RESEARCH REPORT SERIES

Theme 4: Ecology of iconic species and apex predators

THEME REPORT

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GABRP Research Report Number 37

October 2017

bp CSIRO Government of South Australia Primary Industries and Regions SA SARDI South Australian Research and Development Institute The University of Adelaide Flinders University

THIS PUBLICATION MAY BE CITED AS:

Evans K, Rogers P and Goldsworthy S (2017). Theme 4: Ecology of iconic species and apex predators. Theme Report. Great Australian Bight Research Program, GABRP Research Report Series Number 37, 19pp.

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GREAT AUSTRALIAN BIGHT RESEARCH PROGRAM

The Great Australian Bight Research Program is a collaboration between BP, CSIRO, the South Australian Research and Development Institute (SARDI), the University of Adelaide, and Flinders University. The Program aims to provide a whole-of-system understanding of the environmental, economic and social values of the region; providing an information source for all to use.

CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

CONTRIBUTORS TO THE THREE PROJECTS

The three projects of this Theme were contributed to by a large team of people. We would like to acknowledge the other members of the three projects that are co-authors on the reports produced by the Theme: Fred Bailleul, Kirsten Bilgmann, Scott Cooper, Campbell Davies, Mick Drew, Paige Eveson, Peter Gill, Mark Hindell, Alistair Hobday, Dirk Holman, Ian Jonsen, Matt Lansdell, Alice Mackay, Luciana Möller, Guido Parra, Toby Patterson, Sarah-Lena Reinhold and Peter Shaughnessy.

OTHER ACKNOWLEDGEMENTS

The projects within Theme 4 all, at least in part, build on the efforts of researchers and field staff across a number of historical projects that have collected the time series included, some over multiple decades. These include Marinelle Basson, Alastair Baylis, Sophie Bestley, Natalie Bool, Russ Bradford, Thor Carter, Naomi Clear, Luke Einoder, John Gunn, Derek Hamer, Andy Lowther, Jane McKenzie, Lachie McLeay, Brad Page, Tom Polacheck, Clive Stanley, Grant West and Annelise Wiebkin and as well as collaborating agencies in Australia (Roger Kirkwood and Peter Dann of Phillip Island Nature Park,), Japan (National Research Institute of Far Seas Fisheries, led by Tomoyuki Itoh and Ryo Kawabe), New Zealand (the Ministry of Fisheries, led by Talbot Murray), Taiwan (Taiwan Fisheries Agency, led by Eric Chang), and the USA (Dan Costa and Shannon Fowler of the University of California, Santa Cruz). Support for these projects was provided by the Australian Government Department of Agriculture Forestry and Fisheries, Department of Environment and Energy's Australian Marine Mammal Centre and Department of Environment, Water and Natural Resources, as well as the Commission for the Conservation of Southern Bluefin Tuna, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Fisheries Research and Development Corporation and the South Australian Research and Development Institute.

Project delivery was facilitated by the Electronic Tag Support System (ETSS), a comprehensive data processing and management system developed and maintained by CSIRO and the Animal Tracking Facility of the Integrated Marine Observing System (IMOS). The contributions of Marinelle Basson, Russ Bradford, Mark Bravington, Naomi Clear, Jason Hartog, Paavo Jumpannen in developing and maintaining the ETSS and Rob Harcourt and Clive McMahan in association with IMOS are acknowledged.

Those directly involved in the studies within this Theme are thanked for their input into the Theme. The Stehr Group, in particular Marcus Stehr, Robbie Staunton and the skippers and crew of the *FV Yasmin* and *FV Saxon-S* are thanked for their assistance in SBT tagging operations. The crew of Primary Industries and Regions South Australia, Fisheries Patrol Vessel*, FPV Southern Ranger* are thanked for their efforts during the offshore pelagic survey. Matt Read and Shane Gassner made significant contributions during the planning stages, preparation of the vessel and fitting of the equipment. Damien Mathews, Troy Rogers, Steve Kempster, Shane Gassner, Robb McArthur, Pat Tripodi, and Mr Dale McKerlie are thanked for their considerable efforts during and prior to the survey and fishing industry members, Graham Tapley (Australian Southern Exporters Pty Ltd), Mark Thyer (Sarin Marine Farm), and Claire Webber (Australian Southern Bluefin Tuna Industry Association Ltd) are thanked for providing valuable logistic support. The skipper and crew of the *RV Ngerin*, Darren Nohlman, Chris Small, Jason Nichols and Andrew Sellick are thanked for their assistance on the offshore cetacean and Australian sealion and long-nosed fur seal surveys. Helifarm, Tony Jones at Protec Marine, Aqualinc Marine, Darren Guidera and Kangaroo Island Helicopters and

Heliexperiences, Kangaroo Island are thanked for their assistance with Australian sea lion and long-nosed fur seal surveys. Observair and its Chief Pilot, Brad Welch and GAMair and pilot Andrew Merwood are thanked for their assistance with aerial surveys. Vincent Antony, Alana Binns, Juliette Coudert, Dave Donnelly, Maria Garcia, Martine Kinloch, Clarence Kennedy, Sol Kraitzer, Andrew Levings, Ian Roberts, Shae Small and other DEWNR staff are thanked for their assistance with field studies. Madeline Cahill is thanked for advice on the CARS climatology data. Jason Hartog is thanked for his assistance with processing of archival tag data and interpretation of geolocation estimates.

Michael Double (Australian Government Department of Environment and Energy) is thanked for providing the modern commercial whaling catch data. Kelly Waples and Holly Raudino (Western Australia Department of Parks, the Environment and Water) kindly provided data on Australian sea lion populations. The South Australian Department of State Development, particularly Peter Hough who compiled digital records of reports associated with oil and gas exploration and provided insights into the material contained therein are thanked for their assistance. Mark Ducksbury and Meredith Orr (NOPTA) are thanked for their assistance in accessing metadata and spatial information on oil and gas exploration surveys. PGS, particularly Terry Visser, and TGS, particularly Owen Dwyer and Tanya Johnson, are thanked for making metadata and spatial information on oil and gas exploration surveys and marine mammal observations available. Rob McCauley and Arthur Popper kindly provided insights into the impacts of noise on fish, threshold experiments and seismic operations, and provided guidance on analyses of oil and gas exploration survey metadata. A number of national and state recreational fishing organisations are thanked for their support in distributing information on project 4.3, including the Game Fishing Association of Australia (GFAA), SA RecFish and TARFish.

The Great Australian Bight Research Program, a collaboration between BP, CSIRO, SARDI, the University of Adelaide and Flinders University is thanked for funding and support.

1. EXECUTIVE SUMMARY

Through a series of multidisciplinary surveys and modelling approaches to assessing the movements, habitats and behaviour of key iconic and apex predator species, Theme 4, *Ecology of iconic species and apex predators*, directly addresses knowledge gaps for the Great Australian Bight (GAB) in three key areas relating to iconic species and apex predators: (i) distribution, movements, behaviour and status and trends in abundance (ii) overlap and partitioning of oceanic, shelf-slope and neritic habitats, and associated physical and biological oceanographic habitat features of importance, and (iii) historical overlap of oil and gas exploration with southern bluefin tuna (SBT).

The Theme has provided the most comprehensive synthesis of the status, distribution and abundance of apex predator species in the GAB, confirming the GAB as a region of national and global significance for apex predators. Cetacean surveys identified eleven species, with short-beaked common dolphins particularly abundant in coastal waters. Offshore shark surveys deployed 14 satellite tags on four species, with all species traversing widely through the GAB. For the first time information on the abundance of a number of seabird species was collected and declining trends in populations of little penguins from Olive and Pearson Island were identified. The Theme established that the GAB contains more than 90% of Australia's long-nosed fur seal and Australian sea lion populations with fur seal populations increasing, while sea lions are declining. Two regions in continental shelf and slope areas were identified as being favoured by marine predators via the first regional integration of tracking and survey data: the central and eastern GAB, including areas off the western Eyre Peninsula, Kangaroo Island and Bonney Coast (Region 1), and the south coast of Western Australia (Region 2).

