a wide range of marine species, many of which feed and breed throughout the region during different stages of their lives. The iconic, wide-ranging white shark (*Carcharodon carcharias*) is one such species that is known to use these waters, including those within the Nuyts Archipelago and Great Australian Bight marine parks. As a top-order predator, white shark play a vital role in marine ecosystems. White sharks in this area are from the southern-western Australian population (Australia has two populations of white shark, separated by the Bass Strait). In 2018, the CSIRO provided the first abundance estimate of the adult cohort of this southern-western population. However, more information about the juvenile life stage (<3.0 m in length) is needed before an estimate of the total population can be provided. Anecdotal reports suggest juveniles seasonally use near-shore environments around Fowlers Bay: to investigate this theory further, drone surveys were undertaken. The data collected will contribute to our understanding of this white shark population and how they're using the GAB region (Figure 1).

How:
The surveys were undertaken with the assistance of the Yalata land management team. The drone was pre-programmed to undertake the survey flights over previously identified sites: the drone flew 40 m above sea level at a speed of less than 4 metres per second (Figure 2). A camera affixed to the drone recorded video footage for the entirety of each flight. At this height and speed, animals are clearly visible when flying over sandy seafloor habitats in relatively shallow depths. A similar technique has been used in New South Wales around the Port Stephens area to survey juvenile white shark habitat. In addition, free-form flights were

undertaken over areas with more complex seafloor bathymetry, including at Scott Beach and Mexican Hat.

A total of 34 flights have been completed to date (as of January 2020), covering approximately 7.5 km^2. The video footage from each flight was independently viewed by the team to identify marine animals, with a focus on identifying juvenile white sharks.

What did we learn:

A diverse range of marine life was identified from the survey footage including Australian sea lions (*Neophoca cinerea*) (Figure 3), little penguins (*Eudyptula minor)*, Australian salmon (*Arripis truttaceus*) (Figure 4), eagle rays (*Myliobatis australis*), smooth rays (*Dasyatis brevicaudata*) and numerous species of shore birds. From a marine park management perspective, data like this helps us better understand which animals are using Australian Marine Parks.

To date, no white sharks have been observed in the recorded footage but what would it mean if juvenile white sharks are confirmed to be using this area? It would indicate that pupping may also be occurring locally and that would be an exciting development. Researchers have been unable to identify pupping areas for this southern-western population. Further, if this area is a pupping ground then it is also likely that large, mature females are present. Although this work was unable to quantitatively prove this hypothesis, anecdotal evidence gathered during this study reaffirms that State and Commonwealth marine park waters here are important to this white shark population.

What next:

This work has contributed to our understanding of the diversity of marine life using the Head of the Bight waters. Future studies would benefit from coupling aerial surveys with targeted Baited Remote Underwater Video (BRUV) deployments. Further benefits would be gained from broadening the study area: this project only considered a tiny portion of potential white shark habitat in the region. Expanding the surveys to include the neighbouring Nuyts Reef complex, the St Francis Group of islands to the south-east, and Israelite Bay to the south-west, would contribute to our understanding of how the iconic white shark is using marine park waters. This research would also further our broader understanding of marine life and habitats in the Great Australian Bight.

Related data and publications:

Project summary: https://www.nespmarine.edu.au/project/project-a14-identification-near-shore-habitats-juvenile-white-sharks-south-western-australia

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Images:

Figure B 1: Looking east towards Fowlers Bay, South Australia (image: Dirk Holman).

Figure B 2: Recovering the drone (image: Russell Bradford).

Figure B 3: Skull of an Australian sea lion. The endangered Australian sea lion (*Neophoca cinereal*) is distributed throughout the southern coastline of mainland Australia from Victoria's western border to approx. Kalbarri, Western Australia (image: Russell Bradford).

Figure B 4: Large school of Australian salmon (*Arripis truttaceus*) captured in the drone footage (image: Dirk Holman).

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