GREAT AUSTRALIAN BIGHT RESEARCH PROGRAM

RESEARCH REPORT SERIES

Socio-ecological systems of the Great Australian Bight: synthesis of results and findings

Final Synthesis Report GABRP Project 7.1

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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

LIST OF TABLES

EXECUTIVE SUMMARY

The Great Australian Bight Research Program (GABRP) was established to develop scientific knowledge, tools and baselines to inform and support future use, development, management and conservation of the socio-ecological systems of the Great Australian Bight (GAB). The program filled key knowledge gaps on the structure and function of the Bight's ecosystems; the nature and value of its marine industries, including its potential hydrocarbon reserves; and the dependence of the GAB's coastal communities on the amenities provided by the ecosystem.

Critical new scientific knowledge developed in the GABRP include:

- refined understanding of the hydrodynamic processes underpinning the ecosystem;
- new insights into factors driving pelagic productivity and supporting the region's rich pelagic communities, including its diverse assemblage of apex predators and iconic species;
- greater awareness of region's pelagic and benthic biodiversity and endemism, especially in the deep ocean beyond the continental shelf;
- identification of at least 277 species that are new to science and almost 1000 species not previously reported in the GAB;
- improved understanding of the biology and ecology of the region's diverse assemblages of marine mammals, seabirds and sharks;
- improved understanding of the migratory and foraging patterns of southern bluefin tuna;
- confirmation of oil and gas migration in the GAB;
- collation of historical information of seismic activity in the GAB; and
- improved understanding of the values and priorities of people living in the GABs coastal townships.

Valuable new scientific tools developed during the program that provide a significant legacy for future scientific studies, monitoring programs and management advice include:

- a nested suite of improved hydrodynamic models;
- a new tool for sampling pelagic ecosystems (Profiling Lagrangian Acoustic Optical System)
- a new tool for sampling benthic communities (multi-corer);
- habitat models and molecular identification tools for pelagic and benthic species;
- distribution and foraging habitat models for iconic species and apex predators;
- improved statistical methods for estimating the position of SBT from archival tags, and examining their feeding behaviour, habitat preferences and seasonal distribution patterns;
- a model for assessing the economic impacts of future developments; and
- two ecosystem models for evaluating future development scenarios.

The GABRP has transformed the deep ecosystems of the GAB from one of Australia's least studied environments to one of the most well known.

INTRODUCTION

Background

The Great Australian Bight (GAB) extends from Cape Pasley, Western Australia to Cape Catastrophe, Kangaroo Island, South Australia (Figure 1). It is part of the world's longest southern facing coastline and has complex oceanographic features including: a large coastal upwelling system, which enhances the region's productivity; two large inverse estuaries; and a large swell regime (Rogers et al. 2013). The GAB's unusually broad continental shelf supports the world's largest temperate carbonate production system and high levels of benthic biodiversity and endemism. The region has global conservation significance, providing critical habitats and migration pathways for iconic species and apex predators, including Australian sea lions, white sharks, and pygmy blue whales. Australia's largest and most valuable stocks of pelagic fishes, especially Australian sardine and southern bluefin tuna, occur in the GAB, and there are important coastal fisheries for crustaceans (e.g. prawns, southern rock lobster), molluscs (e.g. abalone) and finfish (e.g. snapper, flathead). The GAB is also considered to be one of the most prospective under-explored oil and gas provinces in the world (Rogers et al. 2013).

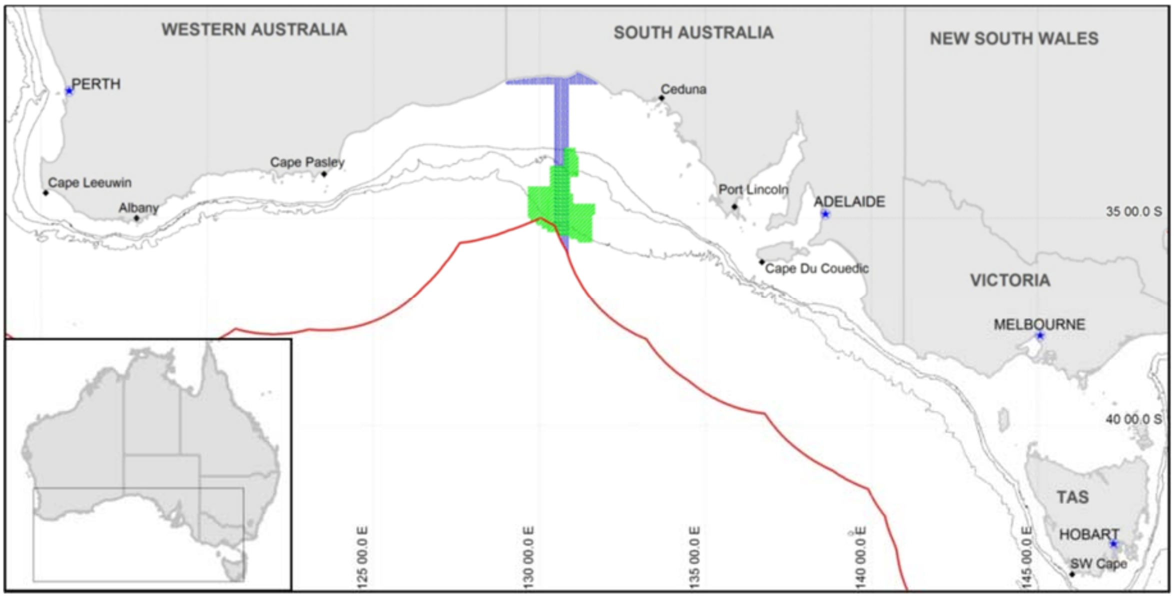


Figure 1. The Great Australian Bight showing the 100 m, 1000 m and 4000 m isobaths and locations mentioned in the text. The Great Australian Bight Marine Reserve is shown in blue and areas that were permitted for oil/gas exploration by BP are shown in green.

The Great Australian Bight Research Program (GABRP) was established in April 2013. It was a four year $20M integrated study of the ecological processes and socio-economic values of the GAB. It was undertaken as a collaborative program involving BP, CSIRO, the South Australian Research and Development Institute (SARDI), the University of Adelaide, and Flinders University of South Australia.

A literature review undertaken prior to the commencement of the program (Rogers et al. 2013) showed that previous research had focused mainly in coastal and shelf waters and that the deep water ecosystems of the GAB were poorly understood. The review identified key knowledge gaps that were addressed through sixteen inter-related projects conducted in the program's seven research themes:

- Physical Oceanography (Middleton *et al.* 2017; Griffin *et al.* 2017);
- Pelagic Ecosystem and Environmental Drivers (Kloser *et al.* 2017; van Ruth *et al.* 2017);
- Benthic Biodiversity (Williams *et al.* 2017; Tanner *et al.* 2017);
- Ecology of Iconic Species and Apex Predators (Goldsworthy *et al.* 2017; Bailleul *et al.*2017; Davies *et al.* 2017);
- Petroleum Geology and Geochemistry (Ross *et al.* 2017a, b; Kempton *et al.* 2017);
- Socio-economic Analysis (Beer and Thredgold 2017; O'Neil *et al.* 2017; Pascoe and Innes 2017a, b);
- Data Integration and Ecosystem Modelling (Fulton *et al.* 2017; Ward et al. 2017).

The references listed for each theme refer to the project reports listed on page 100. These were the source documents used to compile this synthesis report.

Objective and rationale

The objective of the GABRP was to develop scientific knowledge, tools and baselines to inform and support future use, development, management, and conservation of the socio-ecological systems of the GAB

The objective of this report is to synthesise the results and findings of the GABRP in a format and level of detail that will be of use to those undertaking future management-related studies in the GAB, including other research groups proposing or undertaking whole-of-system studies to enhance sustainable management of large, remote regions.

The report is also designed to be a one-stop resource document on the scientific outcomes of the GABRP for use by stakeholders, policy-makers and resource managers with interests and responsibilities in the GAB.

PHYSICAL OCEANOGRAPHY

The Physical Oceanography Theme consisted of two projects. The first investigated the seasonal, inter-annual and spatial circulation patterns in the GAB and provided knowledge to underpin studies of regional hydrodynamic connectivity, pelagic productivity, benthic assemblages, and the ecology of iconic and apex predators (Middleton *et al.* 2017). The second project investigated the effects of surface gravity (swell and wind) waves on circulation patterns and transport of biota, nutrients and pollutants (Griffin *et al.* 2017). The theme generated critical information and tools used by other themes. The knowledge and models developed and refined in the Physical Oceanography Theme are significant legacies of the GABRP.

Circulation patterns

Three hydrodynamic models (two shelf-focused, ROMS and SHOC; one deep-sea focused, BRAN) were used to investigate the circulation patterns in the GAB (Figure 2, 3, 4). Model results matched well with variability in shelf ocean currents observed by five moorings during 2011-2014 (Figure 2, 3, 4). Shelf tidal signals and seasonal variability in shelf currents were well reproduced by the shelf models. Currents and vertical structure in depths greater than 300m were not predicted well by the shelf models.

Shelf circulation in the GAB responds strongly to seasonal winds, with winter circulation driven by i) eastward winds, ii) the eastward shelf edge Leeuwin Current (LC), and iii) deep (200-800 m) upwelling in the west, where the westward deep Flinders Current (FC) is strongest (Figure 2, 3, 4). In the east, the eastward South Australian Current (SAC) is strongest over the shelf break and acts as an extension of the LC, with speeds of up to 20 cm/s. Near the coast, eastward winds drive an eastward Coastal Current (CC). Shelf downwelling is expected from eastward shelf currents and the formation of dense (cold, salty) water along the coast, where evaporation exceeds precipitation year-round. The presence of saline bottom water in the model results for shelf and coastal waters supports this view.

In summer, “westward” winds driven by large high pressure systems a) drive coastal upwelling and a westward CC in the central to eastern GAB and b) lead to a topographic southward Sverdrup transport in the central GAB (Figure 2, 3, 4). The latter is important as the topographic transport “collides” with the equatorward deep ocean transport leading to a) downwelling all year round at the shelf edge and b) a ridge in sea level that drives the SAC to the east against the prevailing winds. Deep (500 m to 1000 m) upwelled water is found in the central to western GAB suggesting the existence of a deep FC.

Data from deep-sea gliders deployed in the central GAB in depths of 200 to 1000 m in September 2014, April 2015 and April 2016 identified the depression of isotherms at the shelf edge, consistent with our understanding of the LC. Some evidence was obtained to support the existence of the FC, but this was overshadowed by relatively weak, spatially complex and variable flows associated with both meso-scale and sub-mesoscale eddies. Intermittent and strong tidal and inertial band variations found in data from the deep BP mooring (~ 100 – 1420 m) were not particularly well reproduced by the models.

As well as the strong seasonal cycle of the LC, there is a high level of inter-annual variation. In some years, transport exceeded 8 Sverdrup whereas in 2015 it dropped to near zero.

Importance of waves

Including wave information by running fully coupled wave-current models did not improve our ability to simulate the structure of the ocean or surface currents. The quantity most influenced by waves is surface drift. In one model, classical Stokes Drift was cancelled out by the hydrodynamical response to Stokes-Coriolis forcing. In the other model, an additional ~5 cm/s shoreward drift eventuated. This velocity would take buoyant surface matter from the shelf edge to the shore within a month - significantly faster than if the effect of waves is ignored.

Key findings and legacies

The primary legacy of the Physical Oceanography Theme is the nested suite of improved hydrodynamic models available for use in future research projects. These models, in conjunction with new data obtained during the GABRP, have provided a refined understanding of the circulation processes in the GAB, especially upwelling in the eastern GAB. The value of these tools is demonstrated in the particle tracking studies undertaken to determine the likely sources of tarballs and asphaltites occurring on beaches of the eastern GAB. The particle tracking capability established will assist future studies that examine recruitment pathways for commercial fish stocks.

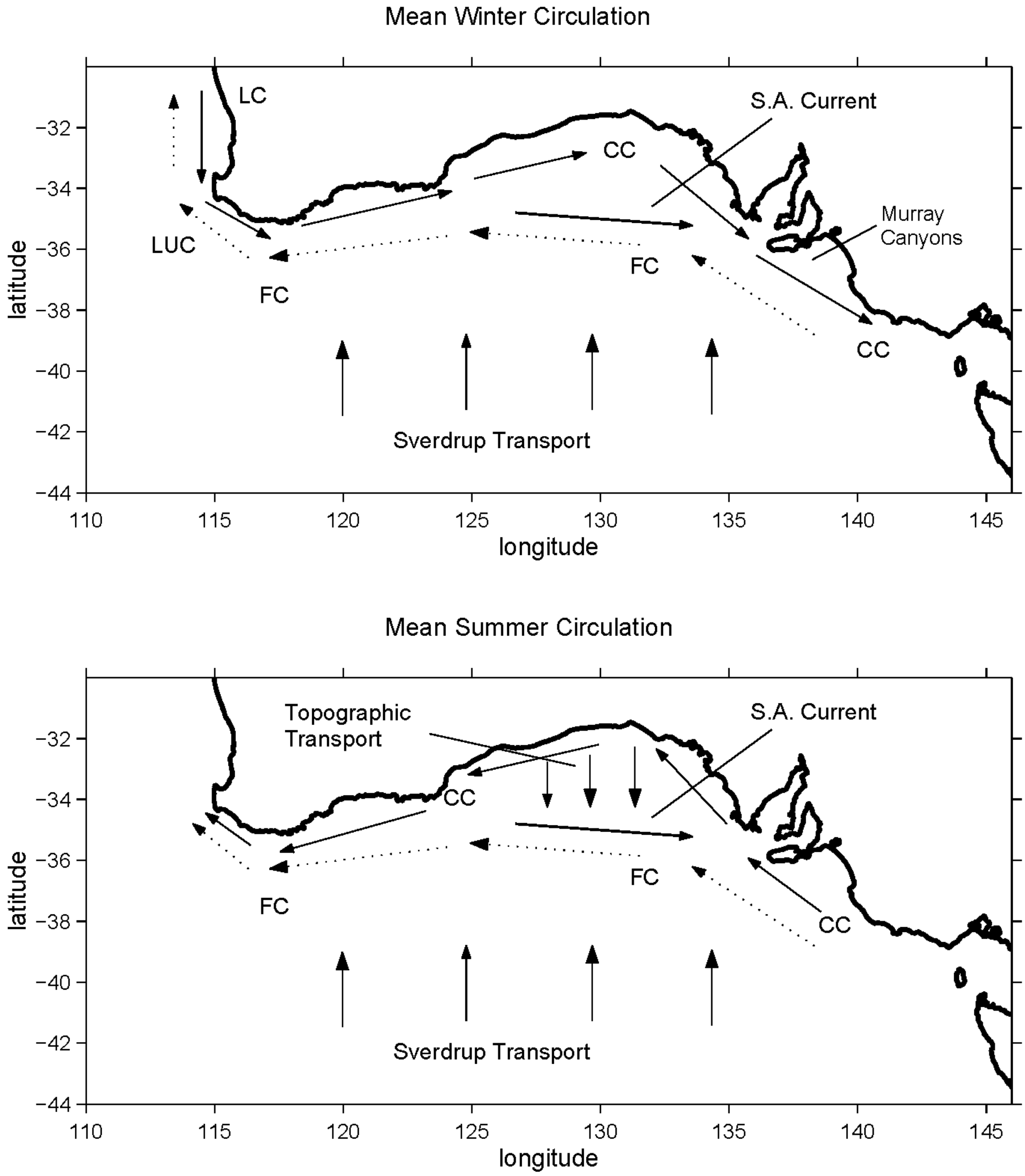


Figure 2. Schematic of Mean Winter (top) and Summer (bottom) Circulation. The major currents are the Coastal Current (CC), Leeuwin Current (LC), Leeuwin Under Current (LUC), Flinders Current (FC) and S.A. Current (SAC).

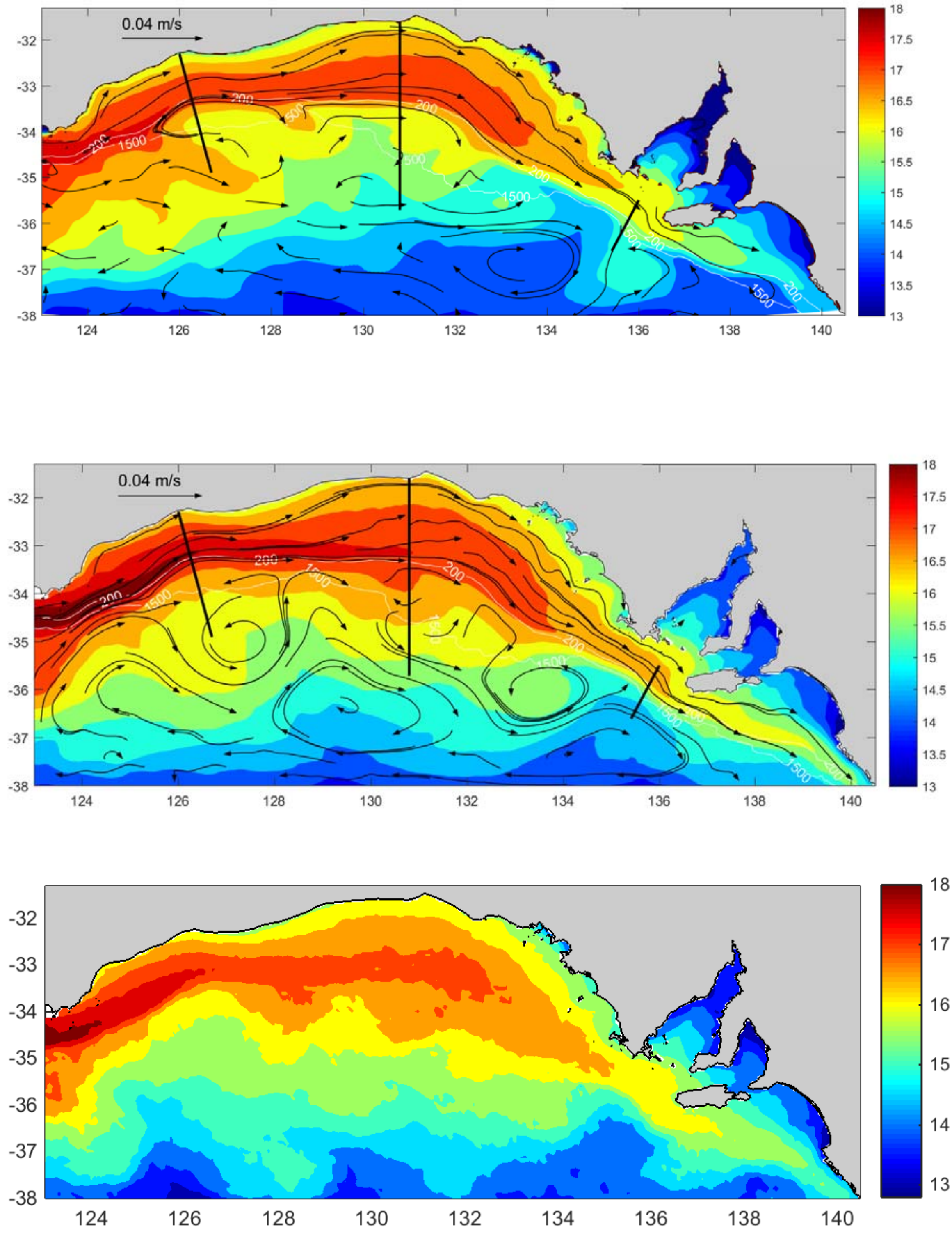


Figure 3. Winter SST and depth-averaged currents for 2011-2012 from ROMS (top), SHOC (middle) and NOAA AVHRR SST satellite data (bottom). Units: m/s and a vector arrow of length 0.04 m/s is shown. Average SST is shown on colour bar in ° C.

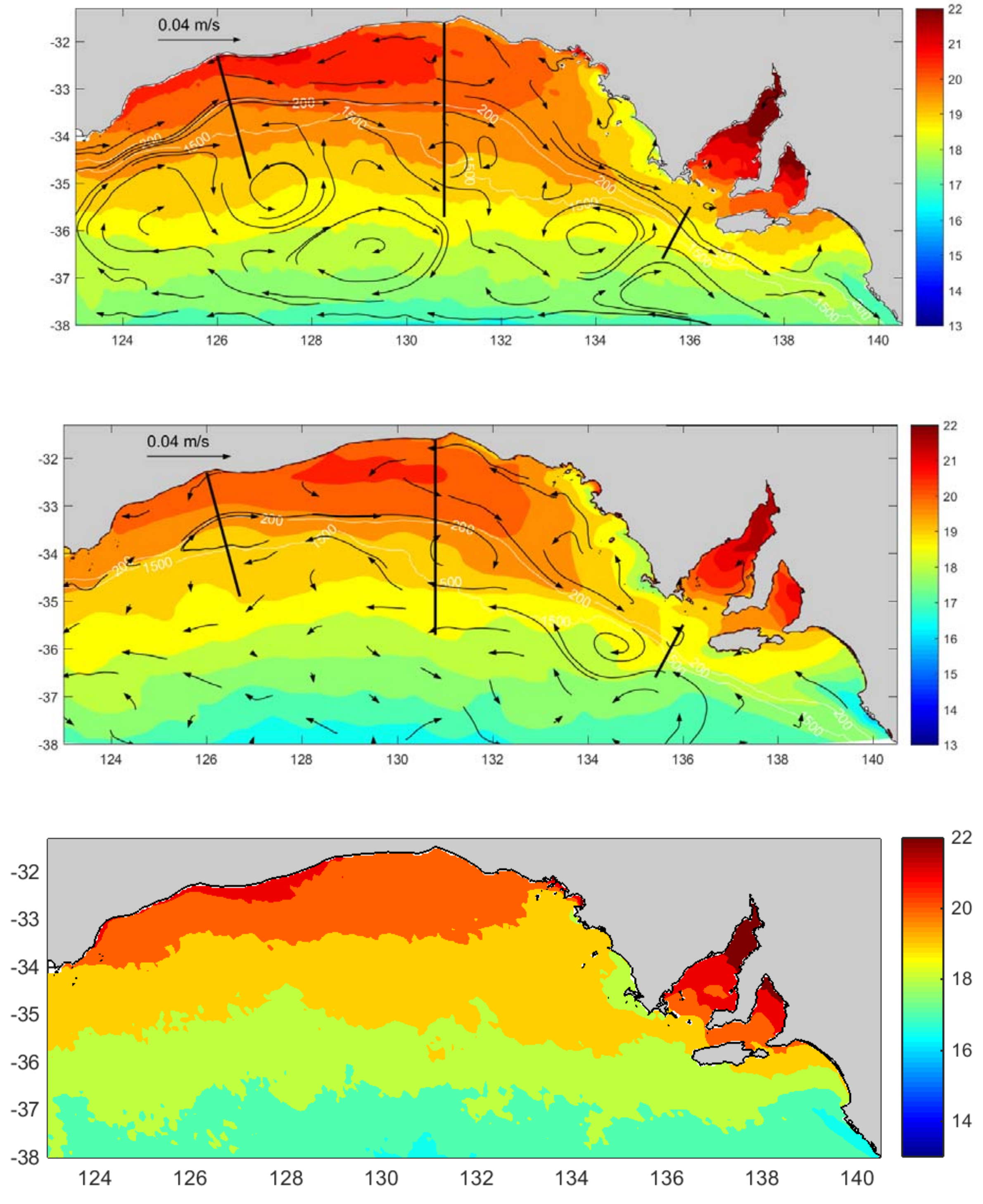


Figure 4. Summer SST and depth-averaged currents for 2011-2012 from ROMS (top), SHOC (middle) and NOAA AVHRR satellite data (bottom). Units: m/s and a vector arrow of length 0.04 m/s is shown. Average SST is shown on colour bar in ^{o}C.