Advancements to quantitative approaches for estimating the movements and behaviour of juvenile SBT highlighted the importance of the region as a stable and consistent summer-autumn habitat. Residency within the GAB appeared to occur in association with higher surface temperatures and lower surface productivity, with the distribution of juvenile SBT progressively shifting eastwards and into offshore regions across the austral summer and autumn months. Although overall, juvenile SBT were largely restricted to the top 50 m of the water column whilst in the GAB, time spent in surface waters (< 20 m) during the day declined across the summer months associated with a deepening of the mixed layer depth and increased mixing of warm waters through the water column. There is no doubt that there has been overlap in the timing of geophysical surveys and the occurrence of SBT in the GAB and at the broad scale observations of movement suggest that tagged individuals remained within the region of the GAB during periods in which geophysical surveys were conducted. The Theme has provided for the ongoing collection of data from juvenile SBT into the near future through the deployment of 125 archival tags on juveniles in the GAB.

Areas for prioritising future research on iconic species and apex predators in the GAB identified include (i) maintaining a capacity to assess populations for longer term change, including expanding information on those species for which there are little or no quantitative data currently available, (ii) expanding analyses to incorporate empirical observations of the factors likely to directly influence marine predator behaviour, thereby allowing for the testing of a range of trophic, physiological, and behavioural hypotheses, and (iii) progressing understanding of the GAB soundscape including anthropogenic inputs and the physiological and behavioural responses of marine predators to sound. Research to support these priority areas will provide essential information for assessing the environmental drivers of variability in populations of predators, allow for the evaluation of impacts of anthropogenic activities on populations and support the evaluation of management measures implemented in response to those impacts.

2. INTRODUCTION

The Great Australian Bight (GAB) is an area of marine conservation significance, and includes more than 130,000 km^2 of marine parks and other marine reserves. The region is also important commercially, supporting a number of fisheries, including the largest in Australia by weight (South Australian Sardine Fishery). A purse seine fishery for southern bluefin tuna (SBT; *Thunnus maccoyii*) is based in Port Lincoln, South Australia and provides fish for inshore ranching operations where juveniles are grown out over a period of four to five months for the export market. This sector of the Australian fishery is of significant value to the regional economy (~$200M annually; Econsearch 2014).

Marine predators (e.g. marine mammals, seabirds, sharks and large pelagic fish) are common in the GAB (Goldsworthy et al. 2013), and the region supports populations of a number of species listed under the *Environment Protection and Biodiversity Conservation Act* 1999. Occupying the highest trophic levels, these predators play an important role in the ecosystem. They can be highly influential in structuring marine food webs through 'top-down' processes, but equally can be affected by processes operating at lower trophic levels ('bottom up'), including oceanographic processes that may control the availability of key prey species (Becker et al. 2007, Cury et al. 2008).

The GAB marine ecosystem is supported by complex and contrasting interactions between oceanographic and biological processes. These include: i) seasonal upwelling in coastal, shelf and shelf slope waters (especially in the eastern GAB) linked to the world's only northern boundary current (Kämpf et al. 2004, van Ruth et al. 2010), ii) down-welling in the coastal, shelf, and slope habitats in the central GAB (Middleton and Cirano 2002, Kämpf 2007, Middleton and Bye 2007), and iii) fronts between water masses in the oceanic waters and the in-flowing tropical Leeuwin Current over the narrow shelf in the western GAB during autumn and early winter (McClatchie et al. 2006). Spatial and temporal variations in climatic and oceanographic conditions are known to be the main drivers of these processes. Indeed, the supply of nutrients and irradiance are both involved in underpinning productivity and food web structure, including the apex predator communities of these ecosystems. How the different components of the food web and the predator communities respond to such marked spatial and temporal variability in production however, is poorly understood. For individual species, such variability may affect migratory patterns, distribution, abundance and residency times, leading to variation in community structure and the locations and extent of ecologically important areas in both space and time.

Within the context of the GAB, there has been concerns raised by some sections of industry and the general community that recent expansion of activities associated with oil and gas exploration over the last five years, specifically activities associated with geophysical surveys and exploratory drilling activities, may impact on the migration and behaviour of a number of apex predators.

In areas where anthropogenic activities are increasing or expected to increase, there is a need to establish baseline information on marine predator populations in order to assess and understand the extent to which populations may be affected, particularly in regard to their migratory patterns, distribution, abundance and residency times. This requires establishing baselines for natural variability from which impacts can be distinguished.

Recognising concerns in relation to oil and gas exploration activities, the limited historical marine research conducted throughout the GAB and the benefit of undertaking a whole of system approach to better understanding the environmental, economic and social values of the GAB ecosystem, the Great Australian Bight Research Program (see Baghurst et al. 2017) was developed to address a number of key knowledge gaps identified for the region (Rogers et al. 2013).

The research conducted under this Theme directly addresses a number of those specific needs and information gaps identified for the GAB. These include:

1. A paucity of baseline information on iconic and apex predator species' distributions and movements and status and trends in abundance.
2. A paucity of information on overlap and sharing of oceanic, shelf-slope and neritic habitats by apex predators and iconic species, spatio-temporal variability in habitat use and the physical and biological oceanographic habitat features of the GAB important to iconic species and apex predators.
3. A lack of compiled information on historical oil and gas exploration and production specific to the GAB and historical overlap of such activities with marine predators.

Three projects were established around these needs and information gaps for iconic species and apex predators. The first (Project 4.1) focused on collecting baseline information on the status, distribution and abundance of a number of predators, the second (Project 4.2) focused on describing the spatial and temporal use of the GAB by a number of predators and any overlap in habitats used and the third (Project 4.3) focused on evaluating the movement and behavior of juvenile SBT and environmental drivers of behavioural variability, as well as establishing a historical description of oil and gas exploration activities in the GAB and potential impacts on SBT.

3. PROJECTS

3.1 Project 4.1: Status, distribution, and abundance of iconic species and apex predators in the Great Australian Bight

3.1.1 Objectives

1. Assess the occurrence and density of southern right whales and other cetaceans using inshore habitats of the GAB.
2. Assess the occurrence and density of pygmy blue whales and other cetaceans using offshore habitats of the GAB.
3. Characterise the spatial and temporal patterns of distribution of pelagic sharks and large teleosts in the GAB.
4. Obtain abundance indices of key pinniped and seabird populations in the GAB.

3.1.2 Key results and discussion

This project undertook a series of targeted, multidisciplinary surveys to assess the status, distribution and abundance of key iconic and apex predator species in the GAB. These included aerial surveys to assess the occurrence and distribution of dolphins and other cetaceans using inshore habitats; offshore ship-based acoustic and visual surveys to assess the occurrence and distribution of baleen and toothed whales in offshore shelf, shelf-break and slope habitats; offshore pelagic longline surveys incorporating satellite telemetry to characterise the spatial and temporal distribution and habitat use of pelagic sharks; and ground and aerial surveys on offshore islands to assess the status and trends in abundance of pinniped and some seabird breeding populations.

Inshore cetacean aerial surveys identified five species of cetaceans, including southern right whale (*Eubalaena australis*), humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera acutorostratus* or *B. bonaerensis*), short-beaked common dolphin (*Delphinus delphis*), and bottlenose dolphin (*Tursiops* spp.). Short-beaked common dolphins were particularly abundant and estimated to number 20,000 – 22,000 individuals (0.67 – 0.73 dolphins/km^2) in coastal waters between Ceduna and Coffin Bay, indicating that shelf waters of the eastern GAB represent important habitat for this species.

There were 58 cetacean sightings recorded during three offshore aerial surveys in the eastern and central GAB. Eight cetacean species were identified, including pygmy blue whale (*B. musculus brevicauda*), fin whale (*B. physalus*), sperm whale (*Physeter microcephalus*), pilot whale *Globicephalus* spp.), killer whale (*Orcinus orca*), Risso's dolphin (*Grampus griseus*), short-beaked common dolphin, common or offshore bottlenose dolphins, and a probable beaked whale. Sightings of sperm whales, pilot whales, killer whales, Risso's dolphins, a fin whale, and what were likely to be beaked whales, were concentrated in upper slope waters (160 – 200 m depths) of the GAB, with sperm whales mostly sighted in deeper, steeper terrain, while pilot whales, killer whales, Risso's dolphins were in shallower, less steep terrain. In contrast, dolphin sightings were widely distributed in shelf and upper slope waters, from close inshore to just offshore of the shelf break. Blue whale sightings were restricted to the Bonney Coast between Robe and Portland.

The offshore visual and acoustic survey encompassed an area of the eastern GAB that had not previously been systematically surveyed for cetaceans. Acoustic surveys detected 15 discrete acoustic events of odontocete (toothed whale) vocalisations. Vocalisations were identified as sperm whales on four occasions, comprising a total of nine individuals in water depths between 500 and 2000 m. Eleven events comprised odontocetes that were not sperm whales, one of which was confirmed visually to be a group of pilot whales. Visual surveys recorded three sperm whales, one group of 100 – 150 pilot whales, and a beaked whale. Maximum entropy modelling using presence only data predicted sperm whale distribution to be highest along the shelf-break and slope.

The offshore pelagic shark survey undertook seven longline sets between the du Couedic Canyon, south-west of Kangaroo Island, and the continental shelf-break area south of Head of Bight. Five pelagic and oceanic shark species were caught on longline sets, including blue (*Prionace glauca*), shortfin mako (*Isurus oxyrhinchus*), common thresher (*Alopias vulpinus*), bigeye thresher (*A. superciliosus*) and school (*Galeorhinus galeus*) sharks. White sharks (*Carcharodon carcharias*) were encountered at the Neptune Islands. Fourteen satellite tags were deployed on four species caught on the longline sets: blue (7), shortfin mako (1), white (5) and bigeye thresher (1) sharks. Analyses of movement data collected by the tags indicated that although species traversed widely, all had significant focal areas in the GAB, and there was evidence of species-specific preference for habitats and depth ranges, with blue sharks preferring the areas offshore from the shelf-break. The occurrence of a bigeye thresher shark a predominantly subtropical and tropical species, in the GAB, and its subsequent migration through the south-east Indian Ocean to tropical waters off Exmouth, Western Australia provided new information on the movements of the species.

The project compiled the most comprehensive synthesis of recent and historic surveys of Australian sea lion and long-nosed fur seal pup abundance in the GAB. The study highlighted that the GAB is highly important for Australia's pinniped biodiversity, containing an estimated 93% and 98% of its Australian sea lion (*Neophoca cinerea*) and long-nosed fur seal (*Arctocephalus forsteri*) populations, respectively. The study identified that while populations of both long-nosed and Australian fur seals (*A. pusillus*) have largely recovered following colonial sealing, populations of the threatened Australian sea lion are smaller than previously estimated and undergoing a rapid decline (Figure 1).

Across the GAB, this decline was estimated to be equivalent to a 76% reduction in numbers over three generations (~38 years), meeting the International Union for Conservation of Nature (IUCN) criteria for 'Endangered' (>50% and <80% decline over three generations). Of significant concern, is the finding that at the individual breeding colony scale, almost 40% of individual breeding sites assessed in the GAB region meet the 'Critically endangered' IUCN criteria (>80% decline over three generations).

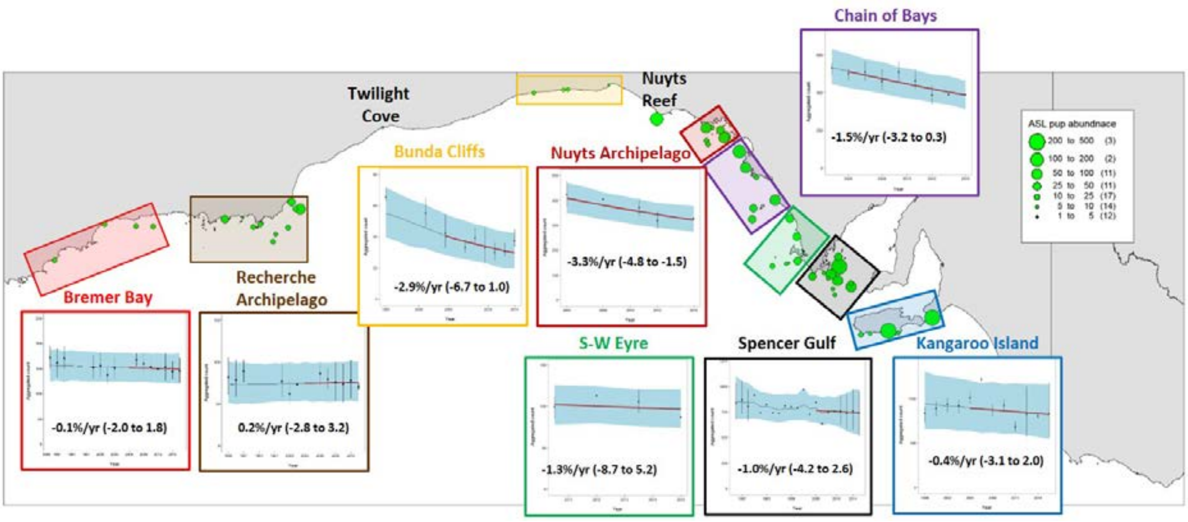

Figure 1. Predicted distribution of aggregated abundance and trend for eight Australian sea lion regions in the GAB Region. The blue envelope represents the 90% highest probability density credible interval of the posterior predictive counts. Points and error bars represent the observed counts with augmented missing values; the red lines are the fitted least-squares predictive trend over the last decade and the black lines are the median of the posterior predictive counts over the entire time interval. Trend estimates are given for the posterior median percentage rate of growth by year, and (in brackets) the lower and upper 90% highest probability density credible intervals (CI).

The project collected abundance data on three key seabird species at some of their offshore island breeding sites, the, crested tern (*Thalasseus bergii*), little penguin (*Eudyptula minor*), and flesh-footed shearwater (*Puffinus carneipes*). Crested tern breeding colonies were surveyed using aerial photography during the nesting period, and the study provided the first abundance estimates for some breeding sites. Little penguins were surveyed at two breeding sites off the western Eyre Peninsula (Olive and Pearson Island) using a combination of burrow transects, census plots and direct burrow counts. Comparison of results from earlier surveys suggest potential declines of 80% and 66% at Olive and Pearson Islands, respectively, since 2004. Flesh-footed shearwaters were surveyed using burrow transects and direct burrow counts at the only breeding sites that occur in South Australia, Lewis and Smith Islands. The surveys estimated 928 and 5,785 breeding pairs at Lewis and Smith Islands, respectively, representing the first population estimates for this species in South Australia.

This project presents the most comprehensive synthesis to date of the status, distribution and abundances of iconic and apex predator species in the GAB. Its findings support previous assessments identifying the GAB as supporting a high diversity, density and biomass of marine predators in coastal Australian waters, making it a region of national and global significance. However, basic information for many of the key species in the GAB is still rudimentary, especially for

cetaceans, seabirds and sharks. The scale, remoteness and logistical challenges in accessing the regions offshore islands, shelf, slope and oceanic habitats, have greatly limited the development of this basic knowledge. The paucity of key baseline data presents a challenge for the management of the region, especially for species that are matters of national environmental significance (threatened, endangered or migratory species), where there are greater requirements to manage and mitigate potential risks and impacts from human activities. Improvement of baseline data on the status and distribution of these species would enhance management of these key species and on the broader GAB region itself.