PELAGIC ECOSYSTEM AND ENVIRONMENTAL DRIVERS

The Pelagic Ecosystem and Environmental Drivers Theme was comprised of two projects, one focusing on shelf waters (van Ruth *et al.* 2017) and the other on the deep continental margin (Kloser *et al.* 2017). Each project compared food web structure and productivity in the eastern and the central GAB. Both projects investigated the hypothesis that the productive “classic food web” dominates in the eastern GAB during periods of upwelling, and that the microbial loop prevails in the central GAB.

Shelf microbial and plankton communities

Physical and chemical data were collected from the *RV* Ngerin between November 2008 and April 2012 (Figure 5). Water samples for nutrient analysis concentrations were collected from a site off Kangaroo Island (NRSKAI, Figure 5) monitored as a part of the National Reference Station Network of the Australian Integrated Marine Observing System (IMOS). Remote sensed daily primary productivity data were obtained from the Australian Ocean Data Network (AODN) portal of IMOS.

A conceptual model of upwelling processes in the eastern GAB showing the five scenarios identified is shown in Figure 6. The upwelling season in the eastern GAB begins during November and ends in April. However, downwelling events also occur during this period The duration and intensity of upwelling varies among years, but neither are closely linked to interannual variations in the level of surface primary productivity. Remote sensed estimates of daily integral primary productivity appear to underestimate primary productivity in the eastern GAB because they do not account for productivity below the surface. Cool (<15°C) water with high nitrate concentrations rarely occurrs on the shelf until relatively late in the season (January to March, Figure 7). The early upwelling season is a pre-conditioning period (Figure 6) that is critical to the development of the pool of cool water that forms off Kangaroo Island, facilitates late season enrichment events and drives overall seasonal productivity. The intensity and number of upwelling/downwelling events during the pre-conditioning period determine the volume of water drawn onto the shelf and the level of nutrient enrichment in the euphotic zone late in the upwelling season (Figure 6). Enriched water does not need to reach the surface to drive high levels of primary productivity; significant primary production occurs below the surface.

Temperatures measured at three depths (5, 40 and 100 m) were used to assign sampling events to one of the five scenarios (Figure 6). Scenarios of moderate and strong upwelling mainly occurred in the late upwelling season; strong upwelling was recorded only once in the early upwelling season (November 2015). The highest average NO_x concentrations occurred in deep water during moderate

and strong upwelling (Figure 7). Highest average concentrations of picophytoplankton occurred under strong upwelling (Figure 8). High Chl *a* concentrations occurred at the subsurface maxima during strong and moderate upwelling (Figure 9). The highest zooplankton biomass occurred during strong upwelling and the lowest when upwelling was suppressed by downwelling favourable winds (Figure 10). In contrast, the highest average zooplankton abundance occurred during winter mixing and preconditioning. The lowest zooplankton abundances occurred under suppression. Copepods abundances were on average highest during strong upwelling.

Small phytoplankton (e.g. nanoplankton, picoplankton, picoeukaryotes, bacteria and viruses) present in the eastern GAB throughout the year persist during periods of upwelling. Larger phytoplankton (e.g. diatoms) are layered on top of the existing microbial food web during upwelling rather than replacing it. Diatom biomass only dominates in the eastern GAB under extreme enrichment conditions. The classic trophic pathway from diatoms to mesozooplankton occurs in the eastern GAB when nutrient rich waters enter the photic zone during strong upwelling, however it co-occurs with a diatom to dinoflagellate to mesozooplankton pathway. The latter may be the more typical trophic pathway in eastern GAB waters, except during periods of strong upwelling. The mechanism for higher numbers of phytoplankton (diatoms, flagellates and *Synechococcus*) and subsequent enhanced zooplankton biomass during pre-conditioning, does not seem to be associated with upwelling of nutrient rich water into the euphotic zone, but is likely related to other changes in hydrographical conditions and the physiological responses of the phytoplankton community. The pre-conditioning scenario may not only provide a bottom layer of high nutrients to enhance biomass and production during upwelling, but may also start the trophic transfer from the lower food web (pico–, nano– and micro–plankton) to higher trophic levels in early spring and summer. High concentrations of SiO_2 in the water column (~1 µM) during winter-mixing in the absence of elevated concentrations of other nutrients supports previous suggestions that there is an additional source of SiO_2 in the GAB not associated with upwelling.

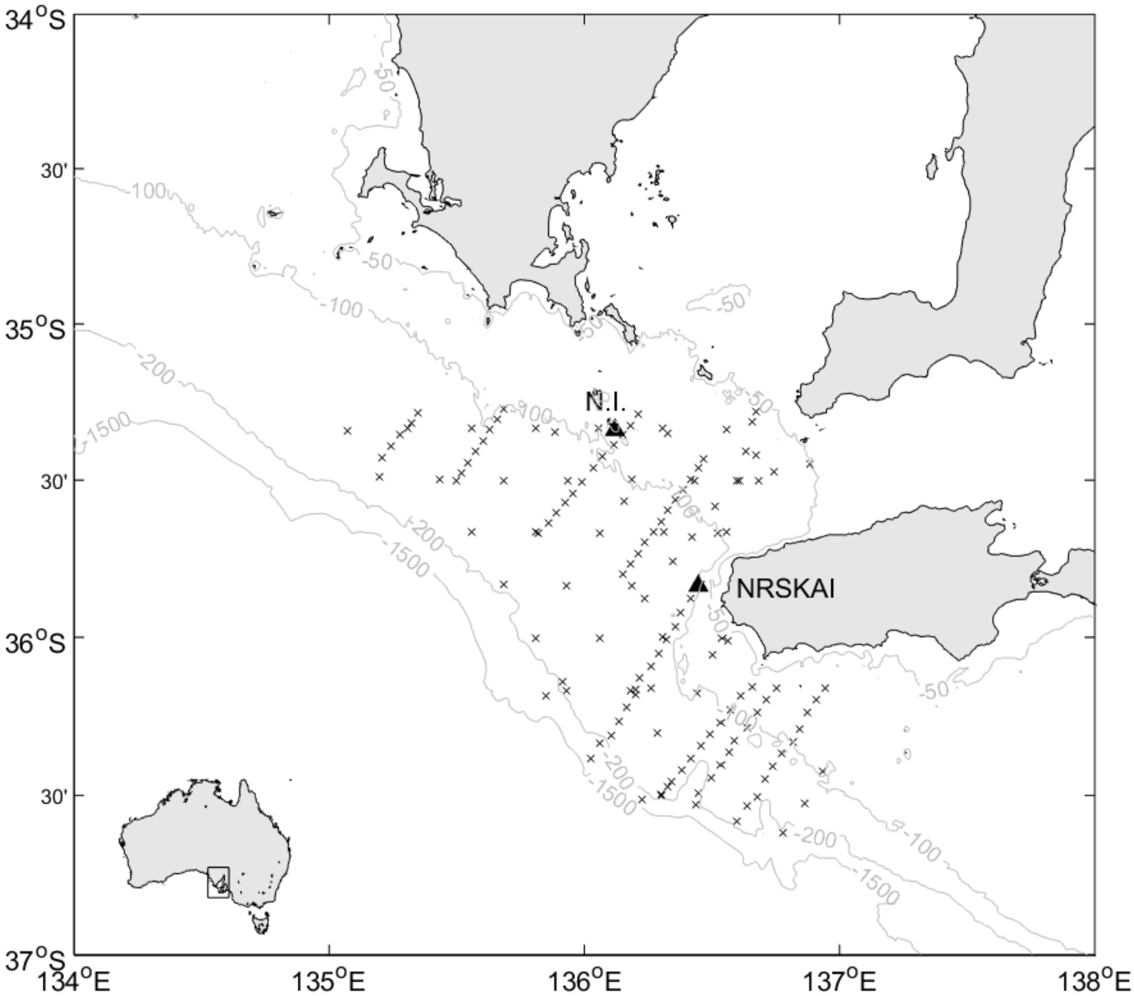


Figure 5. Regional map showing the location of the IMOS national reference station NRSKAI, the location of the Neptune Island weather station (N.I.) and CTD profiling sites (crosses).

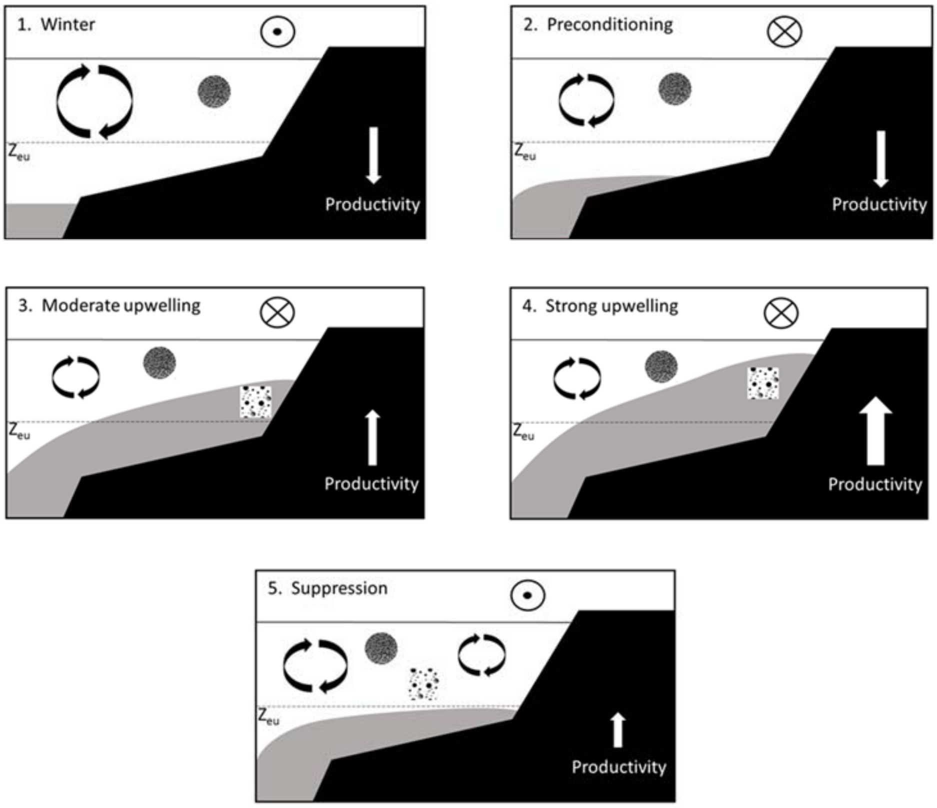


Figure 6. Refined conceptual model of variation in the influence of upwelling/downwelling on mixing, water mass characteristics, primary productivity and food web dynamics in shelf waters of the eastern Great Australian Bight. dot in circle = wind coming out of the page (i.e. south westerly), cross in circle = wind going into the page (i.e. south easterly). = pico-phytoplankton, = microphytoplankton. The black shape denotes the shoreline and the shelf, the grey shape denotes enriched upwelled water. The dashed line indicates the euphotic depth (Z_{eu}). Black arrows indicate mixing, white arrows indicate the expected level of primary productivity.

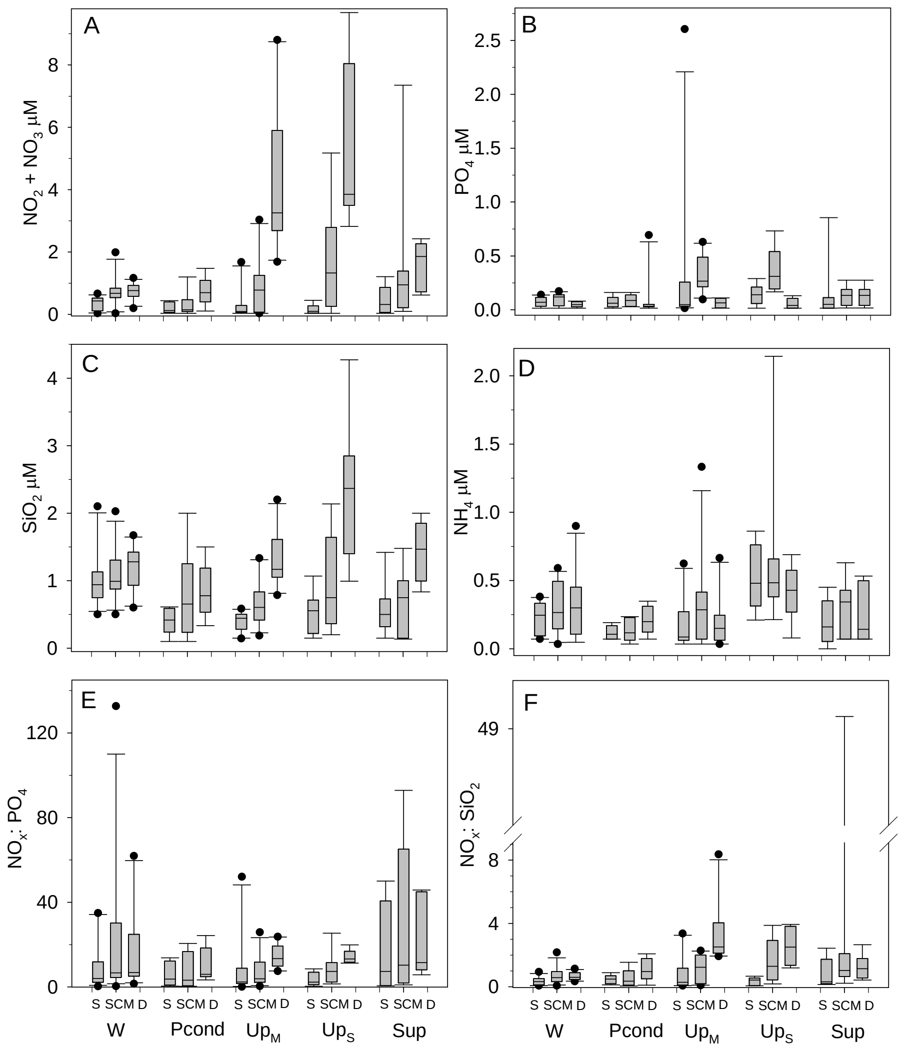


Figure 7. Box-plots of dissolved nutrient concentrations: (A) $NO_2 + NO_3$, (B) PO_4, (C) SiO_2 and (D) NH_4 and (E) NO_x: PO_4 ratios and (F) NO_x: SiO_2 ratios for surface (S), subsurface chlorophyll maxima (SCM) and deep samples (D) under different Scenarios of upwelling and downwelling in the eGAB; W = Winter-mixing, Pcond = Preconditioning, Up_M = moderate upwelling, Up_S = strong upwelling and Sup = Suppression (Figure 6). Values represent median (line) and 25th and 75th percentiles (lower and upper box value), with whiskers representing 10th and 90th percentiles and black circles representing values outside the 10th and 90th percentiles.

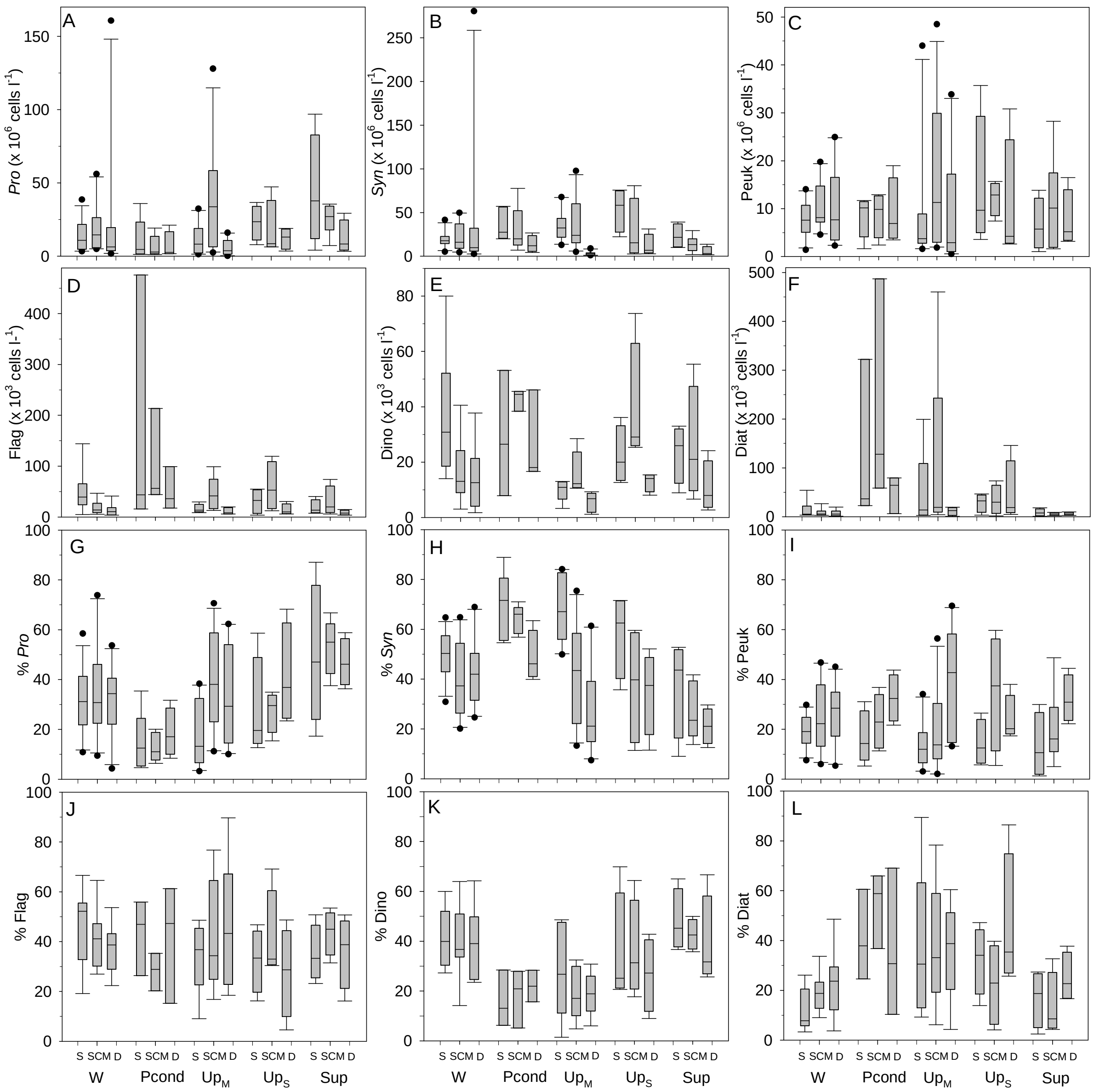


Figure 8. Box-plots of the abundances of picophytoplankton (A – C), larger (> 5 µm) phytoplankton (D – F) , percentages of individual picophytoplankton groups to total picophytoplankton abundance (G – I) and percentages of broad phytoplankton (> 5 µm) groups to total phytoplankton (> 5 µm) abundance (G – I) for surface (S), subsurface chlorophyll maxima (SCM) and deep samples (D) under different Scenarios of upwelling and downwelling in the eGAB; W = Winter-mixing, Pcond = Preconditioning, Up_M = moderate upwelling, Up_S = strong upwelling and Sup = Suppression (Figure 6). Values represent median (line) and 25th and 75th percentiles (lower and upper box value), with whiskers representing 10th and 90th percentiles and black circles representing values outside the 10th and 90th percentiles.

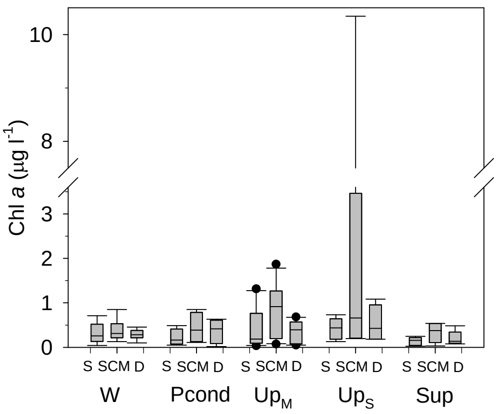


Figure 9. Box-plots of Chl a for surface (S), subsurface chlorophyll maxima (SCM) and deep samples (D) under different Scenarios of upwelling and downwelling in the eGAB; W = Winter-mixing, Pcond = Preconditioning, Up_M = moderate upwelling, Up_S = strong upwelling and Sup = Suppression (Figure 6). Values represent median (line) and 25th and 75th percentiles (lower and upper box value), with whiskers representing 10th and 90th percentiles and black circles representing values outside the 10th and 90th percentiles.