3.2 Project 4.2: Identifying Areas of Ecological Significance for iconic species and apex predators in the Great Australian Bight

3.2.1 Objectives

1. Develop habitat preference and at-sea distribution models for iconic species and apex predators in the GAB.
2. Identify Areas of Ecological Significance (AES) and key regions of inter-specific overlap.
3. Relate biological and physical oceanographic features to foraging strategies and habitat preference.
4. Identify seasonal and spatio-temporal patterns in distribution, abundance and habitat selection in the GAB.

3.2.2 Key results and discussion

Apex marine predators respond to changes in their environment in several measurable ways and can be valuable bio-indicators of the functioning of entire ecosystems. This project represents the first attempt to regionally integrate 20 years (1995–2016) of electronic tracking data for multiple marine predator species in Australian marine ecosystems. Tracking technologies included a range of data-logging, satellite and GPS tags deployed on nine species from three different guilds (seabirds, pinnipeds and pelagic fish). Aerial and boat-based survey data, opportunistic sightings data and historical whaling data provided information on the distribution of two additional species from a fourth guild (cetaceans). Abundance estimates from populations of central-place foragers (pinnipeds, seabirds) were also used. The species assessed were the Australian sea lion, Australian fur seal, long-nosed fur seal, little penguin, short-tailed shearwater (*Puffinus tenuirostris*), pygmy blue whale and sperm whale, white shark, blue shark, shortfin mako shark, and SBT. These species provide a good representation of the diversity of predators using the GAB, and include a spectrum of life history types, from highly residential land-breeding species to highly migratory species, as well as species that can be classified into differing foraging groups based on where they forage for prey in the water column (benthic, pelagic, surface). Data on the movements and distribution of the 11 species examined were combined to describe their spatial and temporal use of the GAB region, and the influence of environmental and oceanographic conditions on their use was also investigated. Data collated included 4,924 tracks, and 15,698 observations from aerial surveys, sightings and historical whaling data from 602 individuals.

Species distribution models (SDMs) developed by the project allowed for the integration of the tracking, survey and whaling data, identification of habitats within the GAB utilised by the 11 species

and enabled spatial patterns in the amount of use by some species in the GAB region to be assessed. Regions of high use in oceanic, shelf-slope and neritic habitats, were identified using a combination of inter-species overlap models.

Two regions favoured by marine predators were identified in continental shelf and slope areas (Figure 2): the central and eastern GAB, including areas off the western Eyre Peninsula, Kangaroo Island and Bonney Coast (Region 1), and the south coast of Western Australia (Region 2). While these two regions have common features including relatively narrow shelves and steep slopes, they are influenced by different oceanographic features. Seasonal coastal upwelling occurs along the Bonney Coast and off Kangaroo Island and the Eyre Peninsula. The enhancement of primary and secondary production during upwelling supports production of nekton, small pelagic fish and squid, which support important predator foraging areas within these regions. In the western GAB, the important shelf and slope area is largely influenced by the Leeuwin Current and the GAB Warm Pool water mass. Different mechanisms to those that occur in Region 1 are known to affect seasonal nutrient supply and production in this system (McClatchie et al. 2006; Middleton and Bye 2007; see also Theme 2).

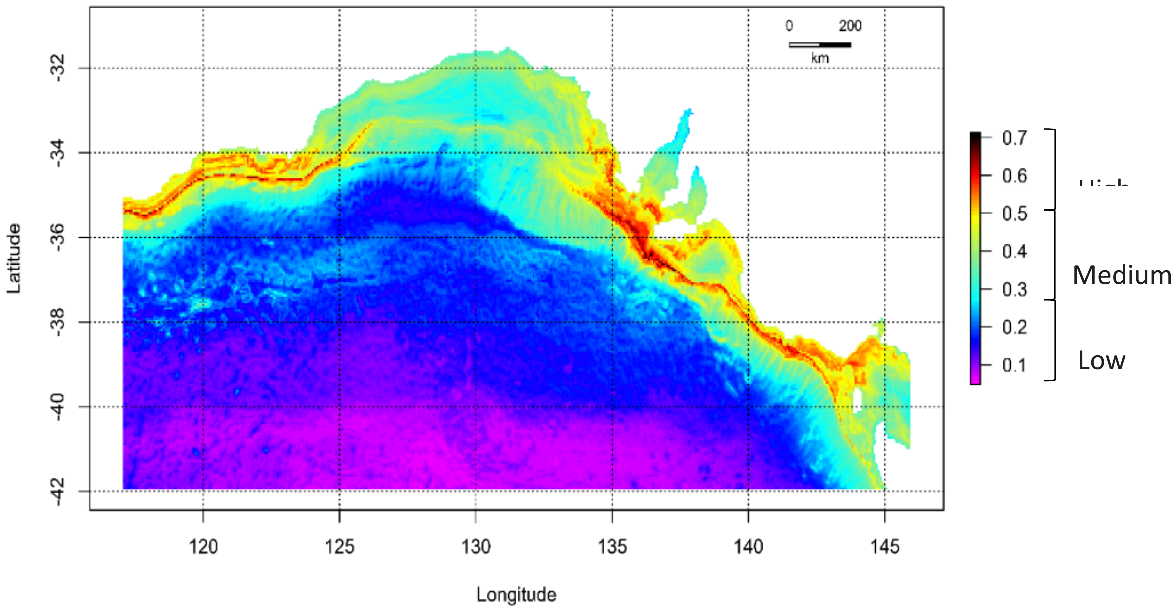

Figure 2: Multi-species overlap calculated as the average of the potential occurrence from the 11 species of the study (Australian sea lion, Australian fur seal, long-nosed fur seal, little penguin, short-tailed shearwater, blue shark, shortfin mako shark, white shark, southern bluefin tuna, sperm whale and blue whale). Areas of high overlap (indicated in red) identified two different regions highly used by the predators are identified: i) the continental shelf and shelf break in the eastern GAB extending along the Bonney coast and the mainland coast north of Tasmania, ii) the continental shelf and shelf break in the western GAB.

In these two regions, central-place foraging species are mainly concentrated over the continental shelf near the coast. In contrast, migratory species (such as SBT, pygmy blue whales and some shark species) concentrate on the shelf break, using it both as a foraging area and as a migration corridor. The different foraging groups were found across continental shelf, shelf break and slope areas indicating that the GAB is an important source of food from the sea bottom to the surface for the

different predators. Available information from project 4.1 when synthesised into the modelling approaches used in this project suggests that the south coast of Western Australia, although as rich in biodiversity of marine predators as the eastern GAB, tends to have a lower biomass of predators. This suggests that although both the western and eastern GAB can support resident species through the whole of the year, overall production in the eastern GAB may be greater than that in the western GAB. The seasonality in the environmental conditions in the two regions of high use is expected to influence the community of predators present in the GAB, with migratory species more prevalent in the GAB in the summer months when productivity, particularly in the eastern GAB (enriched through upwelling) increases.

The study identified regions of high use that are associated with the unique and complex oceanographic features of the GAB. The environmental variability in these regions is likely to impact migratory patterns, distribution, abundance and residency times, and lead to marked variation in apex predator community structure, and the locations and extent that high-use regions are used in both space and time.

3.3 Project 4.3: Southern bluefin tuna: spatial dynamics and potential impacts of noise associated with oil and gas exploration

3.3.1 Objectives

1. Develop quantitative models of juvenile SBT movement, feeding and surfacing behaviour and preferred habitats in the GAB based on historical archival tag data (1994 – 2010).
2. Estimate the extent to which movement and/or behaviour between the historic period and current exploratory period differ and, if so, in what way by comparison with data from contemporary electronic tag deployments.
3. Summarise historical oil and gas exploration activities that have occurred within the GAB from publically accessible records of exploration surveys.
4. Contribute data products, spatial dynamics methods for SBT, and interpretation for integrated analysis of other iconic and apex predators (Project 4.2) and broader integrative modelling of Theme 7.