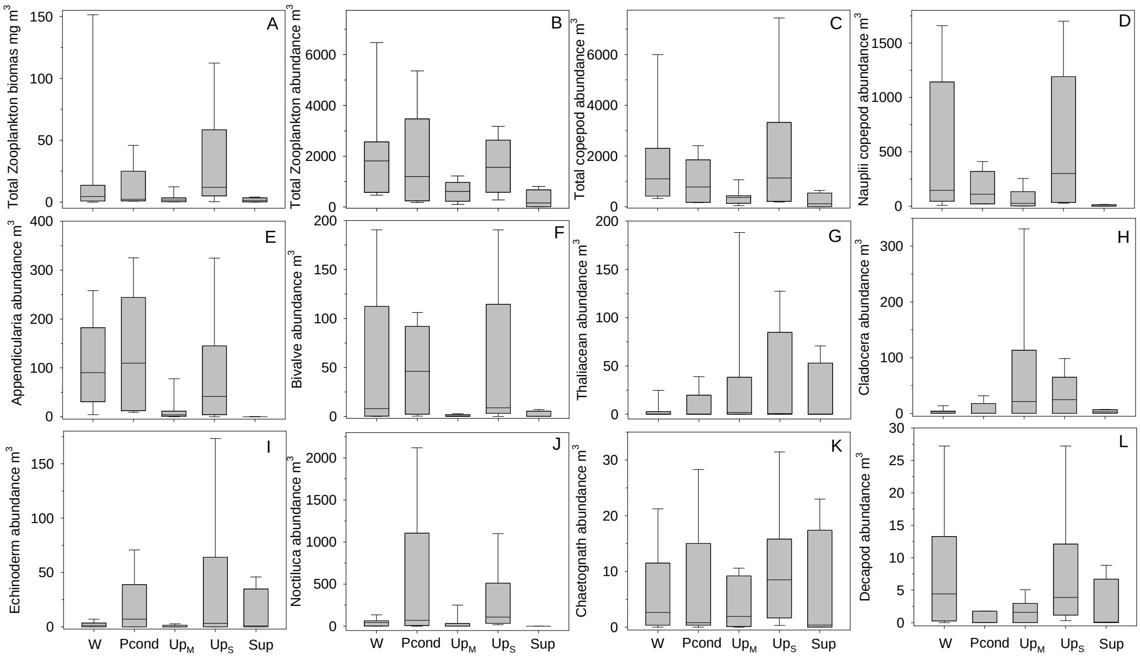


Figure 10. Box-plots of total zooplankton biomass (A) and abundance (B) and abundances of total copepod abundance (C), copepod nauplii (D), appendicularia (E), bivalve (F), thalecean (G), Cladocera (H), Echinoderm (I), *Noctilica scintilins* (J), chaetognath (K) and decapod (L) under different scenarios of upwelling and downwelling in the eGAB; W = Winter-mixing, Pcond = Preconditioning, Up_M = moderate upwelling, Up_S = strong upwelling and Sup = Suppression (Figure 6). Values represent median (line) and 25th and 75th percentiles (lower and upper box value), with whiskers representing 10th and 90th percentiles and black circles representing values outside the 10th and 90th percentiles.

Offshore/slope plankton and micronekton communities

The main source of information for the study of the offshore/slope communities of the GAB was obtained from nine days of pelagic plankton sampling undertaken from the *RV Investigator* during summer, December 2015 (Figure 11). The study demonstrated that different enrichment mechanisms drive primary productivity in the central and eastern GAB (Figure 12). In the east, upwelling produces sporadic and at times intense enrichment, whereas in the central GAB biological processes (nitrification) have a stronger influence and there is intermittent input from turbulent fluxes at the shelf edge (Figure 12). In the eastern GAB, productivity was driven by nutrient rich water above the euphotic depth (80-90 m), with the nutricline occurring at ~40-60 m (Figure 12). In the central GAB, the nutricline occurred at ~100 m, near the base of the euphotic depth (80-90 m, Figure 12). Investigations of nutrient sources and trophic pathways undertaken using stable isotope analysis supported the finding that the main nitrogen source in the eastern GAB was upwelled water and in the central GAB was nitrogen fixation (Figure 13, 14).

No differences were detected in the abundance or composition of microbial communities in the central and eastern GAB (Figure 15). The highest phytoplankton biomass occurred below the surface, with the peak (Chl maximum) occurring a 40–60 m in the eastern GAB and 80–90 m in the central GAB (Figure 16). High productivity in the eastern GAB was driven by the nutrient rich water above the euphotic depth, which contributed to a significant proportion of the total primary productivity. In the central GAB, productivity was highest at the base of the euphotic zone, but this made a minimal contribution to total primary productivity. Despite these differences, long-term mean levels of primary productivity are similar in the two regions. Primary productivity in the east is at times very high, but intermittent and variable. Primary productivity in the central GAB is more moderate and constant.

Nanoplankton (2 – 5 µm) dominated phytoplankton biomass in the east of the GAB, whereas picoplankton (< 2 µm) dominated the central GAB (Figure 17). Diatoms and dinoflagellates dominated the larger phytoplankton (> 5 µm) across the region (Figure 18). The highest zooplankton abundance and biomass occurred on the shelf in the eastern GAB (Figure 19). The zooplankton community in the eastern GAB was dominated by copepods, appendicularians, cladocerans, chaetognaths, echinoderms and the predatory dinoflagellate *Noctiluca*. In the central GAB, copepods, appendicularians and thalaceans were the dominant taxa. The meso-zooplankton community in the eastern GAB was more abundant and grazed at higher rates than in the central GAB.

Micronekton biomass, size and species composition in the eastern and central GAB were similar, with fish being the dominant taxon.. Retained micronekton biomass was higher in the eastern than the central GAB. Krill dominated the shelf break and upper slope. Multi-frequency acoustic estimates of biomass were similar (within 30%) between regions. The newly developed Profiling Lagrangian Acoustic Optical System suggested slightly higher biomass with larger individuals in the central upper slope compared to the east. Large numbers of fish schools were observed over the upper-slope and offshore in the central GAB. Overall, the micronekton communities of the GAB have bio-geographic affinities with those of the Subtropical Convergence.

Gelatinous species were an important component of the micronekton in the central GAB. A total of 18 new records of gelatinous organisms include two species new to science, three first reports of species in the Southern Hemisphere, three first reports in Australia and 10 first reports in the GAB, bringing the regions known species to 140 (Figure 32).

Findings of this study generally support the hypothesis that the microbial food web dominates in waters over the deep GAB continental margin, particularly in the central GAB, and the classic food web dominates in the eastern GAB during periods of nutrient-rich upwelling. However, despite these differences in food web dynamics, long-term patterns in primary productivity are relatively similar in the two regions, particularly on the upper slope. Rates of primary productivity in the eastern GAB are highly variable, with highest rates driven by upwelling. In the central GAB, primary productivity is more moderate, but linked to a constant, biologically-mediated supply of nitrogen that is sustained over long periods of time. These results show that the central GAB is an important contributor to overall productivity in the GAB.

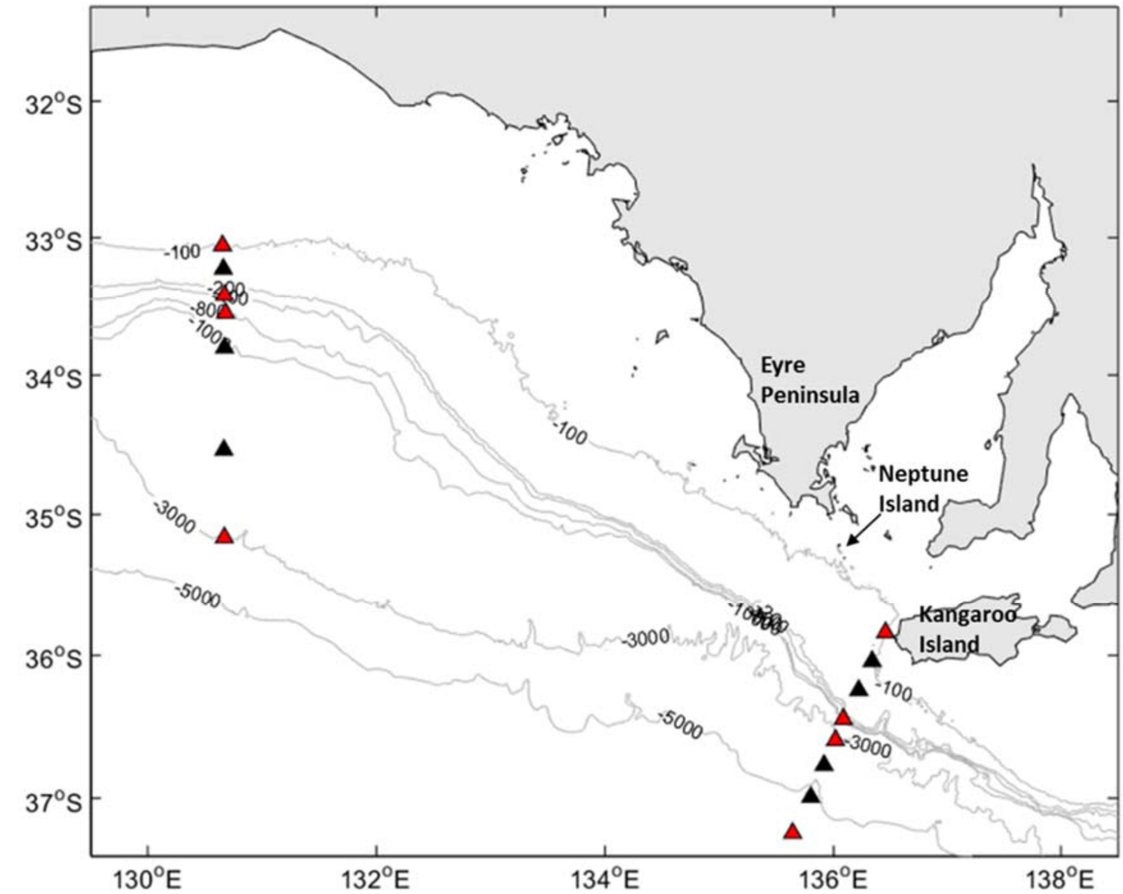
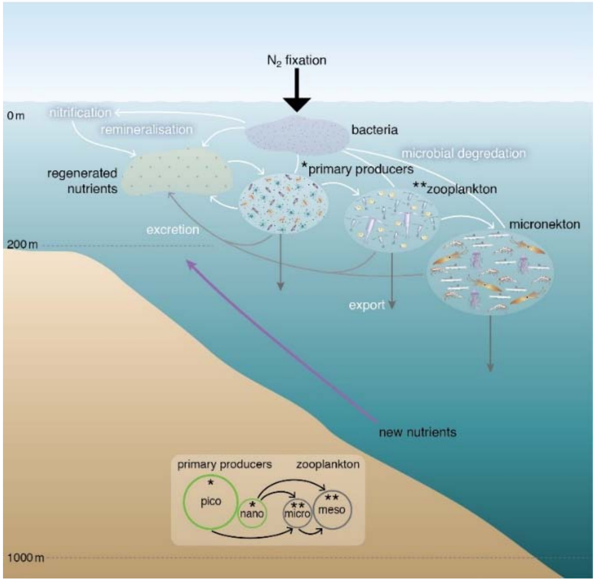


Figure 11. Location of CTD and microstructure profiling stations surveyed on the RV Investigator voyage in December 2015. The bathymetry of the region is described by the 100, 200, 400, 800, 1000, 3000 and 5000 m isobaths. CTD profiles were made at all stations (triangles) along cross-shelf transects in the central and eastern Great Australian Bight. Microstructure profiles were taken at stations identified by the red filled markers and corresponded with the 'shelf', 'upper slope', 'mid slope' and offshore 'oceanic' stations.

CENTRAL GAB



b.

EASTERN GAB

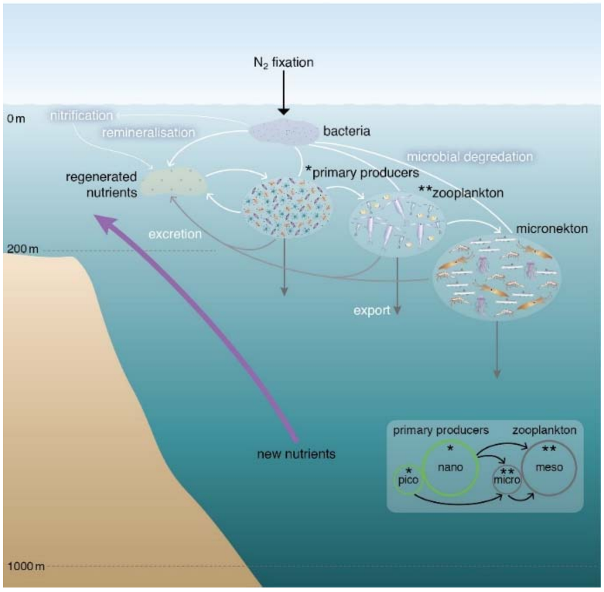


Figure 12. Diagram of functioning of the upper slope GAB highlighting dominant production drivers, (a). Central GAB where nutrient supply is constant but constrained and biological processes dominate nitrogen supply supporting production. (b), Eastern region where nutrient supply is characterized by addition of pulses of upwelled nutrients with a reduced pathway of biological processes. In general zooplankton and micronekton biomass is similar in the eastern and central region.

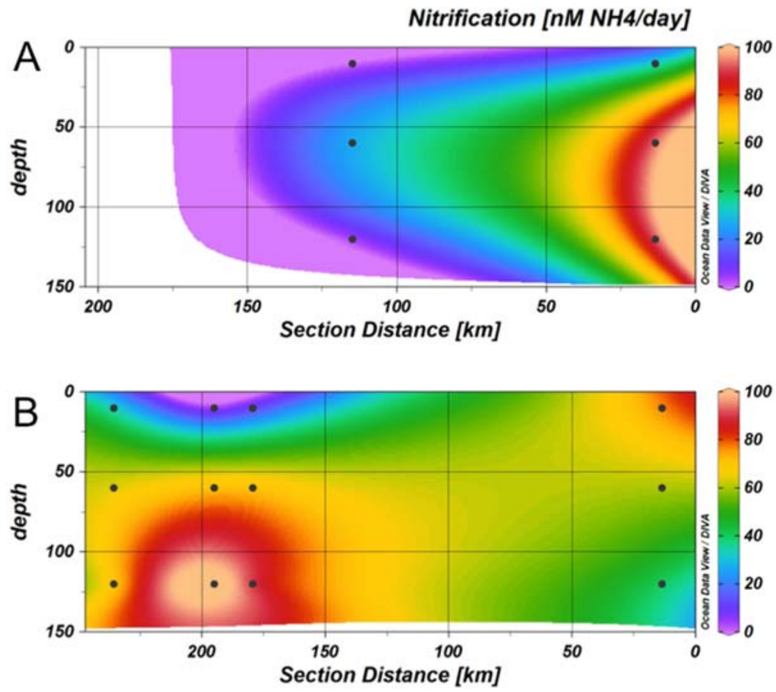


Figure 13. Ammonia oxidation rates (nM NH4 day-1) in (A) the eastern GAB, and (B) the central GAB. Sampling locations are indicated by black dots. Transects are shown from shelf waters on the left to offshore (ocean) waters on the right (broadly, from north to south). Data were plotted in Ocean Data View (ODV) using DIVA gridding.

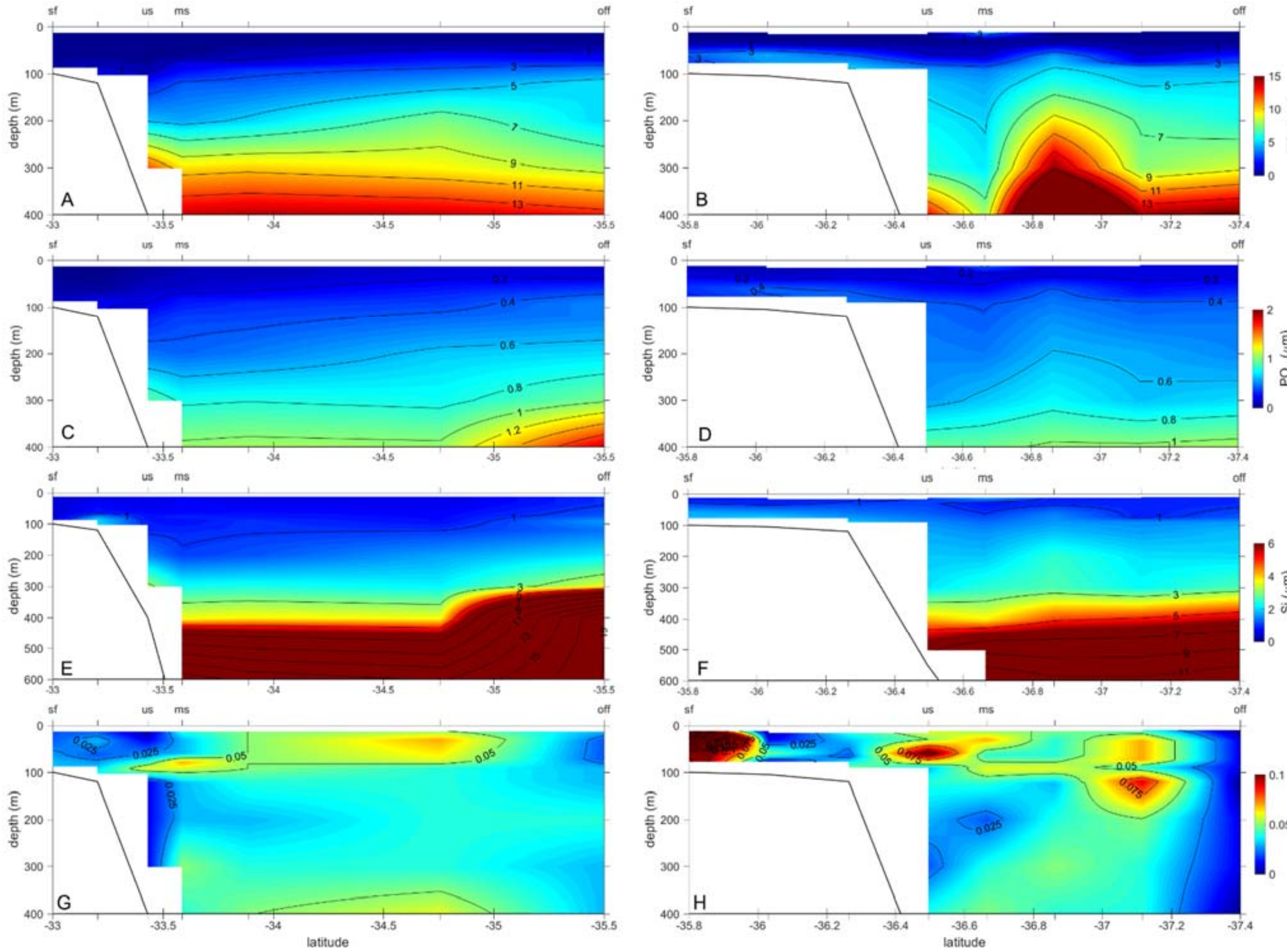


Figure 14. Dissolved nutrient plots of Nitrate + Nitrite (A – B), Phosphate (C – D), Silica (E – F) and Ammonium (G – H) in the central (A, C, E, G) and the eastern (B, D, F, H) GAB.

a.

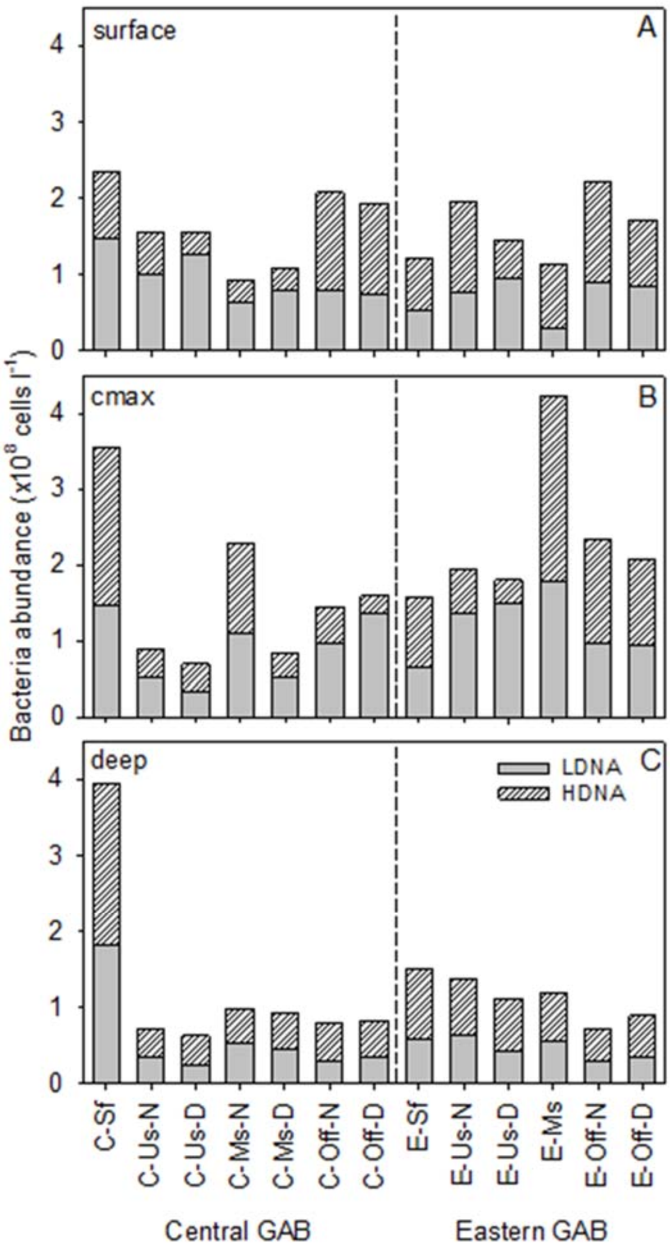


Figure 15. Bacterial abundances (x 10^8 cells L^{-1}) in surface (A), cmax (B) and deep water (C) in the Great Australian Bight (GAB). Prefix 'C' refers to Central GAB (to left of dashed line) and prefix 'E' refers to Eastern GAB (to the right of dashed line). Sf = shelf; Us = upper slope; Ms = mid slope; Off = offshore. Suffix 'N' and 'D' refer to night and day sampling respectively. LDNA = low DNA bacteria and HDNA = high DNA bacteria.

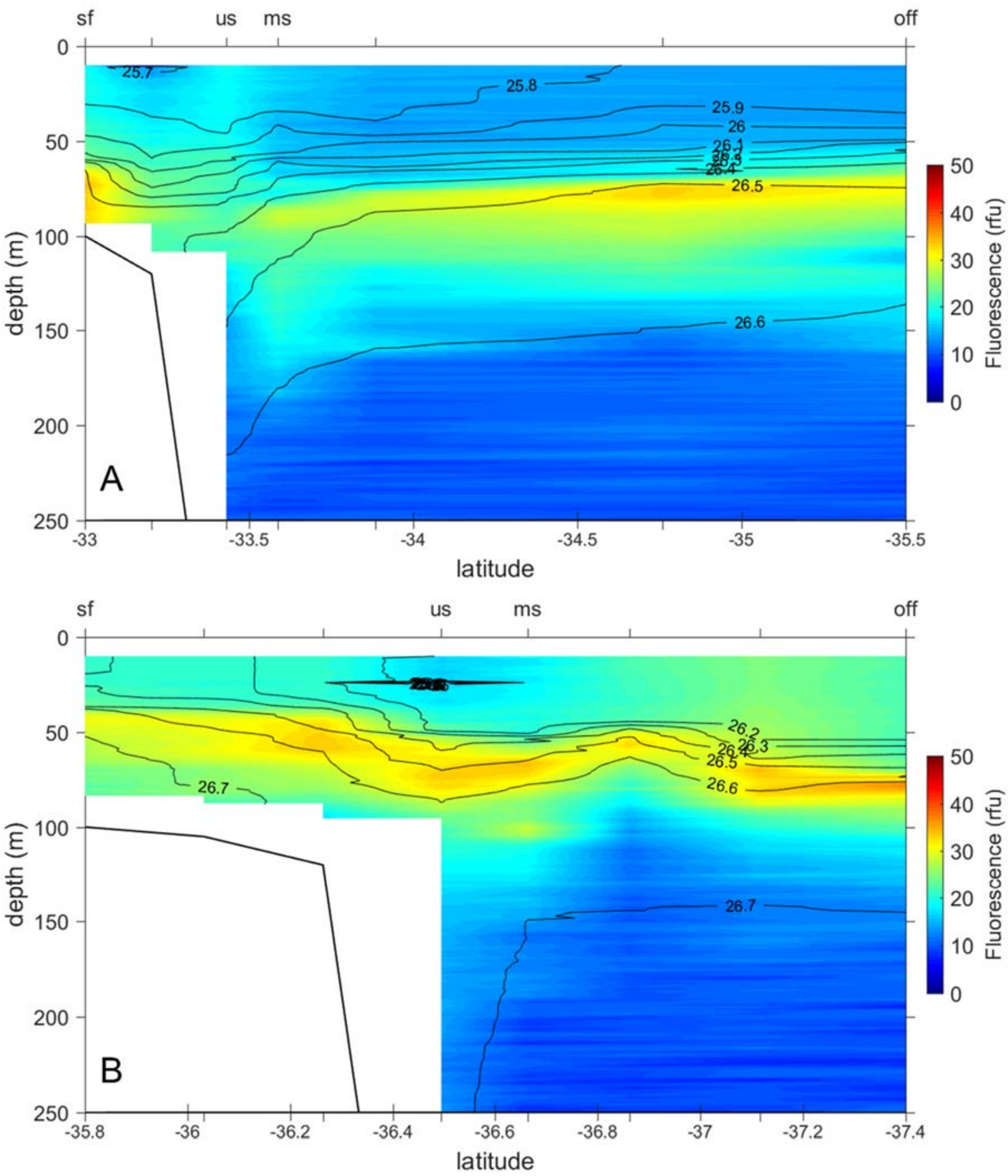


Figure 16. Results from the observational transects constructed from CTD profiles showing the vertical distribution of chlorophyll a fluorescence (relative fluorescence units) to depths of 250 m for (A) the central GAB, and (B) the eastern GAB. Contours show lines of potential density (σ_θ, kgm^{-3}). The locations of stations shown in Figure 11 are marked as small ticks along the top and bottom abscissa. The corresponding position of stations sampled in approximately 100, 400, 800 and 1000 m water depth or greater are indicated by the top abscissa labels 'sf' for shelf, 'us' for the upper slope', 'ms' for the mid slope and 'off' for offshore stations, respectively.

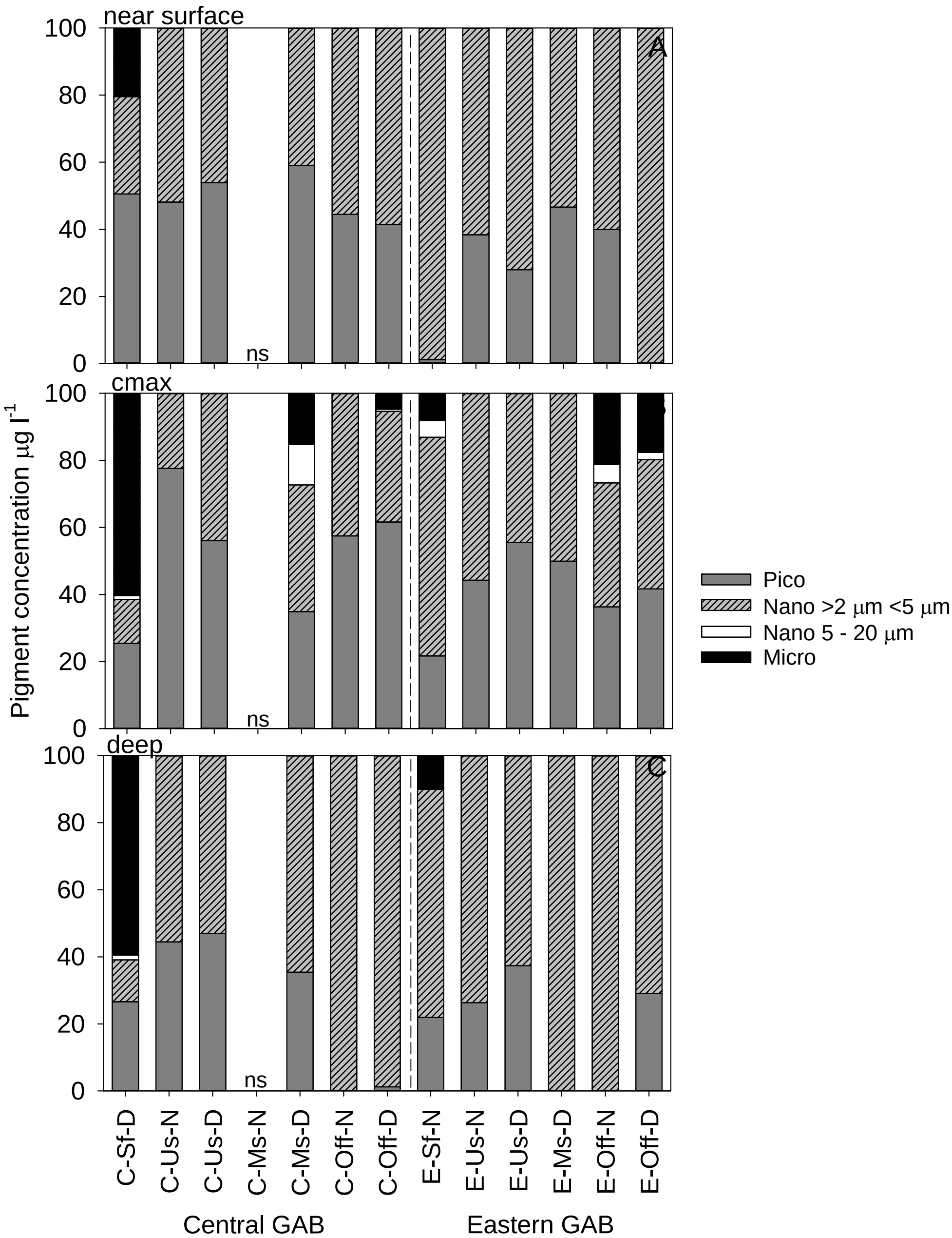


Figure 17. Spatial variation of phytoplankton size fractions in surface (A), cmax (B) and deep water (C) in the Great Australian Bight (GAB). Prefix ‘C’ refers to Central GAB (to left of dashed line) and prefix ‘E’ refers to Eastern GAB (to the right of dashed line). Sf = shelf; Us = upper slope; Ms = mid slope; Off = offshore. Suffix ‘N’ and ‘D’ refer to night and day sampling respectively. ns = not sampled.

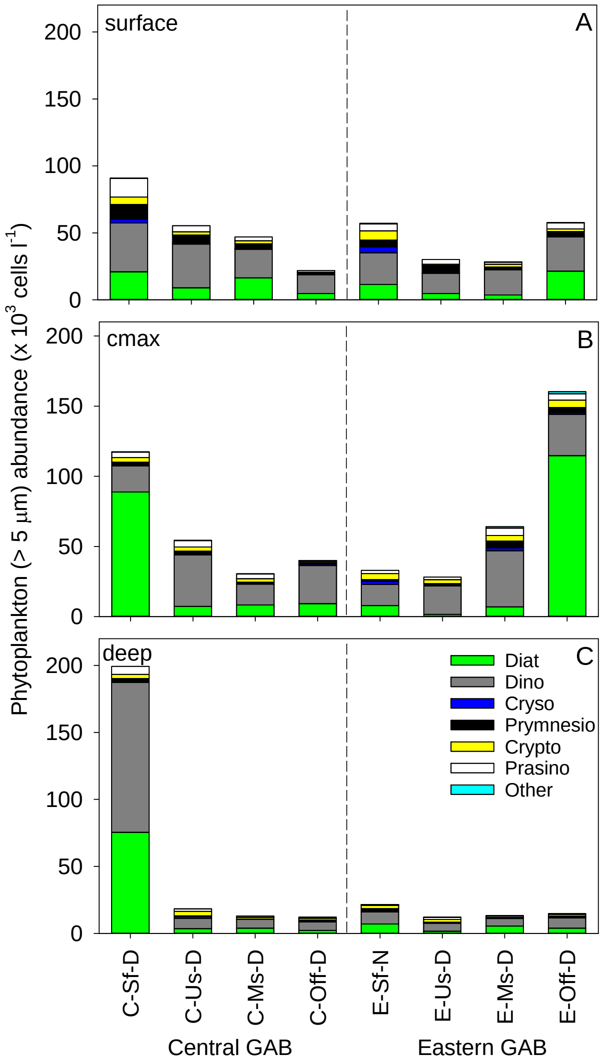


Figure 18. Phytoplankton (> 5 µm) abundances (x 10^3 cells L^{-1}) in surface (A), cmax (B) and deep water (C) in the Great Australian Bight (GAB). Prefix 'C' refers to Central GAB (to left of dashed line) and prefix 'E' refers to Eastern GAB (to the right of dashed line). Sf = shelf; Us = upper slope; Ms = mid slope; Off = offshore. Suffix 'N' and 'D' refer to night and day sampling respectively. Diat = diatoms; Dino = dinoflagellates; Cryso = Crysophytes; Prymnesio = Prymnesiophytes, Crypto = Cryptophytes; Prasino = Prasinophytes and Other = other flagellates not included in previous groups.

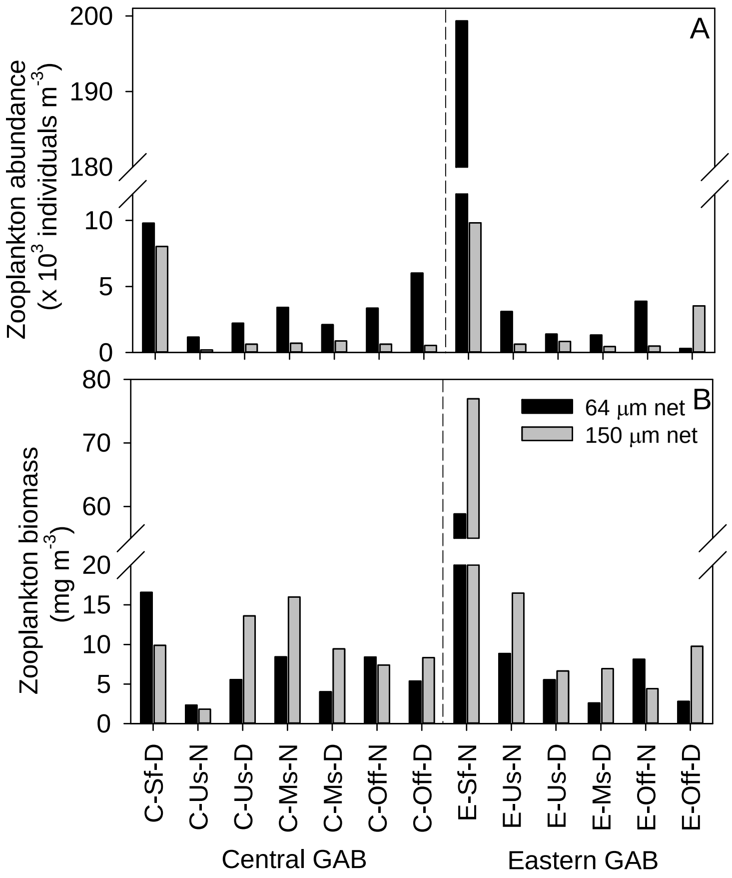


Figure 19. Zooplankton abundance (x 10^3 individuals m^{-3}) and biomass (mg m^{-3}) in the 64 µm and 150 µm net in the Great Australian Bight (GAB). Prefix ‘C’ refers to Central GAB (to left of dashed line) and prefix ‘E’ refers to Eastern GAB (to the right of dashed line). Sf = shelf; Us = upper slope; Ms = mid slope; Off = offshore. Suffix ‘N’ and ‘D’ refer to night and day sampling respectively.

Key findings and legacies

The Pelagic Ecosystem and Environmental Drivers Theme provided important new insights into the structure and function of the lower trophic ecosystems of the GAB. Improved understanding of physical enrichment processes, primary productivity and trophic pathways in the eastern GAB help explain the mechanisms underpinning the region's rich pelagic biomass (e.g. large sardine population). The biologically mediated nutrient enrichment process (nitrification) and shorter than expected trophic pathways identified in the central GAB help to resolve the paradox of a large pelagic biomass occurring in a region where physical enrichment processes are weak or absent. An exciting new tool for investigating the gelatinous community was developed during the study (acoustic and optical probe, PLAOS). Two new species of siphonphores were discovered.

BENTHIC BIODIVERSITY

The Benthic Biodiversity Theme was comprised of two closely linked projects. The first investigated the diversity, distribution and ecology of the benthic assemblages of the continental slope in the GAB (Williams et al. 2017). The second used molecular techniques to investigate benthic biodiversity and assess the presence of hydrocarbon degrading microbes in the GAB (Tanner et al. 2017). Both projects provided recommendations to inform future monitoring of the GAB's benthic communities.

Benthic assemblages of the continental slope

To provide a context for the extensive field studies, information held by Australian museums on the epibenthic and demersal fish assemblages in depths >200 m across southern Australia was collated. Multivariate analyses identified clear geographic patterns and suggested that the GAB supports a distinct deep water assemblage (Figure 20). Species distribution maps were developed for 21 key deep water taxa. The GAB appears to provide suitable habitat for a relatively high proportion of these species.

Surveys undertaken from the Marine National Facility (MNF) RV *Southern Surveyor* voyage in 2013 and MNF RV *Investigator* voyages in 2015 are the deepest systematic surveys for benthic biodiversity undertaken in Australia's marine jurisdiction (Figure 21). Samples were collected from 30 sites on five north-south transects that covered six depth strata: 200 (shelf break), 400, 1000, 1500, 2000 (continental slope) and 3000 m (continental rise). Macrofauna samples were also collected opportunistically from a BP funded geological survey conducted by Fugro (FU201301), and from the Chevron funded GAB Deepwater Marine Program (GABDMP 2016) survey targeting topographically distinct sites.

The benthic sampling operations collected a total of 63,340 benthic invertebrate specimens, comprising 1,073 species, 602 genera and 357 families, from eleven phyla. Of the total species, 275 (26%) have not been described and are new to science. The major taxa recovered are summarised in Table 1. These samples provided the first information on the composition, abundance and distribution of infauna, epifauna, fishes and microbes in deep waters of the central GAB. Preliminary findings indicate that depth plays a dominant role in structuring most assemblages. Benthic assemblages within the deep central GAB don't appear to be structured longitudinally.

The 200 multi-corer samples taken at 30 depth-stratified stations yielded 1303 individual infauna specimens, representing at least 258 species (some taxa were only identified to class or phylum). Individual cores contained an average of 6.5 individuals and four species and were too small to

provide a representative sample of the assemblage. A depth-related pattern of abundance was detected when samples collected at each site were aggregated. Infaunal abundance decreased in waters over 400 m deep. Samples collected in 2013 and 2015 differed, indicating substantial temporal variability in the assemblage. Taxa accumulation curves suggest that less than 25% of infaunal species present in the region were sampled. There did not appear to be any unique co-occurring groups of taxa in the sampled region.

More than 44,000 specimens and 600 species (11 phyla) of invertebrate epifauna (megafauna, >10 mm length) were collected in 30 beam trawls. Approximately 25% of species were undescribed and an additional 77 species were new records for Australian waters. Megafaunal composition (families, genera) was broadly typical for temperate deep-sea regions. Sponges and echinoderms dominated the overall biomass and density, with the former being more prominent in shallower waters. Species richness and abundance (biomass and density) varied with depth (Figure 23). No longitudinal pattern in species richness, biomass or density distribution was evident, suggesting a single provincial-scale bioregion in the GAB. Approximately 70% of species that could be assigned biogeographic data have been previously recorded from Australia, with less than half (146 species, 39%) previously known from the GAB. Endemism was low with two species, the crab *Choniognathus granulosus* and barnacle *Arcoscalpellum inum* known only from the GAB. The GAB assemblage has a stronger affinity to the southern Pacific Ocean than the Indian Ocean.

A total of 108 species of fishes from 49 families in depths of 200-3000 m depths was taken in the beam trawls. Most species occurred infrequently: 42 occurred in one sample (39%), 13 occurred twice (12%), and 53 species (49%) were captured more than twice. The accumulation of species with increasing number of samples showed no asymptote, indicating the total species pool had not been sampled. The great majority of species had been previously recorded from Australian waters (90%) and the GAB (75%). A lower proportion of recorded species occurred at greater depths (1700-3000 m), where there had been virtually no previous sampling: 74% in Australian waters, and 30% in GAB waters. The fauna is dominated by families that typically occupy the deep ocean: rat-tails (Macrouridae), cut-throat eels (Synaphobranchidae), morid cods (Moridae), Oreosomatidae (oreo dories), slickheads (Alepocephalidae), cusk eels (Ophidiidae) and halosaurs (Halosauridae). The Macrouridae was the most diverse and abundant (biomass and density) group in 400 m and deeper strata. Biogeographical affinities varied with depth. Endemic species were most prevalent in shelf break and upper to mid-slope depths (both 52%), and declined with increasing depth (upper to mid-slope species 25%; lower slope/ rise 4%), consistent with a general pattern in the Australian ichthyofauna. Fish biomass was significantly related to depth, relatively very low at 200 m depth, highest at 400 m, then steadily declining to 3000 m depth (Figure 24). Depth was the main factor

explaining assemblage structure, although the lower slope and continental rise (>1500 m depths), that had not previously been sampled in Australian waters, showed relatively little difference to the mid-slope sites (<1500 m depths).

Molecular studies

Genes associated with microbial hydrocarbon degradation are common in both sediment and water samples from the GAB, indicating that microbes in the region have the capacity to degrade hydrocarbons, and may play an important role in processing spilled oil. However, the sequences found were unique, so their functional responses may differ from those in other regions. Bacterial species related to known hydrocarbon degraders were found. Molecular techniques (qPCR assays) were developed for monitoring the abundance of key bacterial taxa present in the GAB. These qPCR assays provide a tool for assessing the response of microbial assemblages to hydrocarbon spills. Endemic microbial assemblages are likely to have the potential to respond to hydrocarbon spills, and play a role in the degradation of spilled material, although the extent of this cannot yet be quantified. Challenge experiments are needed to determine the response of microbial assemblages to the presence of hydrocarbons.

A molecular barcoding database was established for benthic species. Preservation issues prevented recovery of DNA from the infaunal samples, so barcoding focused on epifauna. Few barcoded taxa were detected in the metabarcoding samples. Most taxa detected in metabarcoding are not amenable to traditional sampling as they are too small to be retained on the sieves. Metabarcoding provided insights into the benthic ecology of the region that could not be gained using other methods. When a database of barcoded infaunal species is developed for the GAB, metabarcoding data obtained in the GABRP could be reassessed to obtain a more complete picture of the assemblage. Because of the large proportion of singletons detected in the infaunal samples, a large sampling effort would be required before metabarcoding could replace traditional taxonomy in providing a full understanding of the species present. However, metabarcoding may be suitable for understanding broad changes in the faunal assemblage over time.

Future monitoring

The benthic biological characterisation was used to define and address the needs for future ecological monitoring. The study was underpinned by robust (consistent species-level) taxonomic identification. Species-level data are essential to generate robust indicators and metrics and develop knowledge about structural and functional changes in communities in response to disturbance (including recovery). This study also identified key habitats, communities and species,

developed maps of their distributions, and evaluated methods for monitoring future changes in status. Data from baseline (unperturbed) sites provides the basis for evaluating indicators and metrics for future comparisons – i.e. a reference-site monitoring approach. We identified several opportunities to develop indicators and metrics using both species- and assemblage-level data.

Key findings and legacies

The benthic surveys undertaken in the GABRP are the deepest systematic surveys of the benthos that have been undertaken in Australian waters. The GABRP transformed the region from having the least well known deep-sea benthos in Australian waters to the best known. Over 275 species new to science and 887 species new to the GAB were identified. The new sampling technique (multicorer) developed for the surveys will enhance future investigations of the deep water benthic communities of the GAB and elsewhere. The Benthic Biodiversity Theme also undertook the first study of deep-water hydrocarbon degrading microbes in temperate Australia and successfully characterised the unique assemblage of hydrocarbon degrading microbes in the GAB. The findings and recommendations of the theme will assist the development of monitoring programs to assess future impacts on the regions deep-water benthic communities. The benthic habitat models and molecular identification tools are significant legacies for future science and monitoring programs in the region.