3.3.2 Key results and discussion

This project developed a number of new quantitative models for investigating the behaviour of SBT in the GAB using existing electronic tagging data (110 archival tag records each individually spanning <1 year and up to 4 years over the period 1998 to 2011) from juvenile SBT. Deployment of an additional 125 electronic tags during the summer of 2014 in juvenile SBT in the GAB by the project facilitated ongoing collection of data on the spatial dynamics and behaviour of juvenile SBT, extending the time series to more than 30 years. As a first step in examining the potential impacts of exploration associated with oil and gas on juvenile SBT whilst in the GAB, the project collated and summarised publically available information on oil and gas exploration activities. This provided a comprehensive profile of historical exploration for the region for the first time.

Migrations of individual juvenile SBT between winter foraging areas in the Indian Ocean and Tasman Sea and the GAB were highly variable among individuals and often varied inter-annually. While winter foraging locations often varied within individuals from year to year, seasonal use of the GAB

remained stable, highlighting the importance of the region as a summer-autumn habitat for juvenile SBT. Cyclical movements away from and back to the GAB occurred over periods as short as 61 days and as long as 481 days.

The departure date of juvenile SBT from the GAB was highly variable, but began in February and extended into August, with the majority of fish having left the GAB to migrate west into the Indian Ocean or east into the Tasman Sea by July. The numbers of SBT returning to the GAB started to rise in November, peaking around December/January and continuing through to as late as March. The timing of the return to the GAB appeared to be more consistent across fish than the timing of their departure.

When compared with other areas of residence outside of the GAB, residency within the GAB appeared to occur during periods of higher surface temperatures and lower surface productivity. During the summer (December – February), juvenile SBT were largely concentrated in inshore shelf waters or around the shelf break in the western and central GAB (Figure 3). During autumn (March – May), there was an apparent shift in preference for areas in the eastern side of the GAB, with the northern, more coastal shelf waters of the GAB less frequented. During the winter and early spring months (June – October), the small proportion of tagged SBT remaining in the GAB were concentrated around the shelf break and continued to remain largely absent from the inshore regions of the shelf. As the number of juvenile SBT returning to the GAB increased throughout November, SBT tended to occupy inshore areas of the GAB again.

While in the GAB, juvenile SBT were generally found at an average depth <50 m (90% of all dawn, day, night and dusk time periods), and within an average water temperature band of 16–23°C (90% of all time periods). Juvenile SBT spent more time in surface waters (<20 m) during the day than at night. The time spent in surface waters during the day declined across the summer months and was associated with a deepening of the mixed layer depth and increased mixing of warm waters through the water column. Interestingly, the time spent in surface waters during the day increased with the age of the individuals, but decreased at night. Time spent in surface waters increased as feeding activity increased, with most feeding events occurring during dawn periods when fish were at relatively shallow depths in the water column. The time spent by juvenile SBT at the surface across a 24-hour period demonstrated a crepuscular pattern, suggesting that the time spent at the surface is likely influenced by the diel vertical migration of their prey and the relationship of prey species with the deep scattering layer (DSL). Identification of the time of feeding in juvenile SBT is consistent with this suggesting that the ability of juvenile SBT to track their prey, as the depth of the DSL changes, is a trade-off between the availability of the DSL and the amount of light available, as SBT is considered to be a largely visual predator.

The models used to investigate feeding behaviour suggest a feeding strategy by juvenile SBT in the GAB based on smaller, frequent feeding events relative to that employed when on winter foraging grounds in the Indian Ocean, where feeding was more sporadic and appeared to consist of larger feeding events and, presumably, prey. These findings are consistent with what is known of the diet of juvenile SBT. Small juveniles caught off the west coast of Western Australia have been recorded as having a diet of small pelagic crustaceans and small jack mackerel. Slightly older juveniles caught off southern Western Australia are known to feed on Australian sardines, blue mackerel and jack mackerel, with Australian sardines more abundant in the stomachs of fish in coastal regions and jack mackerel more abundant in the stomachs of fish closer to the shelf edge. Prey items in the stomachs of juveniles off South Australia were found to consist predominantly of Australian sardines and blue mackerel. Once outside of the GAB, SBT have been demonstrated to feed on a much higher diversity of prey.

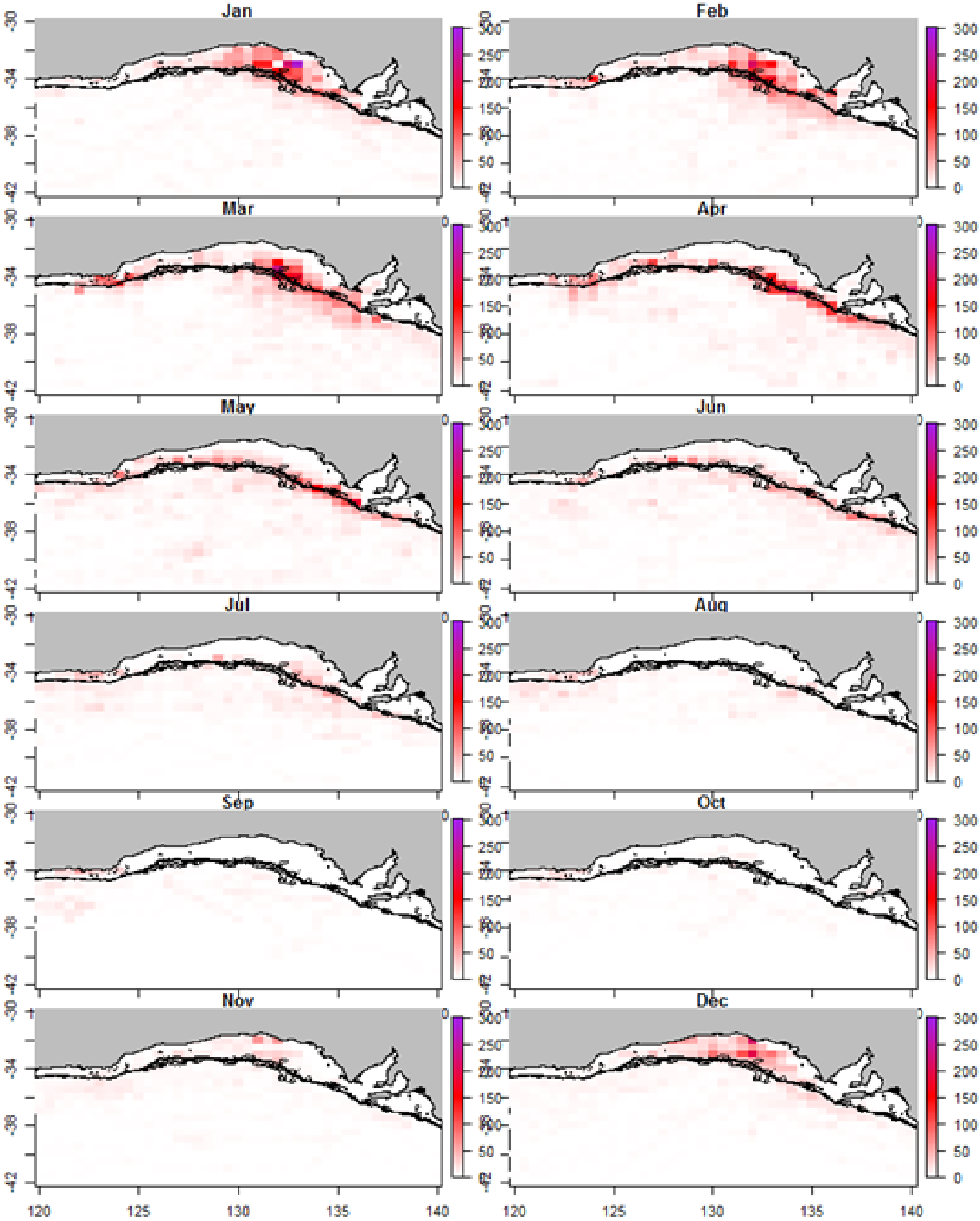

Figure 3. Monthly aggregated counts of position estimates derived from juvenile southern bluefin tuna tagged with archival tags 1998–2011. Bathymetric contour lines associated with the shelf break are included as black lines.