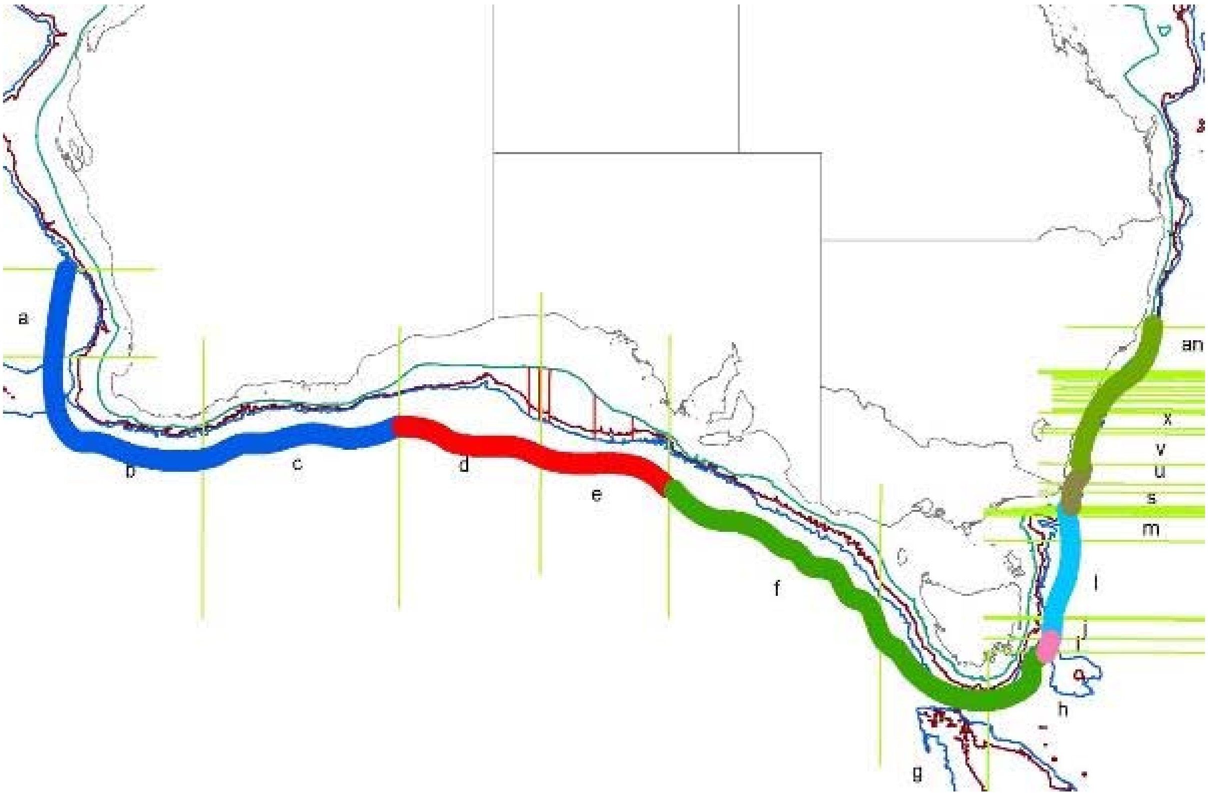


Figure 20. Map of southern Australia showing biogeographic zones based on the multivariate analyses at the species level.

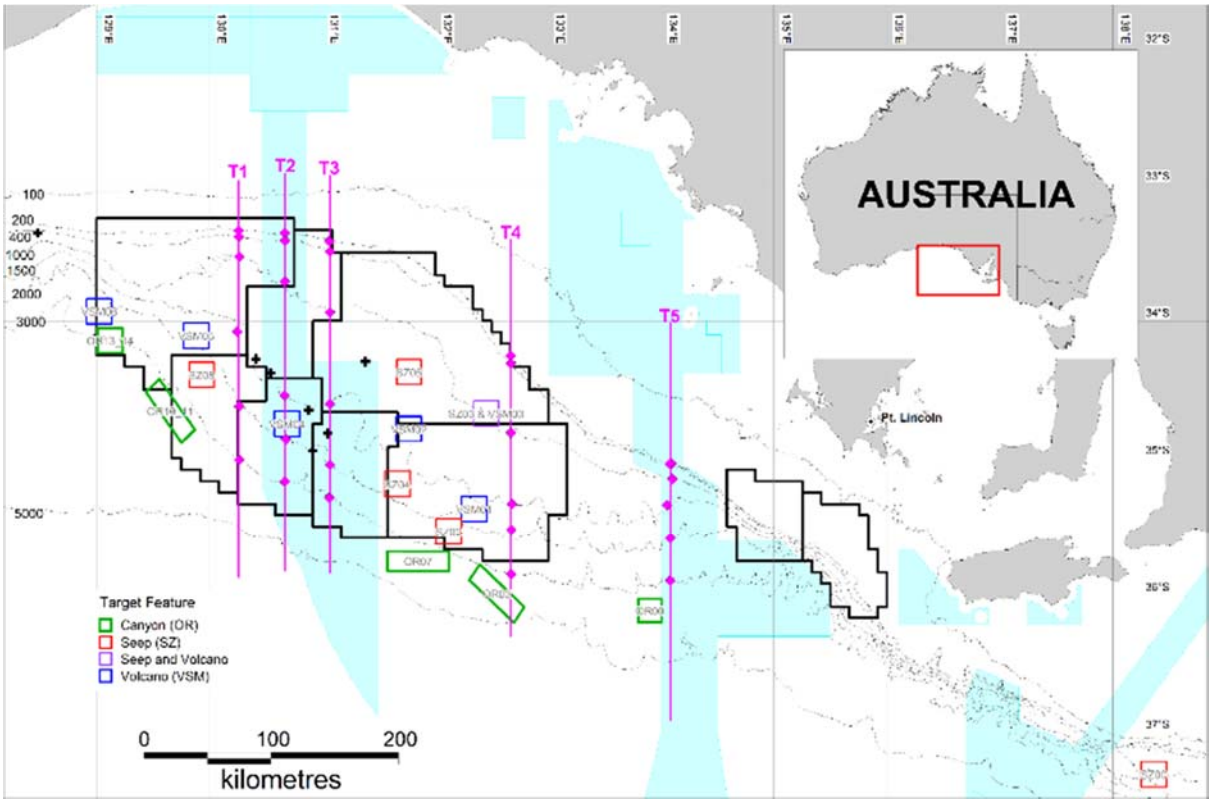


Figure 21. The study area showing the five GABRP transects with depth-stratified sampling sites (pink diamonds), opportunistic macrofauna samples (black crosses), and GAPDMP topographic sites (rectangles - SZ, OR and VSM, see key). Relevant isobaths (labelled); Commonwealth Marine Reserves (shaded light blue); active oil and gas lease blocks (black boundaries) are also shown.

Table 1. Taxonomic and abundance summary of invertebrate fauna, by major taxonomic group.

Phylum	Major group	Total specimens	Families	Genera	Species	Undescr. species	Note
Porifera	Demospongiae	10770 (84 Kg)	34	56	137	1	
	Calcarea	106 (1.4 Kg	11	15	34	7	
	Hexactinellida	84 (3 Kg)	4	4	28	0	
Cnidaria	Hydroida	55 (.5 Kg)	-	-	-	-	
	Siphonophorae	120	1	1	1	0	
	Antipatharia	29 (0.1 Kg)	-	-	-	-	
	Octocorallia	606 (5.3 Kg)	17	32	46	17	3 new genera
	Actiniaria	801	6	14	38	4	
	Corallimorpharia	43	1	2	2	0	
	Zoantharia	177	-	-	-	-	
	Scleractinia	1734 (37 Kg)	5	8	12	0	
Brachiopoda	-	373	4	4	5	0	
Bryozoa	-	2	4	4	6		
Nemertea	-	13	-	-	-	-	
Nematoda	-	382	-	-	-	-	
Annelida	Sipuncula	662	-	-	7	-	
	Echiura	4	1	1	1	-	
	Polychaeta	1117	39	88	159	80	
	Oligochaeta	34	2	2	2	-	
Mollusca	Aplacophora	23	2	1	4	1	
	Polyplacophora	3	3	1	1	0	
	Bivalvia	1705	17	27	36	0	
	Scaphopoda	200	4	5	9	3	
	Cephalopoda	78	13	15	21	4	
	Gastropoda	1291	39	67	95	47	2 new genera
Echinodermata	Crinoidea	5	1	1	1	0	
	Asteroidea	1397	15	31	64	4	
	Ophiuroidea	34616	22	33	55	12	
	Echinoidea	875	11	14	17	1	
	Holothuroidea	1667	12	20	27	11	
Arthropoda	Cirripedia	532	5	16	25	1	
	Cumacea	15	-	-	-	-	
	Tanaidacea	75	-	-	13	-	
	Isopoda	516	20	36	56	45	4 new genera
	Amphipoda	99	23	25	47	13	
	Lophogastrida	12	1	1	2	0	
	Decapoda	2522	35	70	108	19	
	Stomatopoda	15	1	1	1	0	
	Pycnogonida	134	4	7	13	5	
Chordata	Ascidiacea	448	-	-	-	-	
	Total	**63340**	**357**	**602**	**1073**	**275**	

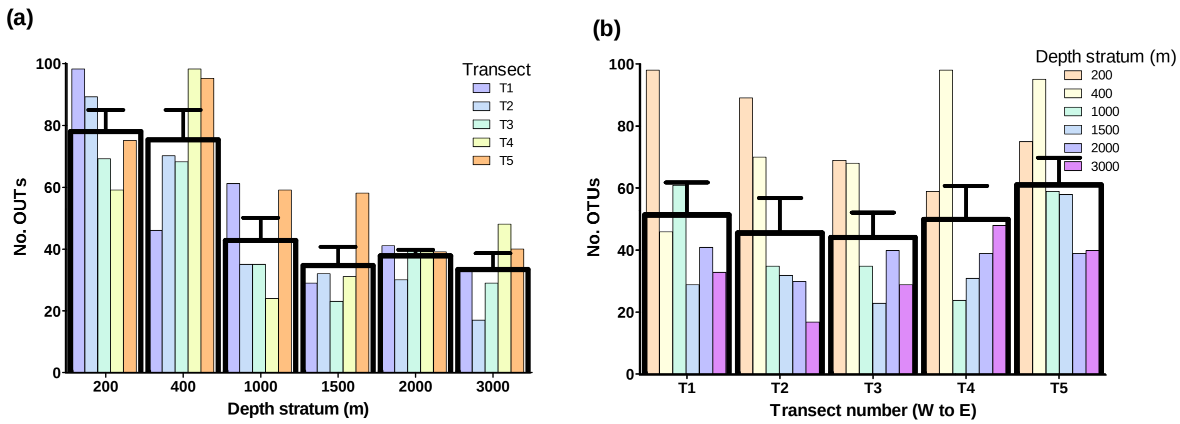


Figure 22. Species richness of benthic invertebrates (measured as the average number of OTUs collected per sample) by (a) depth stratum (N=5) and (b) transect (T1-T5, west to east) (N=6); bar = SE.

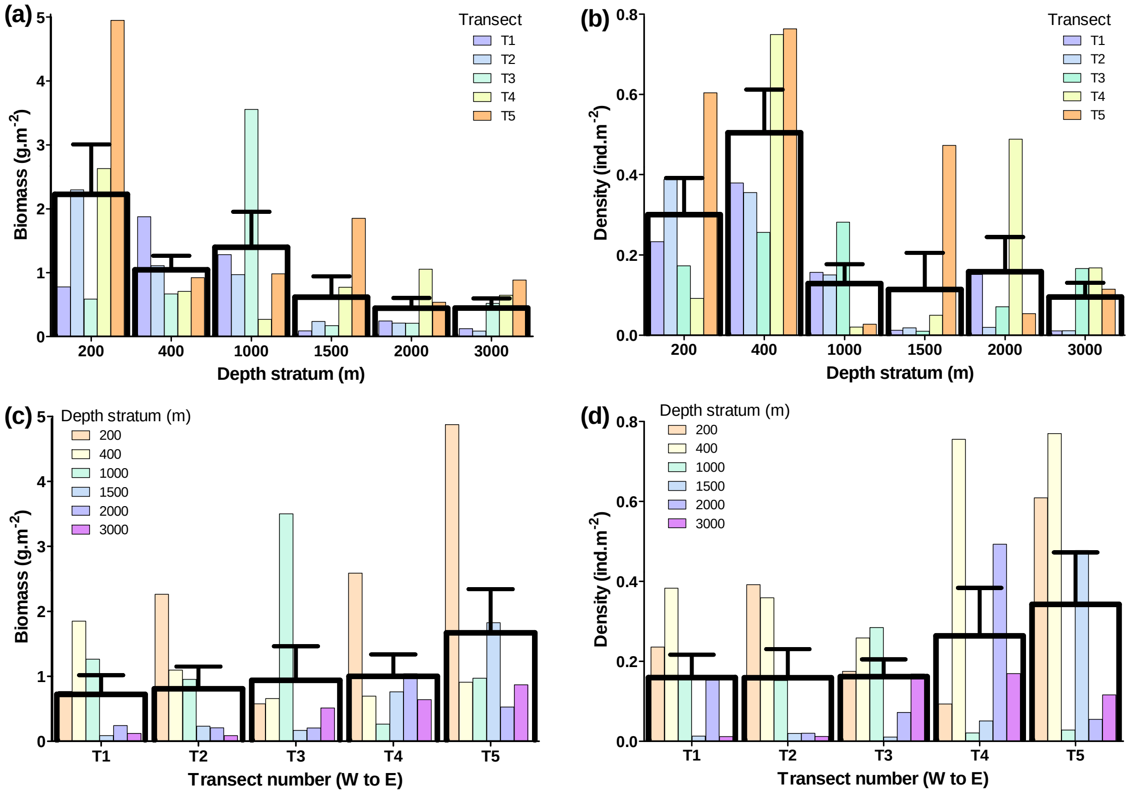


Figure 23. Abundance (biomass and density) of benthic megafaunal invertebrates in beam trawl samples by depth and transect (T1-T5): (a and c) average biomass per sample; (b & d) average density per sample. Number of samples per depth N = 5, per transect N = 6; bar = SE.

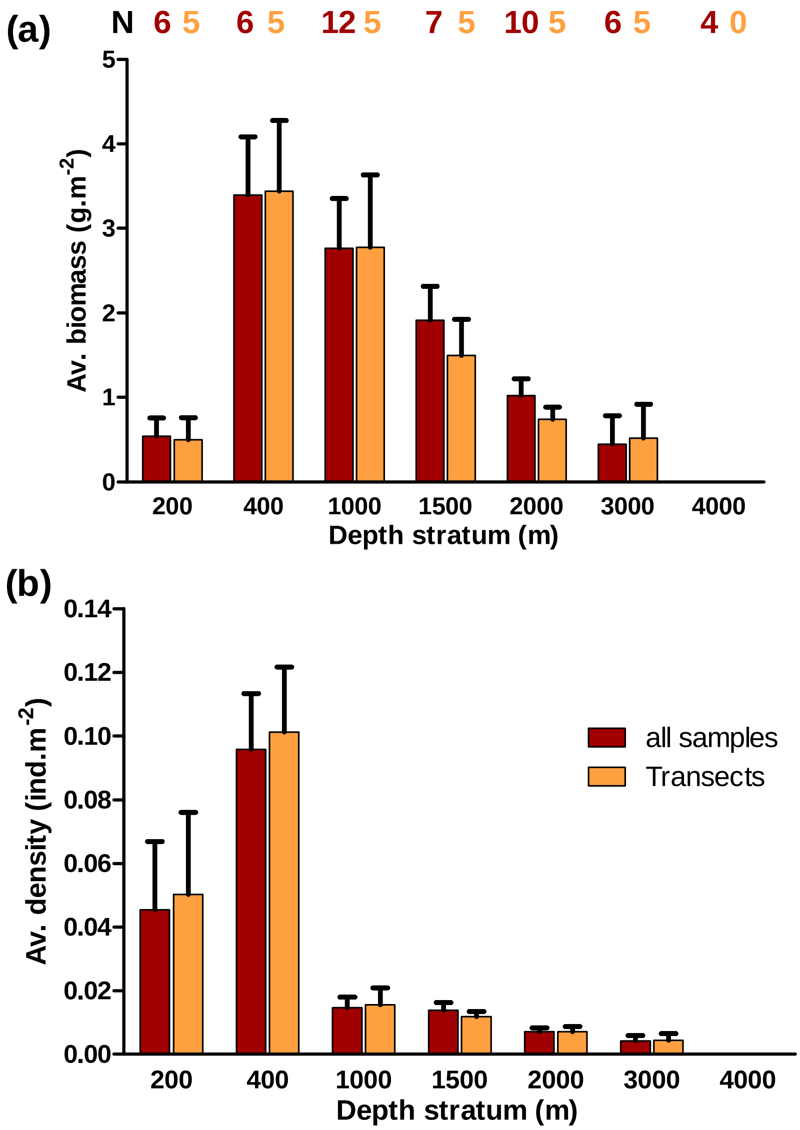


Figure 24. Abundance of benthic fishes in beam trawl samples by depth stratum for transect samples and transect + topography (all) samples: (a) average biomass and (b) average density. Number of samples per depth (N); bar = standard error.

ICONIC SPECIES AND APEX PREDATORS

The Ecology of Iconic Species and Apex Predators Theme was comprised of three projects. The first project established baseline information on the distribution, status and trends in abundance of cetaceans (aerial, acoustic and visual surveys), pelagic sharks (long-line survey and satellite telemetry), pinnipeds (ground and aerial surveys) and seabirds (ground and aerial surveys) needed to underpin sustainable management of these populations (Goldsworthy *et al.* 2017). The second project identified biologically important areas for iconic species and apex predators by integrating electronic tracking data collected over the last two decades (Bailleul *et al.* 2017). The third project investigated historical patterns in the movement, behaviour and preferred habitats of juvenile southern bluefin tuna (SBT) in the GAB and summarised historical patterns of oil and gas exploration activities in the region (Evans et al. 2017).

Status, distribution, and abundance of iconic species and apex predators

Inshore aerial surveys were undertaken in the eastern GAB) between Ceduna and Coffin Bay to assess the occurrence and distribution of cetaceans in coastal and shelf waters out to the 100 m depth contour. Aerial line-transect surveys were used to estimate the relative abundance of short-beaked common dolphins (*Delphinus delphis*). Five species of cetaceans were identified, including southern right whale (*Eubalaena australis*), humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera* sp.), short-beaked common dolphin (*Delphinus delphis*), and bottlenose dolphin (*Tursiops* spp.). A total of 20,000 – 22,000 short-beaked common dolphins were estimated to be present in coastal waters during the survey, demonstrating the importance of the eastern GAB for this species.

Three offshore aerial surveys were conducted in the eastern and central GAB between December 2015 and April 2016 focusing on the shelf-break and 200 m depth contour. A total of 58 cetacean sightings were made, comprising at least eight species, (i.e. blue whales, *Balaenoptera musculus brevicauda*; a fin whale, *Balaenoptera physalus*; sperm whales, *Physeter macrocephalus*; pilot whales, *Globicephala melas*; killer whales, *Orcinus orca*; Risso's dolphins, *Grampus griseus*; short-beaked common dolphins; and common or offshore bottlenose dolphins). Blue whales were sighted along the Bonney Coast between Robe and Portland, but not in the eastern GAB or south of Kangaroo Island. Sightings of sperm whale, pilot whale, killer whale, Risso's dolphin, and probable beaked whale and fin whale sightings were concentrated in upper slope waters (160–200 m depth contours), with sperm whales sighted mostly in deeper, steeper benthic terrain, and pilot whales,

killer whales, Risso's dolphins in shallower, less steep benthic terrain. Dolphins were widely distributed in shelf and upper slope waters, from inshore to just beyond the shelf break.

An offshore visual and acoustic survey was conducted in an area of the shelf-break and slope of the eastern GAB that had previously not been systematically surveyed for cetaceans. Odontocete (toothed whale) vocalisations were detected during 15 discrete acoustic events recorded during 141 hours of passive acoustic monitoring. Sperm whales were acoustically detected on four occasions comprising a total of nine individuals. Two sperm whale acoustic events contained a single individual, one event contained three individuals and one event contained four individuals. Sperm whale encounters occurred in water depths between 500 and 2000 m. Four sighting events were recorded during 56 hours of visual effort which included three sperm whales from two encounters, one group of 100-150 pilot whales, and a probable sighting of a beaked whale. Sperm whale presence-only data, collated from sources including sightings data and commercial whaling data, were used to predict potential sperm whale habitat in the GAB region using Maximum Entropy Modelling (Figure 25).

An offshore pelagic survey was conducted between the du Couedic Canyon, south-west of Kangaroo Island, and the continental shelf-break south of Head of Bight during May 2015. Five pelagic shark species including, nine blue sharks (*Prionace glauca*), six shortfin makos *Isurus oxyrinchus*, one common thresher *Alopias vulpinus*, one bigeye thresher *A. superciliosus*, and two school sharks *Galiorhinus galeus* were caught in seven longline sets. Fourteen satellite tags were deployed on four shark species: blue (7), shortfin mako (1), white (5) and bigeye thresher (1). All species traversed widely; but there was evidence of species-specific preferences for particular habitats and depth ranges. For example, focal areas for blue sharks were in depths >1000 m in oceanic zones beyond the lower continental shelf slope in the eastern and central GAB, Bonney Upwelling Region, and Tasman Sea. The occurrence of the predominantly subtropical and tropical bigeye thresher shark in the GAB, and its subsequent migration to waters off Exmouth, Western Australia was a new scientific discovery.

A comprehensive synthesis of recent and historic surveys of pinniped pup abundance highlighted that the GAB supports 93% and 98% of Australian populations of Australian sea lion (*Neophoca cinerea*) and long-nosed fur seal (*Arctophoca forsteri*), respectively. In contrast, only 18% of the population of Australian fur seal (*Arctocephalus pusillus doriferus*) occurs in the GAB region. Populations of long-nosed fur seal (total abundance 114,540 individuals; 24,063 pups) and Australian fur seal (total abundance 14,811 individuals; 3,291 pups) have largely recovered from historical sealing. However, populations of the threatened Australian sea lion are smaller than previously

estimated (total abundance 10,728 individuals; 2,801 pups) and undergoing a rapid decline. The rate of decline across the GAB was equivalent to a 76% decline over three generations (~38 years), meeting the IUCN criteria for 'Endangered' (>50% and <80% decline over three generations). Almost 40% of individual breeding sites assessed in the GAB meet the 'Critically Endangered' IUCN criteria (>80% decline over three generations).

Baseline or updated abundance data were collected from offshore islands for seabirds from three distinct foraging guilds: crested tern (resident surface plunge diver); little penguins (resident non-flying diving seabird); and flesh-footed shearwater (highly migratory near-surface forager). Crested terns were recorded at six islands: Nuyts Reef, Lounds Island, The Brothers, Donington Rock and North and South Neptune Islands. Surveys conducted using aerial photography identified 1,438 nesting pairs of crested terns at Nuyts Reef, 3,119 at Lounds Island, and 428 and 408 at South and North Neptune Islands, respectively. Comparisons with results from earlier surveys suggests a potential decline in little penguins since 2004 of 80% at Olive Island and 66% at Pearson Island. The first quantitative surveys of flesh-footed shearwaters were undertaken using burrow transects and direct burrow counts at their only known breeding sites in the eastern GAB; 928 and 5,785 breeding pairs were estimated at Lewis and Smith Islands, respectively.

Inter-specific distribution and foraging overlap for iconic species and apex predators

Data from satellite tracking and GPS tags obtained between 1995 and 2016 were collated for nine species (602 individuals): Australian sea lion, long-nosed fur seal, Australian fur seal, short-tailed shearwater, little penguin, white shark, blue shark and shortfin mako shark and southern bluefin tuna (Figure 26). Aerial survey and historical data were collated for pygmy blue whale and sperm whale.

Analysis of 4,924 tracks and 15,698 observations from aerial surveys and historical data showed that species use the GAB either permanently as residents or periodically for feeding or breeding as part of broad-scale migrations (Figure 27). Individuals of some migratory species are present in the GAB region year-round, while others are only (or mainly) present in summer/autumn (Figure 27).

Models were developed to predict the general distribution and foraging habitats of 11 species from the tracking and observational data. The overlap of the general distributions and foraging habitats were mapped for central-place foragers (Figure 28, 29) and non-central places foragers. Central-place foragers mainly used and foraged in three regions: i) over the shelf and shelf break in the

eastern GAB, ii) in the open ocean, and iii) over the shelf along the Bonney coast and the mainland coast north of Tasmania. Non-central place foragers mainly used and foraged at the shelf break, throughout the GAB and along the Bonney coast (Figures 28, 29).

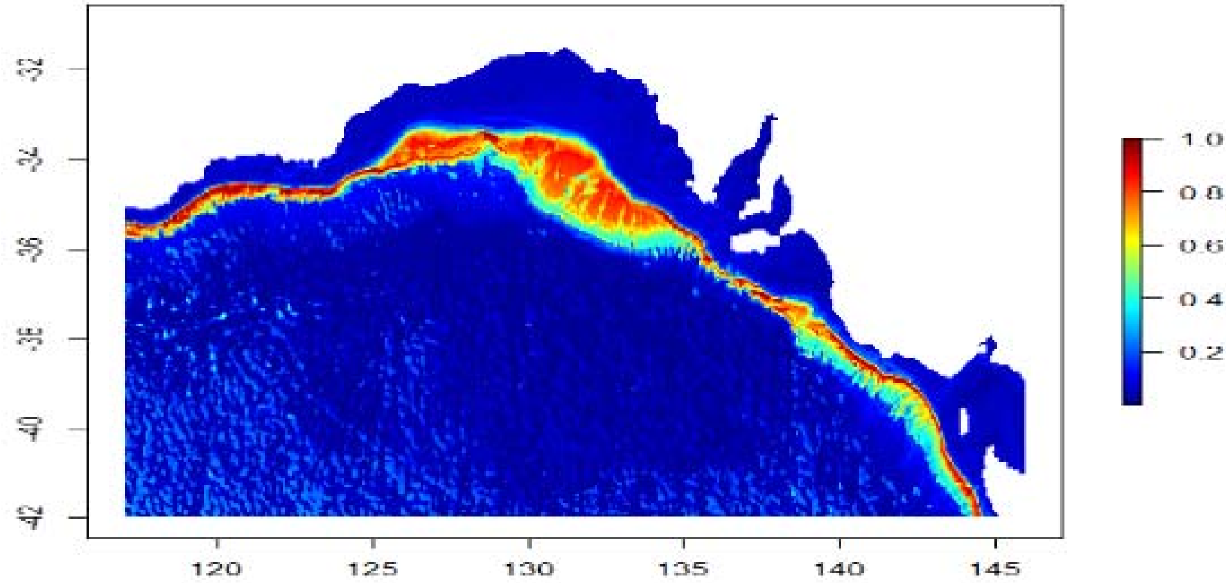


Figure 25. Probability of distribution of sperm whales in the GAB predicted by a habitat suitability model based on presence only data and the variables bathymetry, aspect and slope. Warmer colours indicate higher probability of distribution.

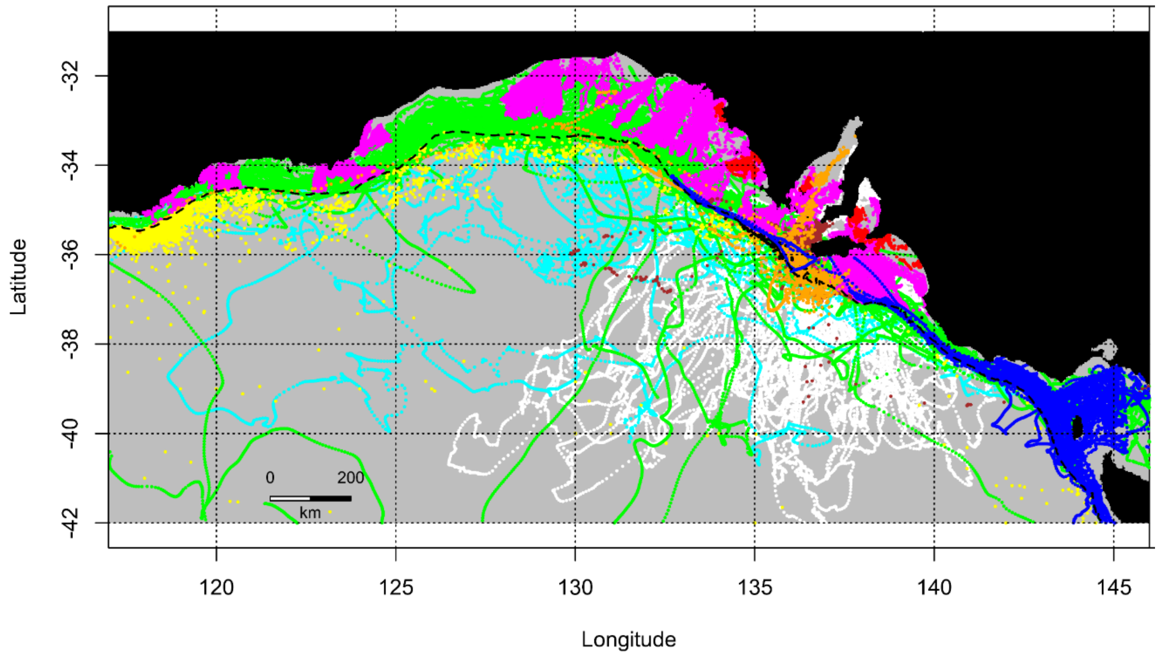


Figure 26. Tracking and observation data for ten different species. For clarity and because of a different data format (gridded), Southern Bluefin Tuna are not represented in this figure. Magenta: Australian sea lions; White: Long-nosed fur seals; Blue: Australian fur seals; Cyan: Blue sharks; Green: Mako sharks; Orange: White sharks; Yellow: Sperm whale; Black: Pygmy blue whale; Red: Little penguins; Brown: Short-tailed shearwater. The dashed line represents the 250 m isobath and marks the extent of the continental shelf.

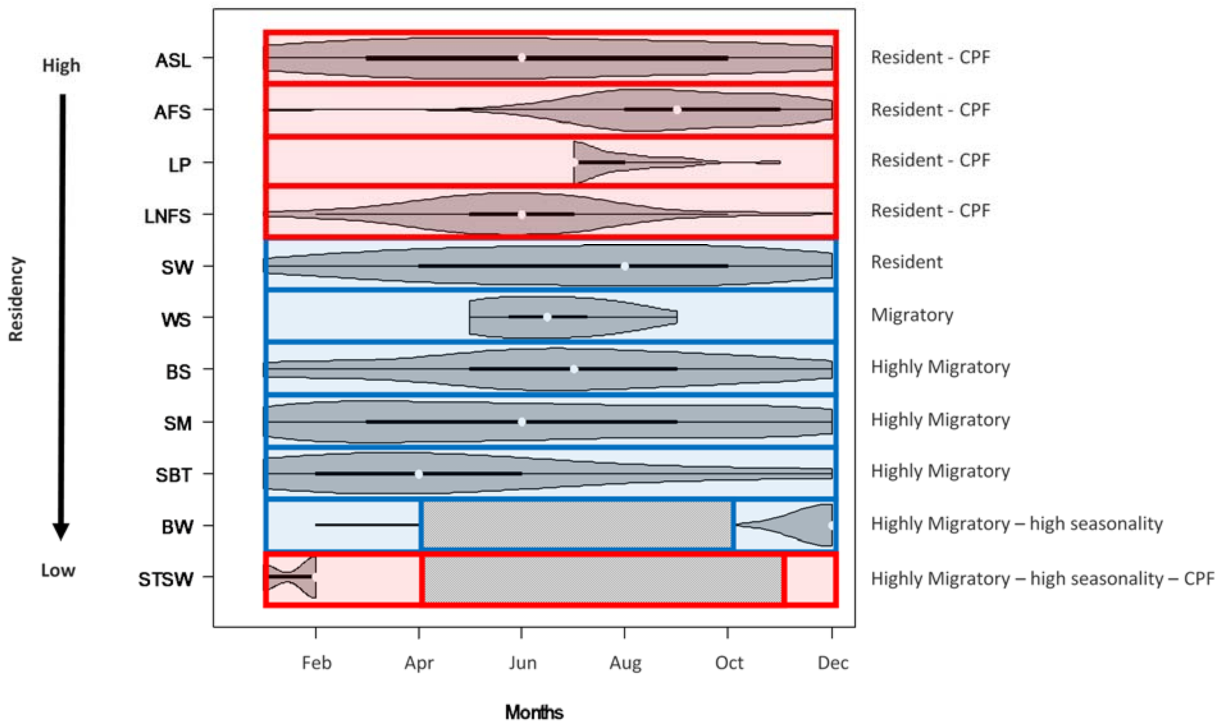


Figure 27: Schematic plot of the 11 predator species arranged by their relative degree of residency (resident to highly migratory). The temporal distribution of observations (tracking and sightings data) used in analyses are presented for each species as violin plots. A violin plot is a combination of a box plot and a kernel density plot. The thick black lines represent the interquartile range and the white square the median. Blue and red shaded background indicate when the species are known or supposed to be present in the GAB (CPF = central-place forager (red); blue = non central-place forager; diagonal stripes = absent). ASL = Australian sea lions; AFS = Australian fur seals; LP = Little penguins; LNFS = Long-nosed fur seals; SW = Sperm whales; WS = White sharks; BS = Blue sharks; SM = Shortfin mako sharks; SBT = Southern Bluefin Tuna; BW = Pygmy blue whales; STSW = Short-tailed shearwater.

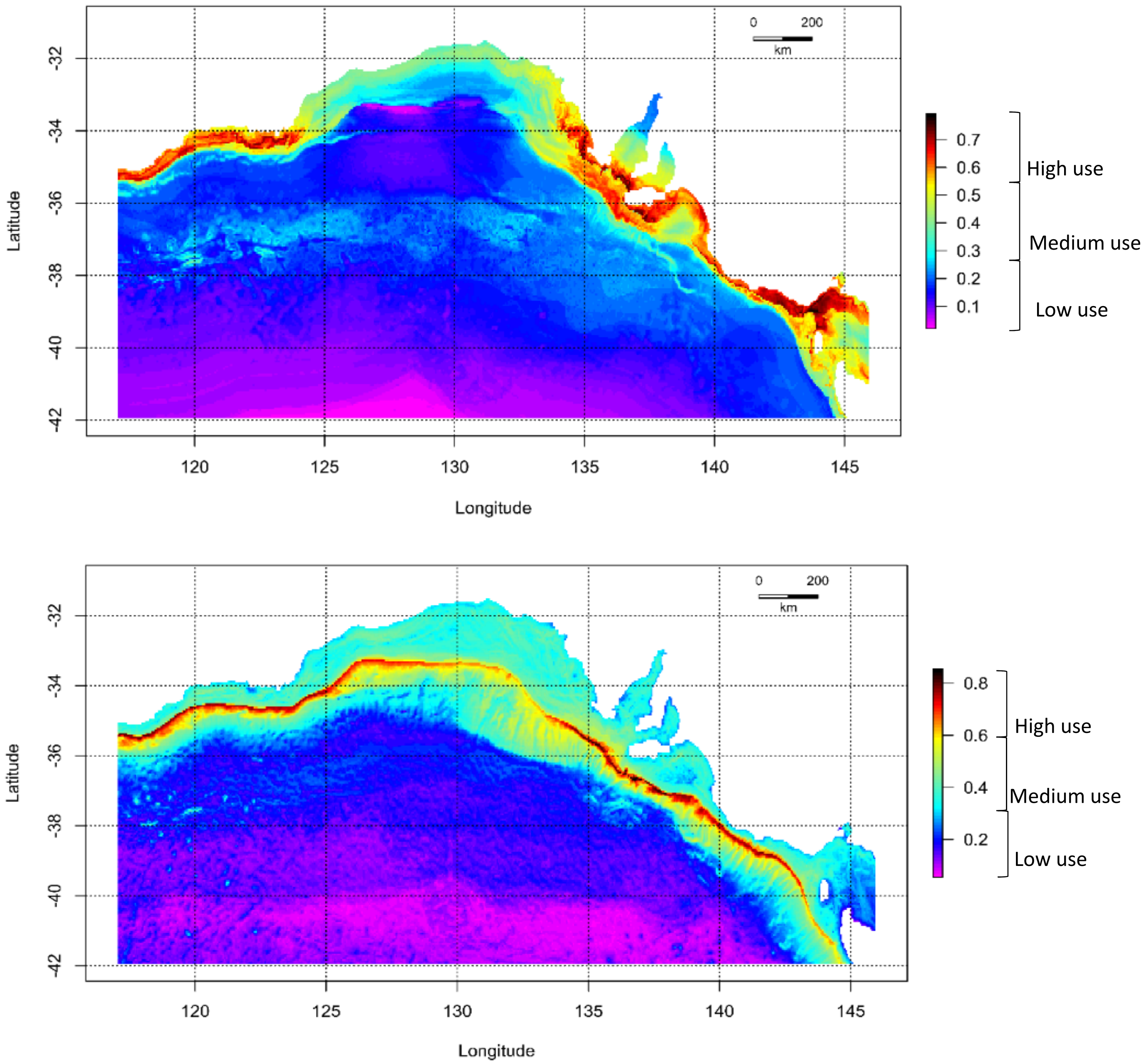


Figure 28: Multi-species overlap of the general distribution (average potential occurrence) of five central-place foragers (above: Australian sea lions, Australian fur seals, long-nosed fur seals, little penguins and short-tailed shearwaters) and six non-central-place forager species (below: blue shark, shortfin mako sharks, white sharks, southern bluefin tuna, sperm whales and blue whales).

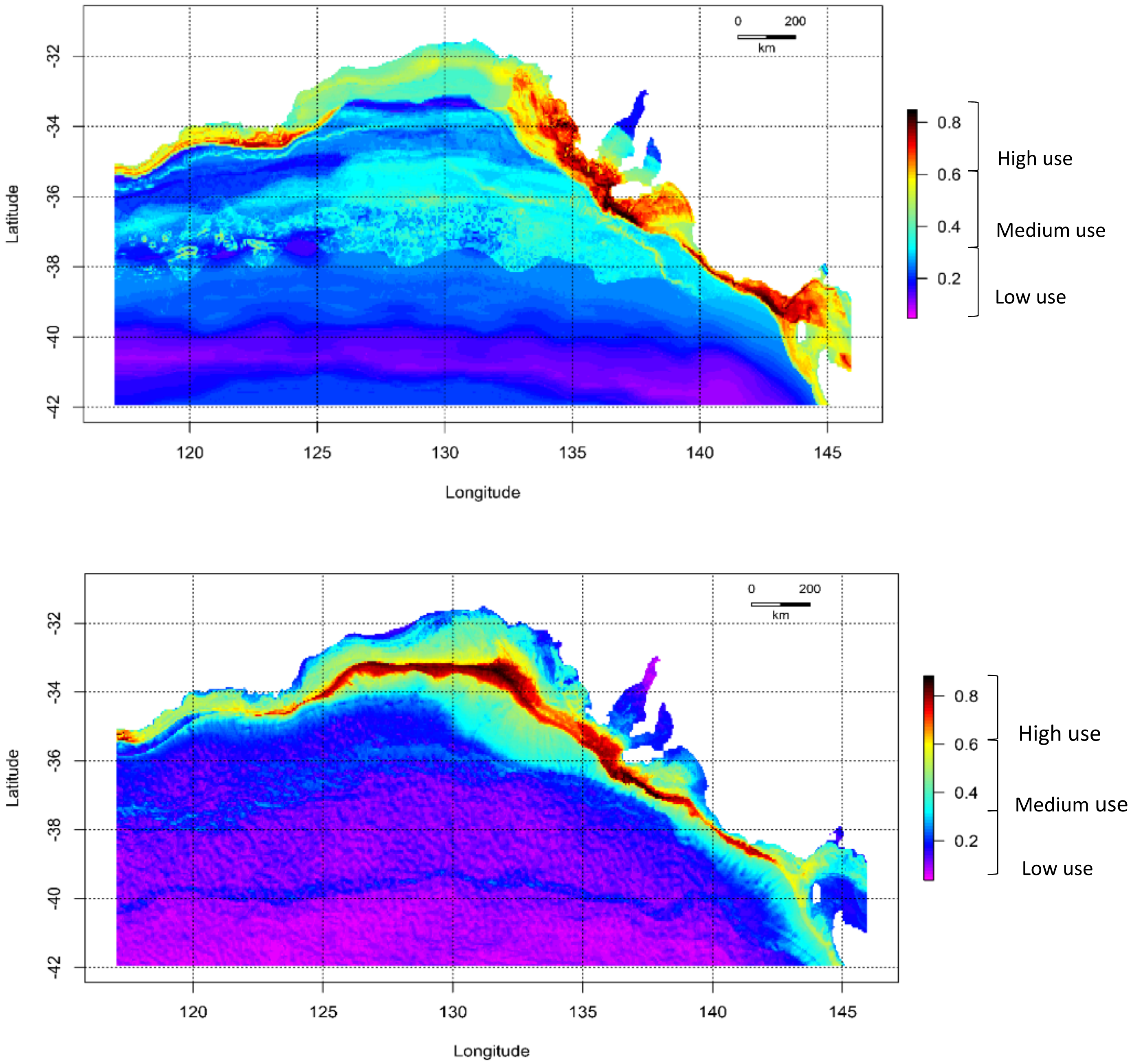


Figure 29. Multi-species overlap of the foraging habitats (average realised occurrence weighted by abundance) of five central-place foragers (above: Australian sea lions, Australian fur seals, long-nosed fur seals, little penguins and short-tailed shearwaters) and foraging habitats (average realised occurrence) of four non-central-place forager species (below: blue shark, shortfin mako sharks, white sharks, southern bluefin tuna).

Spatial dynamics and behavior of Southern Bluefin Tuna

This project developed and used several new quantitative models to investigate factors that influence SBT behaviour in the GAB. Data from 110 archival tags deployed from <1 year up to 3 years during 1998 to 2011 were analysed. An additional 125 electronic tags were deployed during the summer of 2014 to facilitate ongoing studies of spatial dynamics and behaviour of juvenile SBT.

Migrations of SBT were highly variable among individuals and often varied among years for the same individual. Winter foraging locations of individuals often varied among years, but use of the GAB during summer-autumn was consistent, highlighting the global importance of the region for this species. The duration of migrations also varied, with movements to and from the GAB occurring over 61 to 481 days. Intensive residence in the GAB mainly occurred during the first 150 days of the calendar year (Figure 31). By the end of March, residency within in the GAB starts to decline and individuals migrate west into the Indian Ocean or east toward the Tasman Sea.

The departure date of SBT from the GAB was highly variable, beginning in February and extending into August, with the majority having left by July (Figure 31). Returns to the GAB began to increase in November, peaked in December/January and continued through to March. The timing of the return of SBT to the GAB was more consistent among individuals than the timing of their departure.

From December through to February, juvenile SBT were largely concentrated in inshore shelf waters or around the shelf break in the western and central GAB. During March to May, there was an apparent shift towards the eastern GAB. During winter (June – August), the small proportion of tagged SBT that remained in the GAB were concentrated around the shelf break. Juvenile SBT were largely absent from the inshore regions during September and October. Juvenile SBT returning to the GAB through November, tended to occupy inshore areas. Areas of high residence of juvenile SBT are shown in Figure 32.

While the proportion of time juvenile SBT spent in surface waters while in the GAB varied both temporally and spatially, most spent their time at depths of 50 m or less throughout both the day and night). However, more time was spent at the surface during the day than at night. Time spent at the surface during the day declined across the summer and was associated with a deepening of the mixed layer depth and increased mixing of warm waters through the water column. 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 around dawn when fish were at relatively shallow depths. The surfacing behaviour of juvenile SBT demonstrated a crepuscular pattern, suggesting that this behaviour is likely to be

associated with the diel vertical migration of their prey and the relationship of prey species with the deep scattering layer (DSL).

The timing of feeding events suggests that juvenile SBT track their prey. As the depth of the DSL changes, there is a trade-off between the availability of the DSL and the amount of light available. SBT is a largely visual predator. Dawn and dusk periods are likely to provide enough light for identifying and pursuing prey, while also being dark enough for the DSL to have ascended into those depths with light levels suitable for feeding.

Juvenile SBT undertake smaller, more frequent feeding events in the GAB than on winter foraging grounds in the Indian Ocean, where feeding appears to be more sporadic and consists of larger prey (Figure 33). Temperatures associated with feeding events are consistent with juvenile SBT moving into cooler offshore waters over the winter period. The GABs thermal regime could be a driver for the use of the GAB by juvenile SBT. Previous growth studies have shown that a large proportion of the annual growth increment of SBT is achieved during summer in the GAB. Juvenile SBT in the GAB spend a large proportion of the day at the surface; this may be a form of behavioural thermoregulation, allowing them to increase their body temperature, which could increase digestion and growth rates above levels that could be achieved in other coastal or oceanic environments.