It has been hypothesised that a decline in the lipid content of prey items, such as sardines, associated with seasonal declines in productivity may be the driver for juvenile SBT leaving the GAB (Ward et al. 2006). Sardines have been reported as having relatively high lipid content during the summer months, after which lipid content decreases by more than half, suggesting potential

linkages between the distribution of small scale, patchily distributed productivity events, the energetic benefits of prey items and the presence of juvenile SBT in the GAB.

Thermal regimes may provide additional drivers for the use of the GAB by juvenile SBT across the summer, in particular with the higher temperatures experienced in summer whilst in the GAB potentially inferring physiological benefits. Previous growth studies have shown that a large proportion of the annual growth increment of SBT is achieved in summer while in the GAB. Whilst in the GAB, juvenile SBT spend a large proportion of their days in warm surface waters, which is thought to be a form of behavioural thermoregulation. Surface warming in higher temperature waters may allow fish to increase their body temperature, which in turn would be expected to increase digestion and increase growth rates to a higher level than could be achieved in other coastal or oceanic environments.

There is no doubt that there has been overlap in the timing of geophysical surveys and the occurrence of SBT in the GAB and that this temporal overlap within the GAB has been occurring for more than five decades. The extent of both spatial and temporal overlap between juvenile SBT and geophysical surveys, however, has varied through time. Peaks in exploration activity have occurred at relatively regular intervals, with the most recent associated with the release of lease areas in the offshore waters of the Bight Basin. Use of more complex, higher density 3D surveys has increased gradually since the turn of the century, with coarser 2D surveys decreasing. At the broad-scale, observations of the movements of SBT suggest that tagged individuals remained within the broader vicinity of the GAB during the period across which surveys were conducted, and for those individuals for which observations are available across multiple years, continued to return to the GAB across the austral summer period.

Direct measurements of spatial overlap however, are largely impossible because of inherent errors in the light-based geolocation process used to estimate position. Although the improvements made to the process as part of this study has progressed our ability to better define the movements and areas of residency of juvenile SBT, it does not allow the pinpointing of an individual at an exact location at an exact time. Further, ascertaining any cause and effect relationships is impossible from observational data alone, particularly given the complexity of relationships between the environment of the GAB and juvenile SBT, as identified by this study. While some environmental parameters could be identified as influencing the behaviour of juvenile SBT, which ones, and the strength and direction of the relationships, varied temporally and across individuals. This made identifying clear relationships between behaviour with environmental parameters difficult, suggesting that the drivers for the behaviour of juvenile SBT are complex, and potentially interdependent and covarying in nature.

The numerous potential compounding factors influencing the movements and behaviour of juvenile SBT whilst in the GAB would need to be accounted for before the extent of overlap and any associated behavioural responses to exploration activities could be determined. Such experiments are inherently complex, logistically difficult, and expensive. Without due consideration of the requirements for adequately assessing the behavioural responses to noise generated by activities such as oil and gas exploration, assessing the impacts of these activities on marine animals will continue to be difficult and, as a result, largely either a qualitative or modelling exercise with inherent uncertainties.

4. CONTRIBUTION TO THE GABRP

4.1 New knowledge and significance

The projects in Theme 4 have substantially increased our understanding of the abundance and status, distribution, behaviour and habitats of key iconic and apex predator species in the GAB. This included for the first time:

- an abundance estimate for common dolphins in an inshore region of the GAB
- information on the cetacean species assemblage in an offshore region of the GAB
- estimates of the abundance of flesh-footed shearwaters at two sites in South Australia
- estimates of abundance of crested terns from a number of sites in the GAB
- establishment of trends in the abundance of little penguins from Olive and Pearson Islands
- compilation of multi-species tagging datasets, facilitating an investigation of habitat utilisation and overlap
- modelling of surfacing behavior of SBT in the GAB
- modelling of spatial variability in feeding events and relative feed size of SBT
- compilation of information on historical oil and gas exploration and development allowing for a preliminary investigation of spatio-temporal overlap with SBT

The projects also increased understanding of:

- pinniped population estimates and trends, including further confirmation of declines in Australian sea lion populations
- pelagic shark movements and habitats both within and outside the GAB
- southern bluefin tuna movement and habitats within the GAB, whilst also providing for the ongoing collection of data from juvenile SBT into the near future

The projects have also progressed quantitative approaches for establishing the foundations for assessments of the behaviour of marine predators in relation to their environment into the future, identifying important habitats for iconic species and apex predators and overlaps in habitats between multiple species. These results provide the necessary foundation for the design and implementation of targeted research projects to directly address the questions of the interaction of physical and biological oceanography, meso-pelagic abundance and distribution and higher order predator spatial and trophic dynamics. They also provide important information required for resolving overlap between habitats used by multiple predators with human activities, thereby improving the capacity to manage potential impacts and interactions. These results are also relevant more broadly to species recovery plans and marine park management.

4.2 Links to other Themes

The projects under Theme 4 draw contextually on findings from Theme 1 and Theme 2 in particular, in understanding how large scale climate and ocean features drive seasonal variability in the GAB and how lower trophic level productivity and variability might influence higher trophic levels in the GAB. Project 4.2 provided direct input into Project 2.1 via inclusion of a chapter in the report for the project (Bailleul, F., Richardson, L., Van Ruth, P., McMahon, C.R., Harcourt, R.G., Middleton, J., Ward, T., Goldsworthy, S.D. Animal-borne instruments provide new observations of seasonal subsurface oceanographic features over the continental shelf of the Great Australian Bight).

Projects 4.1, 4.2 and 4.3 produced important datasets for inclusion in the ecosystem modelling undertaken by Theme 7, providing for the parameterisation of the higher trophic components of each ecosystem model and facilitating a comprehensive whole-of-system understanding of the environmental, economic and social values of the region. In particular, inclusion of the data produced by these projects allowed for scenario testing and better understanding of impacts on ecosystem components by Theme 7.

4.3 Knowledge and data gaps and priorities for future research

The projects in Theme 4 highlighted a number of knowledge gaps and associated areas for further work. Knowledge gaps specific to each project can be referred to in each project report, however a number were consistent across the three projects and therefore can be identified as key areas for prioritising future research on iconic species and apex predators in the GAB. These include:

- Much of the investigations conducted (particularly those in Projects 4.2 and 4.3) would not be possible without the time series of observations provided by the historical datasets collected and held by the research agencies involved in the program. The projects highlight that in order to ascertain population-level responses to environmental variability, and pressures associated with human activity, long time series from animal populations are required. Continuation of collection of long-term datasets will allow ongoing assessment of trends in populations and for longer term changes to populations to be discerned. This is particularly important for those species known to be in decline (e.g. Australia sea lions). Developing and maintaining a capacity to assess populations for longer term change is essential for understanding how components of the population respond and are impacted by pressures placed on them and for evaluating any management measures implemented in response.
- For those populations where new data were produced by projects in this Theme, ongoing monitoring to support quantification of population status and trends, particularly those species that are suspected to be in decline (e.g. little penguins), will ensure that agencies tasked with management of marine species in the GAB have the information needed for setting management priorities, focusing management efforts and ensuring ongoing sustainability of activities in the GAB.
- While the investigations detailed here have expanded measures of population abundance for a range of species and has increased our understanding of species movements and behaviours, there remains little or no quantitative data on the distributions and abundance of many species that occur in the GAB, particularly in regards to seabirds, cetaceans and sharks.
- The projects in the Theme explored variability in the behavior of marine predators largely with a range of proximal factors rather than direct observation of factors likely to directly influence behavior, such as the distribution of prey species. This is largely because few data relating to factors directly influencing marine predator populations exist, particularly in relation to spatial and temporal variability in these factors. Incorporation of observations of the factors likely to directly influence marine predator behavior, such as the distribution of prey species would allow for the testing of a range of predator-prey, physiological, habitat related and migration hypotheses, provide essential information for assessing the environmental drivers of variability in populations of predators in the GAB and allow for the evaluation of impacts of anthropogenic activities on populations.
- The evaluation of oil and gas activities conducted highlights that marine animals in the pelagic environments of the GAB have and are exposed to sound generated from a variety of sources, both natural and anthropogenic. The future extent of acute sources of sound such as that associated with oil and gas exploration and production is at present unknown and

will depend on many social and economic factors, but at least in the short term is anticipated to continue. In order to better understand the impacts of oil and gas exploration activities not only on juvenile SBT, but also other marine predators, further work across a range of disciplines would be required. This would include (i) better understanding the processes involved in hearing in species and associated thresholds, thereby providing a direct basis for testing behavioural responses and thresholds associated with the impacts of noise and (ii) extending monitoring of sounds in the marine environment of the GAB to allow development of ocean soundscape models that capture the spatial and temporal variation inherent in the ocean environment and provide an overall baseline understanding of the sounds generated in the environment that marine predators are exposed to.

4.4 Theme outputs and outcomes

4.4.1 Project 4.1

4.4.1.1 Outputs

Bilgmann, K., Parra, G. J., Möller, L M. Occurrence, distribution and abundance of cetaceans off the western Eyre Peninsula in the Great Australian Bight. Deep Sea Research II (submitted).

Bilgmann, K., Parra, G.J., Möller, L.M., 2014. Inshore Cetacean Survey between Ceduna and Coffin Bay, eastern Great Australian Bight. Great Australian Bight Research Program. GABRP Research Report Number 1. Flinders University, Adelaide, 40pp.

Gill, P.C., 2016. Offshore cetacean aerial surveys in the Great Australian Bight. GABRP Research Report Number 10, Great Australian Bight Research Program, Great Australian Bight Research Program. Blue What Study Inc, 26pp.

Goldsworthy, S.D., Mackay, A.I., Bilgmann, L.M., Möller, L M., Parra, G.J., Gill, P., Bailleul, F., Shaughnessey, P., Reinhold, S.-L., Rogers, P.J., 2017. Status, distribution and abundance of iconic species and apex predators in the Great Australian Bight. Great Australian Bight Research Program. Great Australian Bight Research Report Number 15. SARDI Aquatic Sciences, Adelaide, 229 pp.

Goldsworthy, S.D., Mackay, A.I., Shaughnessy, P.D., Bailluel, F., 2017. Status and trends in abundance of pinnipeds in the Great Australian Bight. Great Australian Bight Research Program. Great Australian Bight Research Report Number30. SARDI Aquatic Sciences, Adelaide, 34pp.

Mackay, A.I., Bailleul, F., Goldsworthy, S.D., 2017. Passive acoustic and visual survey of cetaceans in the Great Australian Bight. Great Australian Bight Research Program. Great Australian Bight Research Report Number X, Great Australian Bight Research Program.

Reinhold, S.L., Mackay, A.I., Bailleul, F., Holman, D., Goldsworthy, S.D., 2017. Status and trends in abundance of seabirds in the Great Australian Bight. Great Australian Bight Research Program. GABRP Research Report Number 31. SARDI Aquatic Sciences, Adelaide, 61pp.

Rogers, P.J., Drew, M., Bailleul, F., Goldsworthy, S.D., 2016. Offshore survey of the biodiversity, distributions and habitat use of pelagic sharks in the Great Australian Bight. Great Australian Bight Research Program. Great Australian Bight Research Report Number 7. SARDI Aquatic Sciences, Adelaide, 77pp.

Rogers, P.J., Drew, M., Bailleul, F. Pelagic shark niche dynamics in the SE Indian Ocean: roles of ancient submarine coastlines and oceanographic features in the distribution and migration patterns of highly migratory predators (in prep).

Rogers, P., 2015. Pelagic shark research: an overview of SARDI projects. SARDI Seminar Series, SARDI Aquatic Sciences, Adelaide, 29 October 2015.

Rogers, P., Drew, M., 2016. An overview of research and monitoring of highly migratory pelagic sharks in South Australia. Natural Resource Management (NRM) Science Conference – Sharing Science for Better Outcomes, Adelaide, 13-15 April 2016.

This project collected a number of new datasets for cetaceans, Australian sea lions and long-nosed fur seals, seabirds and sharks via surveys conducted under the project.

4.4.1.2 Outcomes

Through a series of multidisciplinary surveys this project has substantially increased our understanding of the abundance and status, and distribution and habitats of key iconic and apex predator species in the GAB. The project provided for the first time information on the abundance of a number of species including common dolphins, flesh-footed shearwaters and crested terns, the species assemblage of cetaceans in an offshore area of the GAB and the establishment of trends in little penguins from Olive and Pearson Island. The project also increased current understanding of Australian sea lion and long-nosed fur seal population estimates and trends and pelagic shark movements and habitats.

The findings of this project support previous assessments identifying the GAB as a region of high diversity, density and biomass of marine predators in Australian waters, making it a region of national and global significance.

4.4.2 Project 4.2

4.4.2.1 Outputs

Bailleul, F., Richardson, L., Van Ruth, P., McMahon, C.R., Harcourt, R.G., Middleton, J., Ward, T., Goldsworthy, S.D. Animal-borne instruments provide new observations of seasonal subsurface oceanographic features over the continental shelf of the Great Australian Bight. Deep Sea Research II (submitted).

Bailleul, F., Goldsworthy, S., Mackay, A., Rogers, P., Page, B., McKenzie, J., Baylis, A., Jonsen, I., Hindell, M. Biologically important areas for iconic species and apex predators in the Great Australian Bight (in prep).

Bailleul, F., Goldsworthy, S.D., Rogers, P.J., Mackay, A.I., Jonsen, I., Hindell, M. Patterson, T., 2017. Identifying biologically important areas for iconic species and apex predators in the Great Australian Bight. Great Australian Bight Research Program. GABRP Research Report Number 23. SARDI Aquatic Sciences, Adelaide, 116 pp.

Bailleul, F., van Ruth, P., Patten, N., Redondo Rodriguez, A., Doubell, M., Harcourt, R., McMahon, C., Goldsworthy, S. Estimating primary production in continental shelf areas using instrumented animals as environmental data collectors (in prep).

Bailleul, F., Goldsworthy, S., van Ruth, P., Harcourt, R., McMahon, C. Assessing the smallest by one of the biggest: Australian sea lions as investigators of primary production in the Great Australian Bight. Australian Marine Science Association conference, Geelong, 5–9 July 2015

Bailleul, F., Goldsworthy, S., Mackay, A., Rogers, P., Page, B., McKenzie, J., Baylis, A., Jonsen, I., Hindell, M. The places to be in the Great Australian Bight: Areas of Ecological Significance for multiple iconic species. 21st Biennial Conference on the Biology of Marine Mammals, San Francisco USA, 13–18 December 2015

Bailleul, F., 2015. In the eyes of the lion…Looking at behaviour and habitat of Australian Sea Lions and other iconic marine predators in the GAB region. SARDI Seminar Series, SARDI Aquatic Sciences, Adelaide, 25 May 2015.