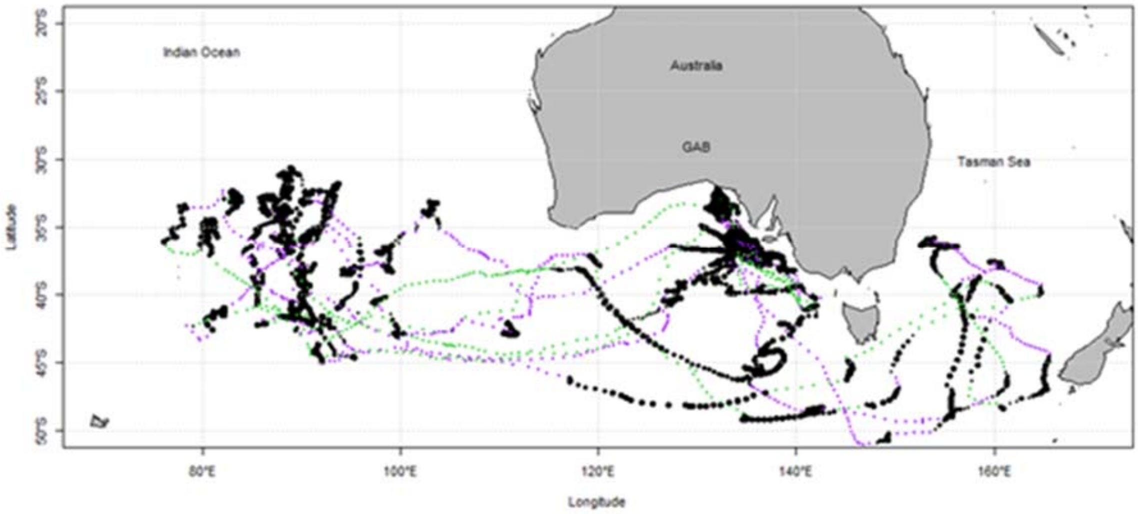


Figure 30. Example of the migration of an individual juvenile SBT. Locations are coloured according to most likely state classification (black = periods of residence, purple = migrations towards the GAB and green = migrations away from the GAB.

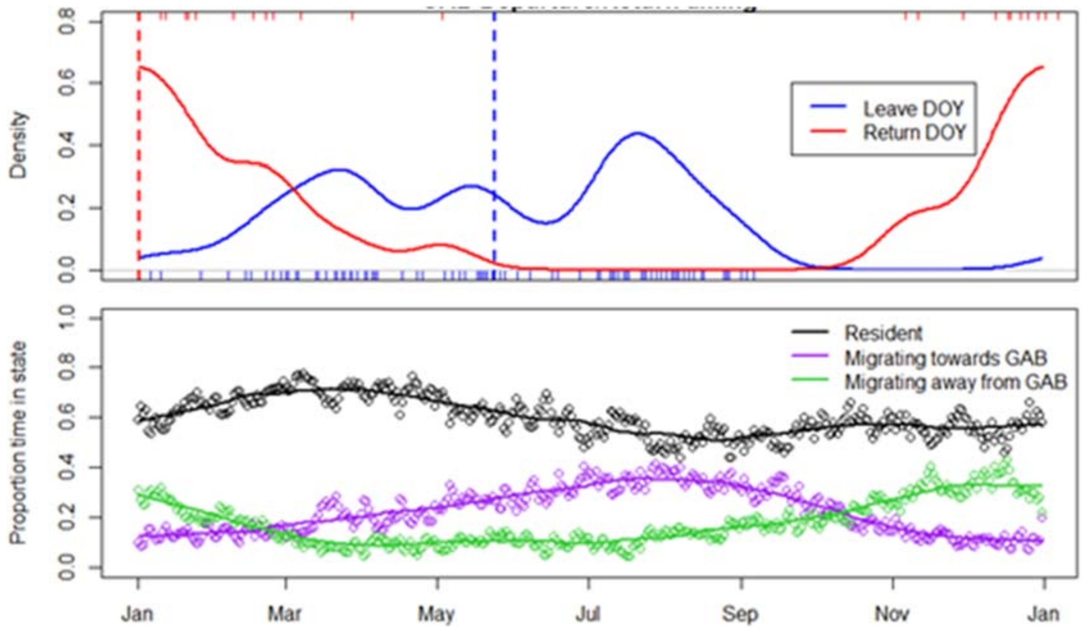


Figure 31. Density of juvenile SBT migrating away from the GAB (blue) and towards the GAB (red) by day of the year (top) and the proportion of positions in each behaviour state by day of the year (bottom).

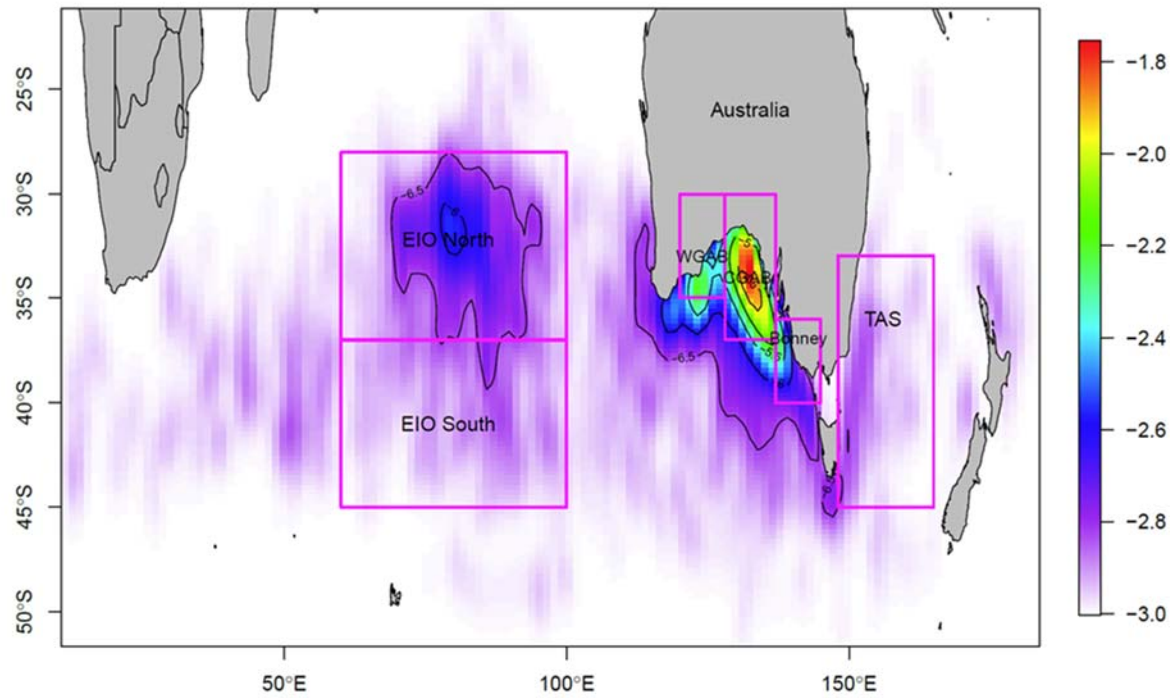


Figure 32. Areas of high residence utilised by juvenile SBT identified by kernel density estimation.

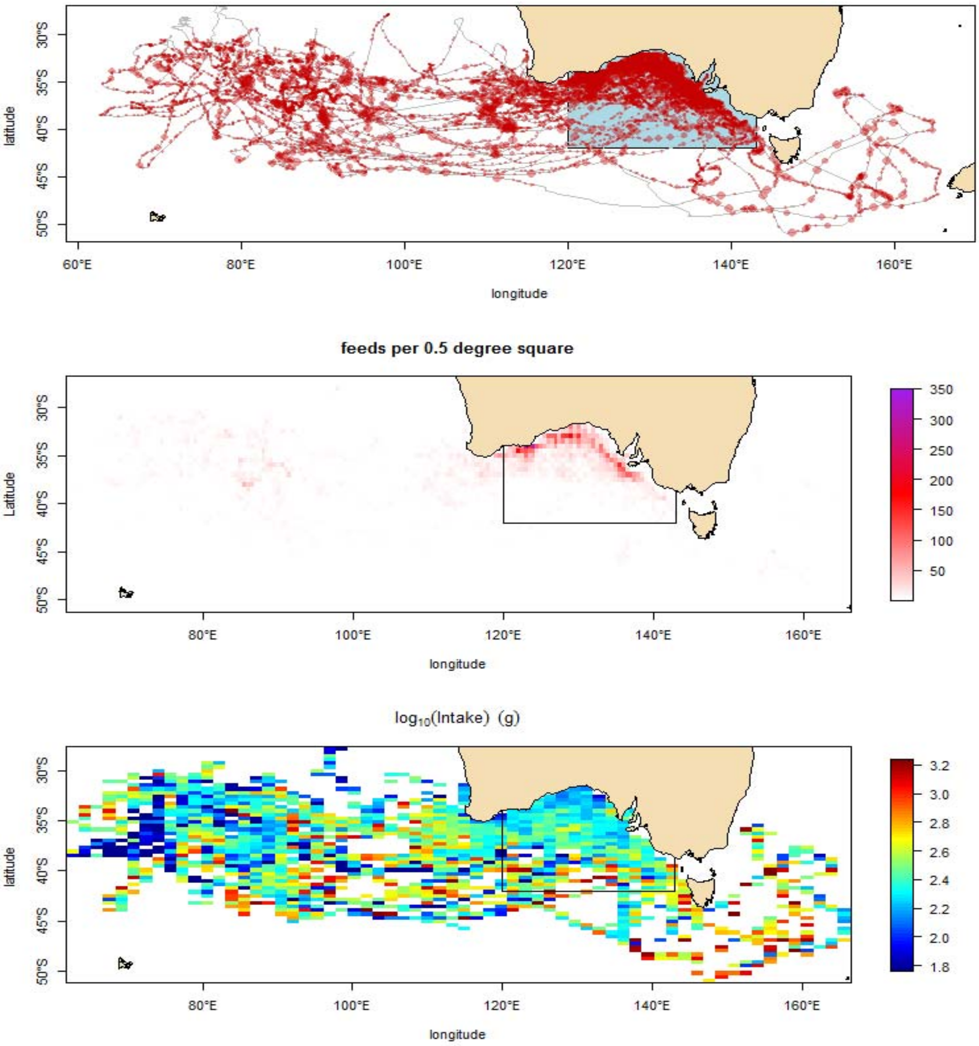


Figure 33. Feeding events and intake amounts interpolated onto the estimated tracks of juvenile SBT (n = 15; top). The size of the circle is proportional to the food intake amount. The number of feeding events per 0.5 x 0.5 degree grid square (middle). Food intake interpolated onto a grid and plotted on a base-10 log-scale to identify regions of high food intake (bottom). Values that fall on the same grid square are averaged.

Noise impacts on Southern Bluefin Tuna

Geophysical surveys for oil and gas exploration have been conducted in the GAB and surrounding areas for more than five decades. Peaks in exploration activity have occurred throughout this time with the most recent increase associated with the release of lease areas in offshore waters of the Bight Basin. Use of more complex, higher density 3D surveys has increased since the turn of the century and coarser 2D surveys have decreased (Figure 34).

There has been substantial temporal overlap between seismic surveys and the occurrence of SBT in the GAB. Both exploration activity and SBT occur in the GAB during the summer months; 2007 was the only year when exploration activity occurred outside the summer period. Measuring the spatial overlap of exploration activity and SBT is prevented by errors in the light-based geolocation process used to estimate juvenile SBT positions in the GAB. Improvements made during this study have progressed our ability to define the movements of juvenile SBT, but do not allow the exact location of an individual at an exact time to be determined.

Using observational data to determine the responses of animals to noise is problematic, and does not allow cause-and-effect relationships to be established. Determining the responses of fish species to noise, requires well designed experiments that include adequate sample sizes and controls to account for potential confounding factors. Such experiments are inherently complex, logistically difficult, and expensive. Experiments should not only be able to detect and measure changes in behaviour, but also attribute changes to particular aspects of noise (e.g. frequency, duration, volume), as well other factors such as the physical environment. Successful experimental design, execution, and analysis requires expertise from a range of disciplines including animal behaviour, experimental design, statistical analysis, hearing and auditory perception, sound generation and propagation, ambient noise, and signal detection.

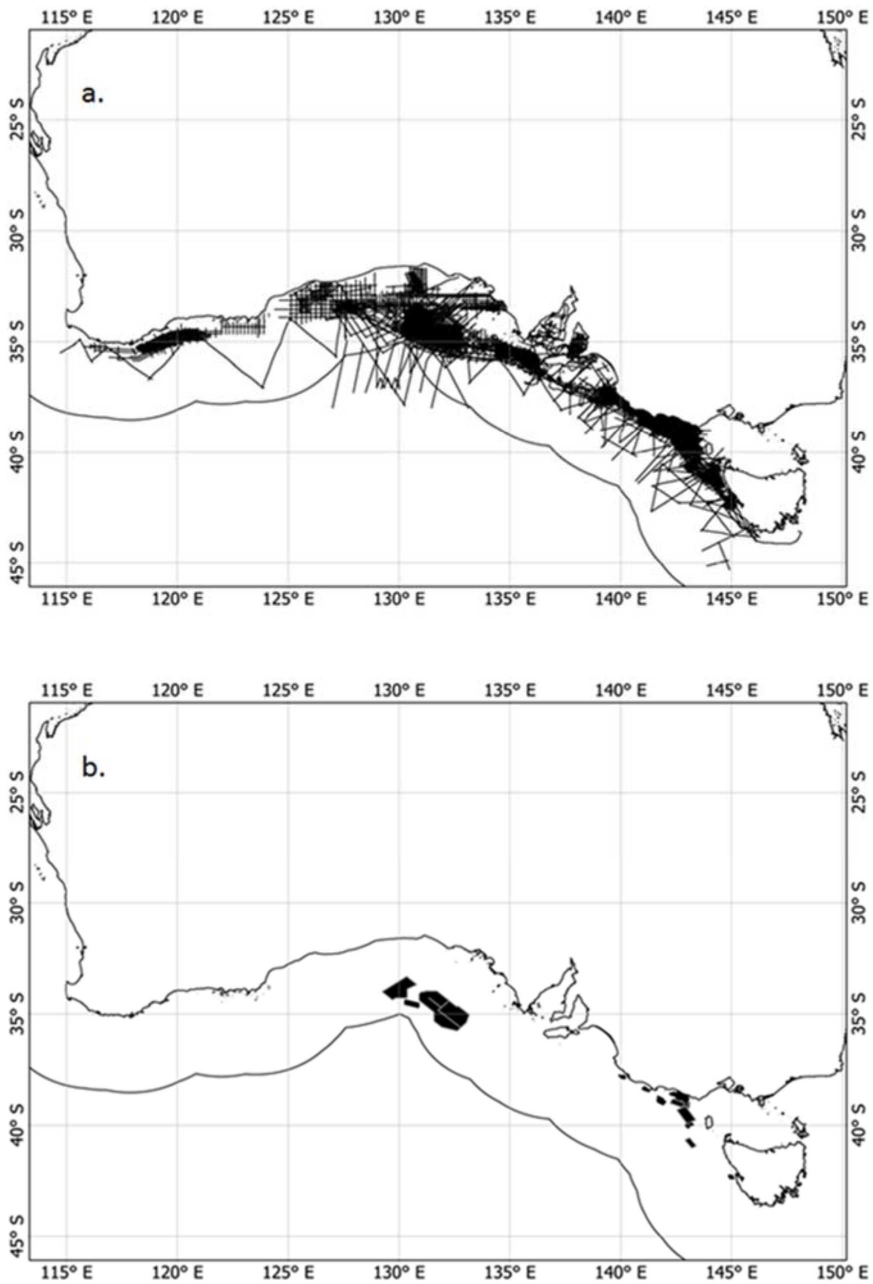


Figure 34. The distribution of (a) 2D and (b) 3D surveys across the extended Great Australian Bight region 1960-2016.

Key findings and legacies

Field surveys and tagging programs conducted during the GABRP provided critical new scientific knowledge on the distribution, abundance and movement of several iconic species. This includes the first abundance estimates for common dolphins in the eastern GAB and for two colonies of flesh-footed shearwaters and little penguins on offshore islands. The Ecology of Iconic Species and Apex Predators Theme also undertook the first surveys of the occurrence and distribution of baleen and toothed whales in offshore shelf and slope habitats, including the first characterisation of the foraging habitats of sperm whales. The integration of existing data on populations of Australian sea lions, long-nosed fur seal and Australian fur seals is a significant legacy from the GABRP that will enhance future management of these species. The program also developed distribution and foraging models for a suite of marine mammals, seabirds and sharks. Improved statistical methods were developed for estimating the position of SBT from archival tags, and examining their feeding behaviour, habitat preferences and seasonal distribution patterns. New insights were obtained on the migration patterns and feeding behavior of SBT. Historical information on seismic activity in the GAB was collated.

PETROLEUM GEOLOGY AND GEOCHEMISTRY

The Petroleum Geology and Geochemistry Theme was comprised of three projects. The first project investigated the occurrence, and potential mechanisms of hydrocarbon seepage and measured hydrocarbon concentrations in the Bight Basin (Ross *et al.* 2017a). The second project investigated the distribution, composition and likely origins of asphaltites and tarballs along the South Australian coastline (Ross et al. 2017b). The third project aimed to constrain key elements of the petroleum system(s); migration, source and timing, and provide geochemical analogues to assess the potential origin of coastal bitumen strandings (Kempton *et al.* 2017).

Delineation and characterisation of cold hydrocarbon seeps

A multi-disciplinary approach was used to identify potential sites of hydrocarbon seepage, including: interpretation of seismic data, determination of fault leakage risk through a structural and geomechanical evaluation, identification of seabed features and morphologies indicative of seepage, delineation of water column acoustic contacts indicative of fluid and gas escape from the seabed, classification of sea surface slick anomalies and sampling of the seafloor in areas of possible seepage and far field locations to understand the distribution of hydrocarbons in sediments.

None of the 81 areas identified from the rapid screening of 2D seismic data displayed unequivocal evidence of fluid leakage through the subsurface to the seafloor. Features with the highest potential for leakage occurred on the deep water slope of the Ceduna Basin (Figure 35). Biogenic mound complexes interpreted at the Middle Eocene hiatus are potentially indicative of hydrocarbon paleo-seeps and possibly paleo-leakage up faults (Figure 36). Such an interpretation would support the presence of an active hydrocarbon system at the time of Middle Eocene extension, fault movement and reactivation. However, this assessment requires further research.

Structural and geomechanical assessment modelling did not conclusively predict sealing or leaking with respect to across fault flow, with the geomodel predicting intermediate across fault flow in the most likely scenarios. These model iterations demonstrate the high sensitivity of the modelled lithologies to across fault flow sealing.

Studies of sea surface slicks included the acquisition of four additional synthetic aperture radar scenes which augmented the 231 publically available scenes (Figure 37). A total of 23 sea surface anomalies were identified within the four additional scene captures which clustered near anomalies

identified in previous scene captures. These data were used in conjunction with the areas of interest identified by screening of 2D seismic data to identify areas for reconnaissance (Figure 38).

Three seafloor areas were identified where reconnaissance for potential seepage could be undertaken within the time available during surveys (Figure 38). Data collected during two voyages provided no evidence of seepage (Figure 38). The absence of seepage in the Basin has not been confirmed, as the Basin is large and limited data have been collected.

Quantitative analysis of solvent extracts isolated from seawater samples indicate that polycyclic aromatic hydrocarbons (PAHs) are largely absent in and around the GAB BP leases. Qualitative organic geochemical analyses of extractable organic matter isolated from seawater, seabed sediment, net samples and headspace gases extracted from multicore/piston core samples indicate that petroleum hydrocarbons are below the limits of detection, suggesting an absence of hydrocarbon seepage in and around the sampling region.

Asphaltite and tarball surveys

This project provided the first multi-annual geospatial, geochemical and oceanographic study of the stranding of coastal bitumen (asphaltite and tarballs) on representative beaches along the entire South Australia coastline. A total of 31 beaches were sampled after winter in 2014, 2015 and 2016, and yielding a total of 631 specimens, the largest collection from an Australian region (Figure 40).

Tarballs (waxy bitumen) mainly strand in the upper parts of southwest-facing ocean beaches; denser asphaltites tend to accumulate on beaches with a northwest aspect. Waxy bitumens are most common on the Limestone Coast; asphaltites are more common along the west coast of the Eyre Peninsula.

Physical, elemental, isotopic and biomarker characterisation identified fifteen oil families and sub-families. Most waxy bitumens had distinctive Cenozoic lacustrine biomarker signatures suggesting origins in the Indonesian Archipelago. Asphaltite and waxy bitumen strandings have declined over the past 20+ years, suggesting reduced seepage, and/or, in the latter case, improved environmental practices for tanker washing and oil spillage in Indonesian waters.

One soft asphaltic bitumen recovered from the Limestone Coast was unique, and likely to be a product from a Cretaceous marine source rock similar to that which gave rise to the asphaltites; both suggest the existence of an active petroleum system in the Bight Basin. At least two waxy bitumen sub-families lack Indonesian signatures and may originate from seeps in offshore basins along Australia's western and southern continental margins. The discovery of new oil families of

non-Indonesian provenance in bitumens found on the South Australian coastline has important implications for the prospectivity of the GAB.

Oceanographic models that simulated currents and Stokes drift describe observed strandings of tarballs and asphaltites (Figure 41). Winter conditions transport materials west to east and can supply materials to all beaches in the GAB, consistent with the widespread discovery of Indonesian waxy bitumens. Bitumens from the Ceduna or Duntroon Sub-basins are unlikely to reach the coastline at the Head of Bight or northern Eyre Peninsula during winter (Figure 41). There is a low probability of materials from west of Kangaroo Island reaching beaches on the Eyre Peninsula. The most likely source of strandings on the Eyre Peninsula is located west of Kangaroo Island and overlies the Duntroon Sub-basin and eastern part of the Ceduna Sub-basin (Figure 41). Seismic data suggest potential leakage indicators occur in this region.

Petroleum migration in the Bight Basin

A total of 36 samples were analysed using CSIRO's *Grains with Oil Inclusions (GOI™)* technique to screen the Bight Basin for the presence of hidden hydrocarbons. Samples analysed were obtained from seven historic exploration wells: Central Ceduna Sub-basin; Potoroo-1, the previously untested Gnarlyknots-1A well and Eastern Ceduna/Duntroon Sub-basin; Borda-1, Duntroon-1, Greenly-1, Jerboa-1 and Platypus-1 (Figure 35).

The identification of oil-bearing and gas-rich inclusions at low abundance (GOI <0.7%, up to a maximum of 1.1% in Greenly-1) provided positive evidence for widespread oil and gas migration in the Bight Basin (Table 2, Figure 42, 43, 44). These hidden oil indications are more frequent in intervals from the Late Cretaceous White Pointer, Tiger and Hammerhead Supersequences and are a significant improvement over conventional oil indicators that are limited to Greenly-1. The presence of these hydrocarbon inclusions implies generation and expulsion from active petroleum systems, and therefore the presence of effective source rocks. The result improves exploration potential, particularly in the poorly understood deep water of the Ceduna Sub-basin.