This project developed a number species distribution models for the GAB ecosystem.

4.4.2.2 Outcomes

This project facilitated the first regional integration of tracking and survey data available for 11 species of marine predators in the GAB. The main outcome of the project is the clear identification of two key regions in the GAB highly-used by predators, especially for foraging: the eastern and central GAB (Region 1), and the south coast of Western Australia (Region 2).

The presence of such a diversity of predators in these systems, especially during summer when productivity is strongly enhanced, implies the development of rich local ecosystems from the sea bottom to the surface underpinned by the unique and complex oceanographic features of the region. Conservation and management of these ecosystems is challenged by the marked intra- and inter-annual variation in environmental and oceanographic conditions with direct implications for economic aspects of the GAB including fisheries, aquaculture and tourism. For individual species, such variability may impact migratory patterns, distribution, abundance and residency times, leading to marked variation in apex predator community structure and the locations and extent of highly used regions' distribution in both space and time.

4.4.3 Project 4.3

4.4.3.1 Outputs

Davies, C., Evans, K., Patterson, T., and Eveson, P., Overview of SBT spatial dynamics project and wider Great Australian Bight Research program. CCSBT Scientific Committee 2012, 2013, 2014, 2015, 2016.

Evans, K. Great ocean wanderers: southern bluefin tuna. Portland Upwelling Festival, Portland, Australia, 1 November 2014.

Evans K. Southern bluefin tuna: spatial dynamics and potential impacts of noise associated with oil and gas exploration. Australian Southern Bluefin Tuna Industry Association science workshop, Port Lincoln, Australia, 27 November 2014.

Evans K, Davies C, Eveson P, Patterson T. 2015. Southern bluefin tuna spatial dynamics and potential impacts of noise associated with oil and gas exploration. ASBTIA industry workshop, Port Lincoln, 11 November 2015.

Evans K, McCauley R, Eveson P, Patterson T. A summary of oil and gas exploration in the Great Australian Bight with particular reference to southern bluefin tuna. Deep Sea Research II (submitted).

Evans, K., Patterson, T., Eveson, P., Davies, C. Multi-decadal variability in the spatial dynamics of juvenile southern bluefin tuna. Fifth Symposium on Biologging Science, Strasbourg, France 22–27 September 2014.

Evans K, Patterson T, Eveson P, Davies C, Lansdell M, Hobday A, Cooper S. Multi-decadal variability in the spatial dynamics of juvenile southern bluefin tuna. Fourth International Conference on the Effects of Noise on Aquatic Life, Dublin, Ireland 10-15 July 2016.

Evans K, Patterson T, Eveson P, Hartog J, Hobday A, Cooper S, Lansdell M, Davies C. Southern bluefin tuna spatial dynamics and potential impacts of noise associated with oil and gas exploration. ASBTIA industry workshop, Port Lincoln, 15 November 2016.

Evans K, Patterson T, Eveson P, Hartog J, Hobday A, Cooper S, Lansdell M, Davies C. A summary of research on juvenile southern bluefin tuna as part of the Great Australian Bight Research Program. CSIRO, Hobart.

Evans, K., Patterson, T., Eveson, P., Hobday, A., Lansdell, M., Cooper, S., Davies, C.R. 2017. Southern bluefin tuna: spatial dynamics and potential impacts of noise associated with oil and gas exploration. Great Australian Bight Research Program. Great Australian Bight Research Report Number 18. CSIRO Oceans and Atmosphere, Hobart, 95pp.

Eveson P, Patterson T, Hartog J, Evans K. Modelling surfacing rates of southern bluefin tuna in the Great Australian Bight. Australian Marine Science Association Conference, Darwin, Australia 2–6 July 2017.

Eveson P, Patterson T, Hartog J, Evans K. Modelling surfacing rates of southern bluefin tuna in the Great Australian Bight. Deep Sea Research II (submitted).

Patterson TA. Statistical classification of feeding activity in southern bluefin tuna (*Thunnus maccoyii*) (in prep).

Patterson TA, Eveson JP, Hartog J, Evans K, Hobday AJ, Cooper S, Lansdell M, Davies C. Cyclical migration dynamics in juvenile southern bluefin tuna. Australian Marine Science Association Conference, Darwin, Australia 2–6 July 2017.

Patterson TA, Eveson JP, Hartog J, Evans K, Hobday AJ, Cooper S, Lansdell M, Davies C. Cyclical migration dynamics in juvenile southern bluefin tuna (in prep).

Patterson TA, Eveson JP, Hartog J, Evans K, Hobday AJ, Davies CR. Separating observation uncertainty from individual variability in movement and migration: a step toward more accurate habitat prediction for large pelagic predators. Third CLIOTOP Symposium, San Sebastian, Spain 14–18 September 2015.

Patterson T, Hobday A, Hartog J, Eveson P, Davies C, Evans K. Seasonal residency and distribution of southern Bluefin tuna in the Great Australian Bight (in prep).

This project developed a number of new quantitative models of behaviour of SBT in the GAB ecosystem and generated new datasets for juvenile SBT via five archival tag returns.

4.4.1.2 Outcomes

This project has vastly improved our knowledge of the behaviour of juvenile SBT and has progressed quantitative approaches for assessments of the behaviour of juvenile SBT in relation to their environment. It also has provided for the ongoing collection of data from juvenile SBT into the near future; tags deployed under this study are likely to continue to be returned over the coming years, adding to the dataset generated by this study. The predictive models developed and results obtained in this project, along with the results of the oceanography and pelagic themes of the Great Australian Bight Research Program, provide the necessary foundation for the design and implementation of targeted research projects to directly address the questions of the interaction of physical and biological oceanography, meso-pelagic abundance and distribution and higher order predator spatial and trophic dynamics.

Further collection of movement and behaviour from individuals tagged with archival tags under this project provides the opportunity for monitoring the dynamics of juvenile SBT as the rebuilding

program for the population progresses. If, as the population recovers, the increase in population is reflected in changes in the distribution of juveniles, archival tags deployed under this study will provide important data for monitoring these changes.

5. CONCLUSION

This Theme has facilitated the collection of new data on iconic species and apex predators, progressed quantitative approaches for assessments of the behaviour of these species and increased our understanding of the status, distribution, behaviour and habitat use of iconic species and apex predators in the GAB marine ecosystem. Seasonal variability in productivity in the GAB most likely drives the occurrence of migratory species in the GAB during the austral summer and autumn months, and the distributions and productivity of marine predator populations that occur within the GAB. The predictive models developed and results obtained by this Theme, along with the results of the oceanography and pelagic themes of the Great Australian Bight Research Program, provide the necessary foundation for the design and implementation of targeted research projects to directly address the questions of the interaction of physical and biological oceanography, meso-pelagic abundance and distribution and higher order predator spatial and trophic dynamics.

A number of marine predators that occur within the GAB have been impacted by historical pressures on populations and some continue to decline despite protection. Anthropogenic activities (such as oil and gas exploration, shipping) and anthropogenically sourced pressures (such as climate change) have been increasing in the GAB over the last two decades (see Evans et al. 2017 for broader discussion of pressures on the marine environment). Whilst it is certain some pressures will continue to exert further pressure on the marine ecosystems of the GAB (e.g. climate change) and it is almost certain that some will continue to increase given ongoing increases over the last decade (e.g. shipping), whether some of the other pressures will continue to increase (e.g. oil and gas exploration) is largely unknown and will depend on many social and economic factors. How these will impact populations of iconic species and apex predators in the GAB and what will be the associated responses of individuals remains, at least at present, unknown. Ongoing monitoring of marine predator populations will be essential for understanding how these populations respond and are impacted by the pressures placed on them, identifying risks associated with pressures and prioritising and evaluating management of both populations and the pressures impacting them into the future.

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