To geochemically fingerprint hydrocarbons, CSIRO's *Molecular Composition of oil Inclusions (MCI)* and gas-isotope techniques were performed on minute quantities of oil and gas extracted from the fluid inclusions (Table 2, Figure 42, 43, 44). Fluid inclusion (FI) oil from Gnarlyknots-1A (4,390 to 4,425 mMD; Tiger Supersequence) comprises a mixture of types including oil and gas-condensate. The *n*-alkane and biomarker characteristics show a mixed organic matter input from both algae and terrestrial plants and was generated from source rock(s) deposited in suboxic-oxic marine environment(s). The wide range of maturities, 0.65% to 1.3% equivalent vitrinite reflectance (VRE),

in the Gnarlyknots-1A FI oil suggests either a mixture of oils generated from different source rocks. Blue Whale and Tiger have potential marine algal input, while the White Pointer has potential terrestrial plant input–or from the same source rock at different maturity stages–perhaps an unrecognised paralic facies of the White Pointer, containing both algal and terrestrial organic matter. Either way, the recognition of some algal input is the first direct evidence for generation from rocks containing Type II kerogen and this significantly improves the prospectivity in the deep water Ceduna Sub-basin.

By comparison, FI oil from Greenly-1 (4,8064,818 mMD; White Pointer Supersequence) comprises only oil, with no gas-condensate visually detected (Table 2, Figure 42, 43, 44). The *n*-alkane and biomarker characteristics indicate significant organic matter input from terrestrial plants, and a minor contribution from bacteria, and generation from a source rock deposited in an oxic, clay-rich fluvio/deltaic depositional environment. This FI oil represents a pristine oil sample that was generated over a narrow maturity band at the early to peak oil window (0.8% to 1.1% VRE), and lacks the mixed algal input of the current oil indications in the same well. Previous suggestions that these oil indications correlate to a Bronze Whaler source sequence is not supported by the MCI data, which lacks algal input and potentially indicates a White Pointer source sequence instead.

To understand the timing of oil migration, the *pressure-temperature (PT)* trapping conditions of hydrocarbon inclusions were determined in Gnarlyknots-1A, Greenly-1, Duntroon-1 and Potoroo-1. The intra-Coniacian primary well target in Gnarlyknots-1A (4,41015 mMD; Tiger Supersequence) was a migration pathway, over an extended period of time, for a variety of hydrocarbon fluid compositions modelled by Petroleum Inclusion Thermodynamic (PIT) as black oil, light oil, gas-condensate and gas+CO_2. There is good concordance in the measured *PT* data with independent *PT* curves from basin models. The earliest oil entrapment took place at a minimum of 58°C, with constrained *PT* conditions of light oil (240-270 bar; 69.2°C) in the Late Cretaceous at ~70-75 Ma (Campanian). Phase separation of light oil, and entrapment of both gas-rich phases and gas-depleted black oil, occurred at *PT* conditions (285-308 bar; 80-85°C) consistent with the Late Cretaceous at ~70 Ma (Maastrichtian). Subsequent entrapment of gas-condensate took place at pressure conditions (350-410 bar; 80°C) reached later at ~35-15 Ma (Oligocene to Early Miocene), followed by gas+CO_2 at *PT* conditions (370-408 bar; 78-88°C) reached at ~27-15 Ma (Late Oligocene to Early Miocene). This apparent sequence of hydrocarbon entrapment from oil to gas over time might simply be explained by generation from a single source rock over a range of thermal maturity stages. Late black oil entrapment, at pressure conditions (400 bar) reached at ~18 Ma (Miocene), might be from a different source rock that entered the oil window later in the basin history.

Key findings and legacies

The study of bitumen strandings provided evidence of active, hitherto unknown, petroleum systems in the GAB. Although a definitive origin was not identified for the new tarball oil families and asphaltites, the most likely source of strandings on the Eyre Peninsula is located west of Kangaroo Island and overlies the Duntroon Sub-basin and eastern part of the Ceduna Sub-basin.

Hidden hydrocarbons, trapped in fluid inclusions were detected in both Gnarlyknots-1A and in supplementary wells. This study proved, for the first time, the existence of hydrocarbons in the central deepwater Ceduna Sub-basin. Geochemical analysis of the composition of liquids and gases provided a clearer understanding of possible source rocks that generated these hydrocarbons, including the eastern Ceduna/Duntroon Sub-basins. Detailed information of the timing of entrapment and oil type has permitted constraints on when hydrocarbon charge took place which, in turn, helps to validate petroleum systems models. The outcomes of this project have significantly enhanced prospectivity and reduced exploration risks within the Bight Basin.

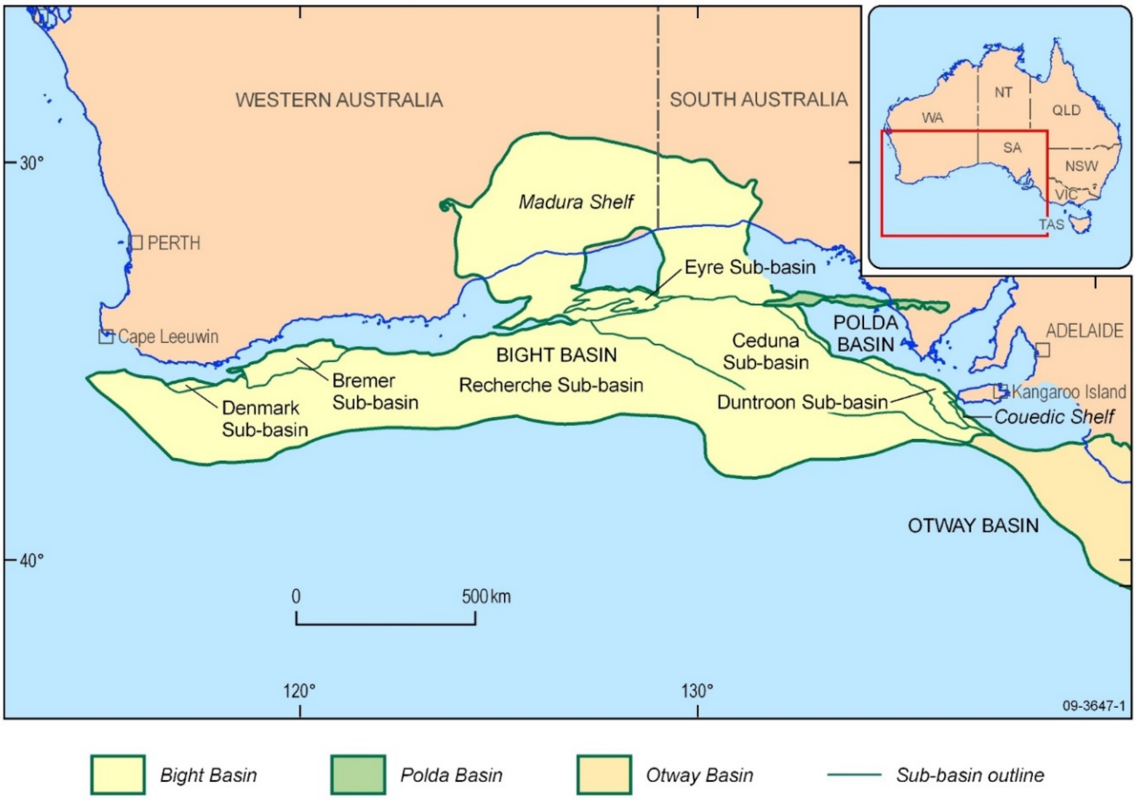


Figure 35. Location of the Bight Basin with component sub-basins. © Commonwealth of Australia (Geoscience Australia) 2016

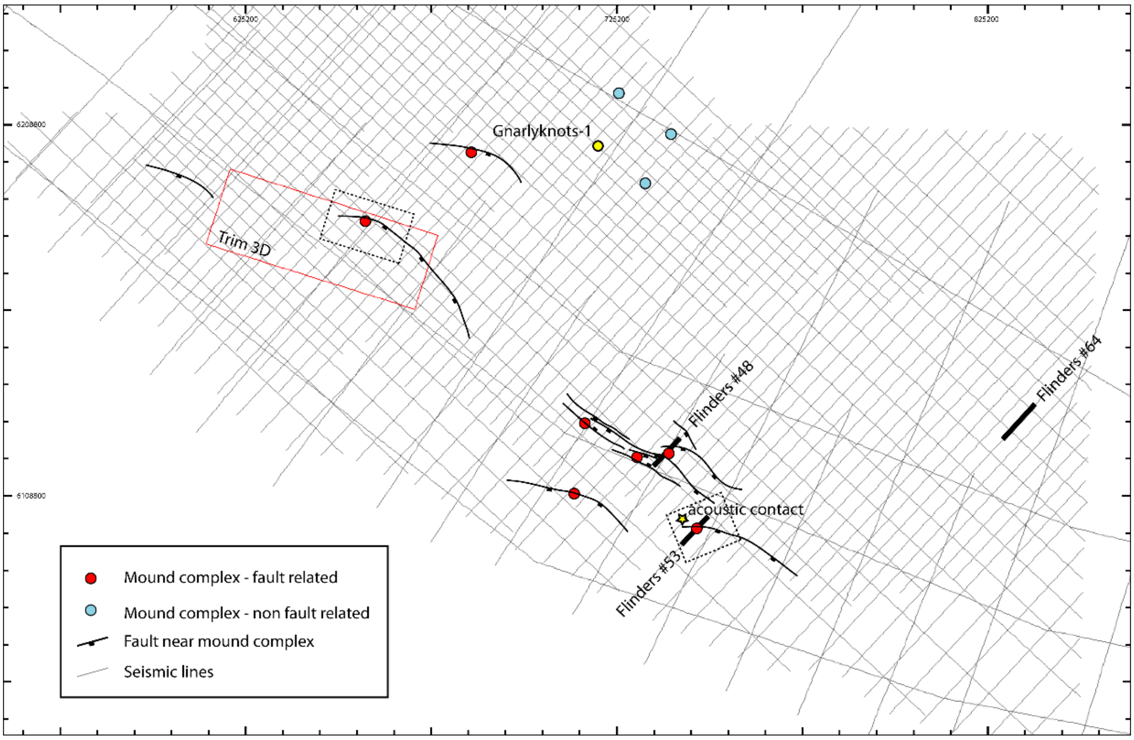


Figure 36. Mound complexes in the central Ceduna Sub-basin.

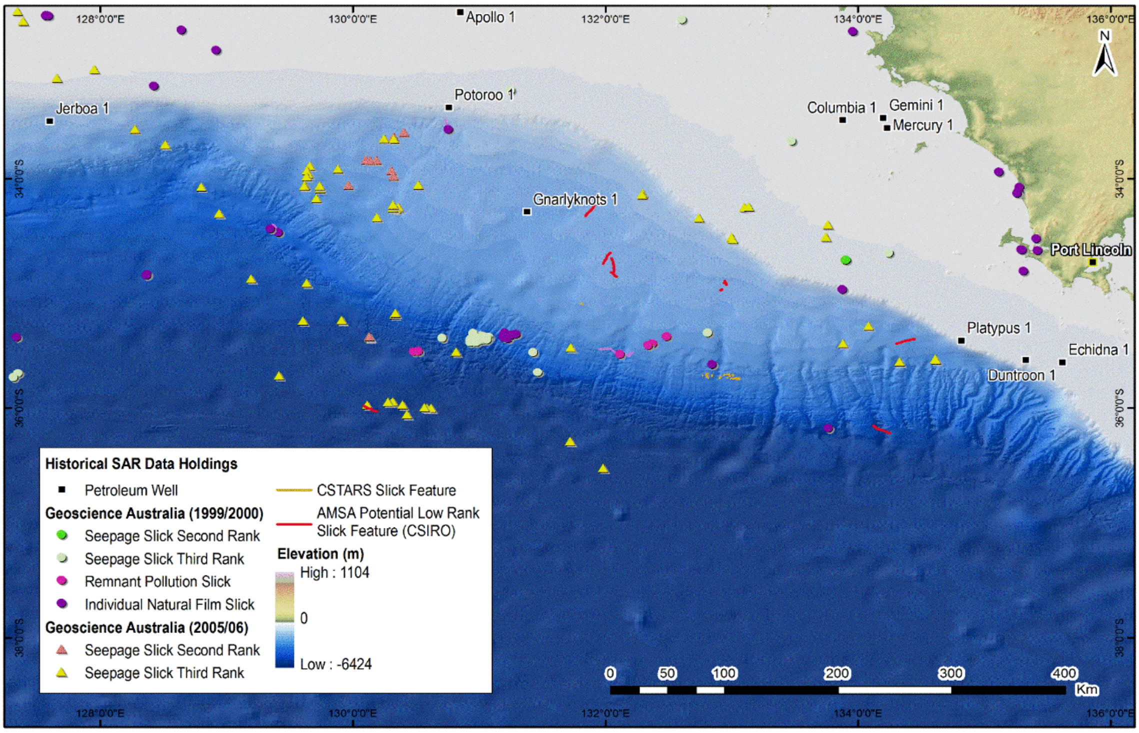


Figure 37. Combined historical and capture program (CSTARS Slick Features) sea surface synthetic aperture radar anomalies for the Great Australian Bight.

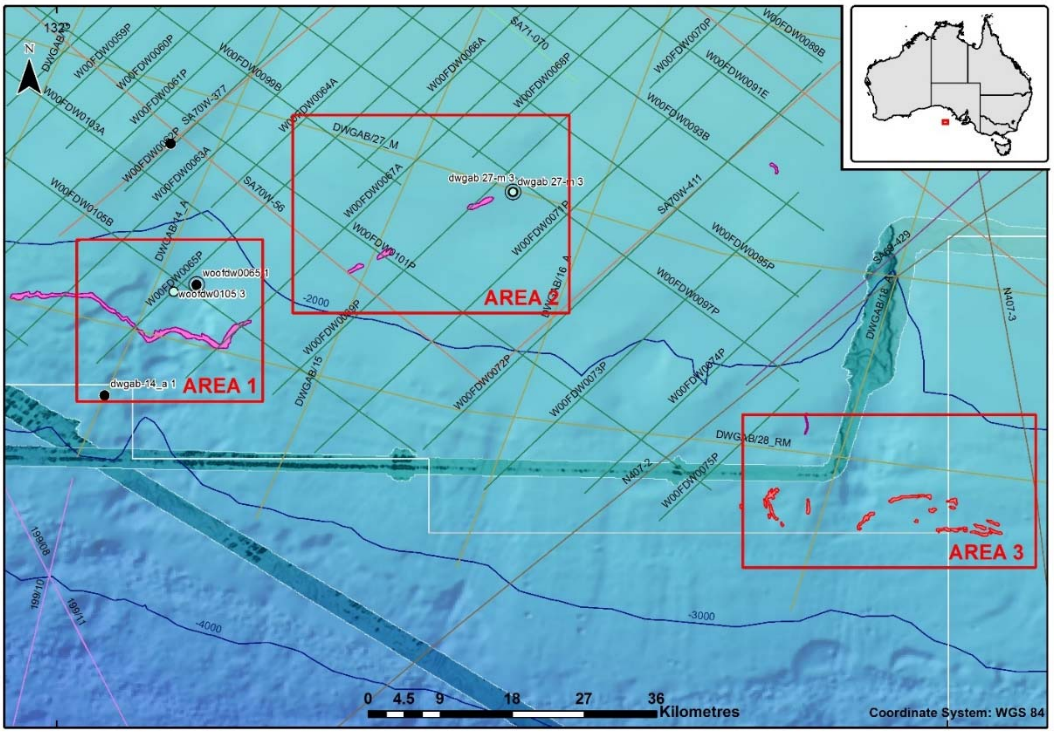


Figure 38 Showing target areas 1-3 interpreted as having indications of potential seepage. The labelled lines are the available public 2D seismic holdings. Black or light blue dots are seismic anomalies. The purple outlined areas are slick extents from the GA/NPA 199/2000 SAR study whereas the red areas are potential slick extents from the CSTARS data collected during this study.

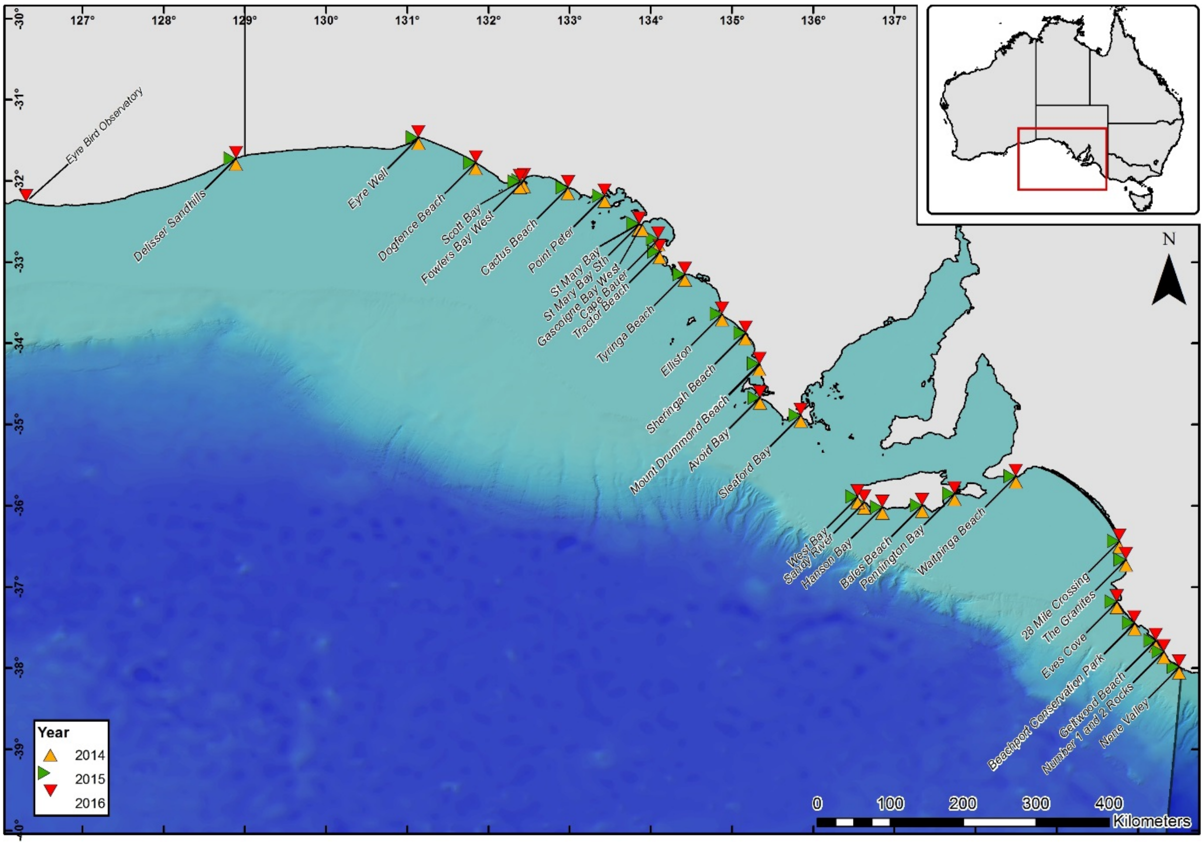


Figure 39. Beaches visited during the 2014 / 2015 / 2016 seasons.

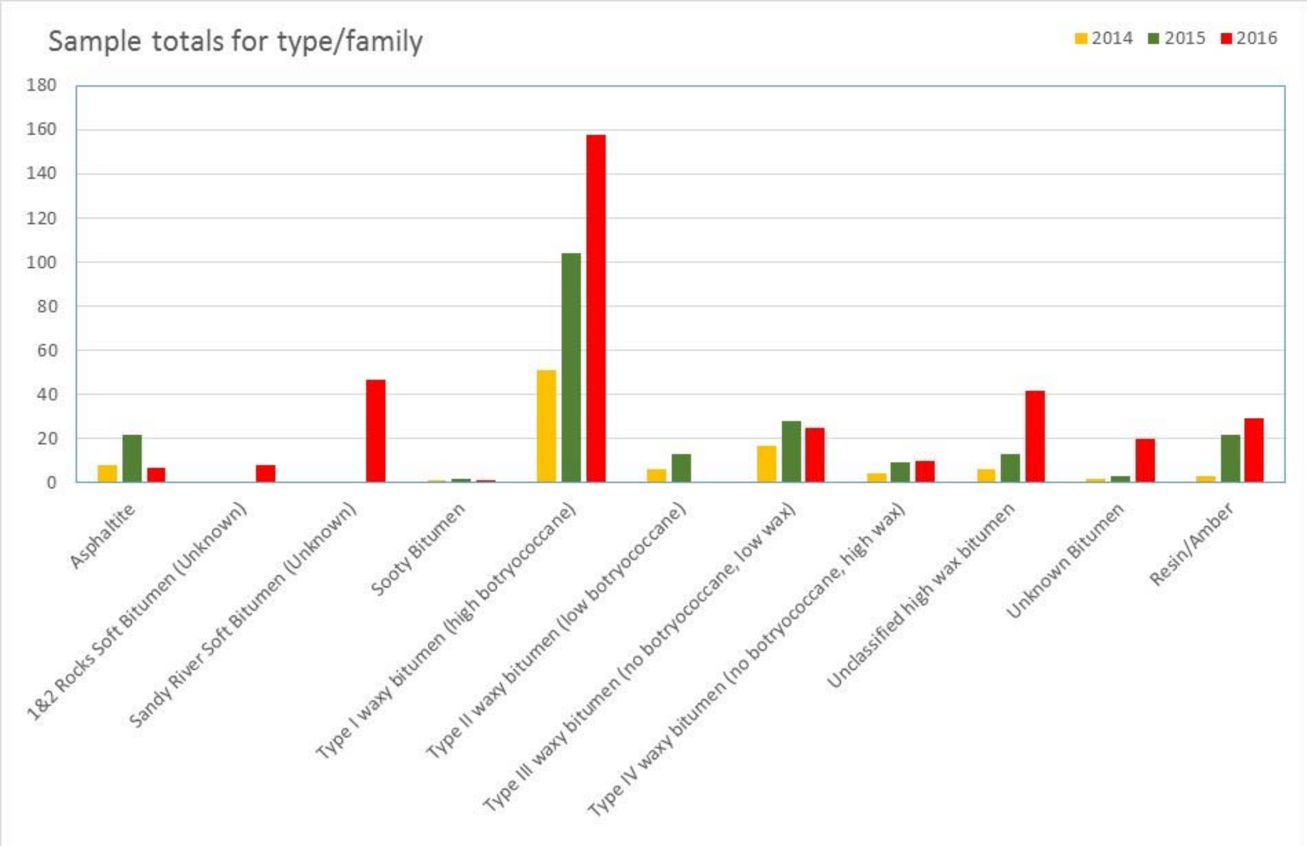


Figure 40. Sample numbers plotted against oil family (determined by whole oil GC-MS) by year after exclusion of donated samples plus unclassifiable and miscellaneous materials.

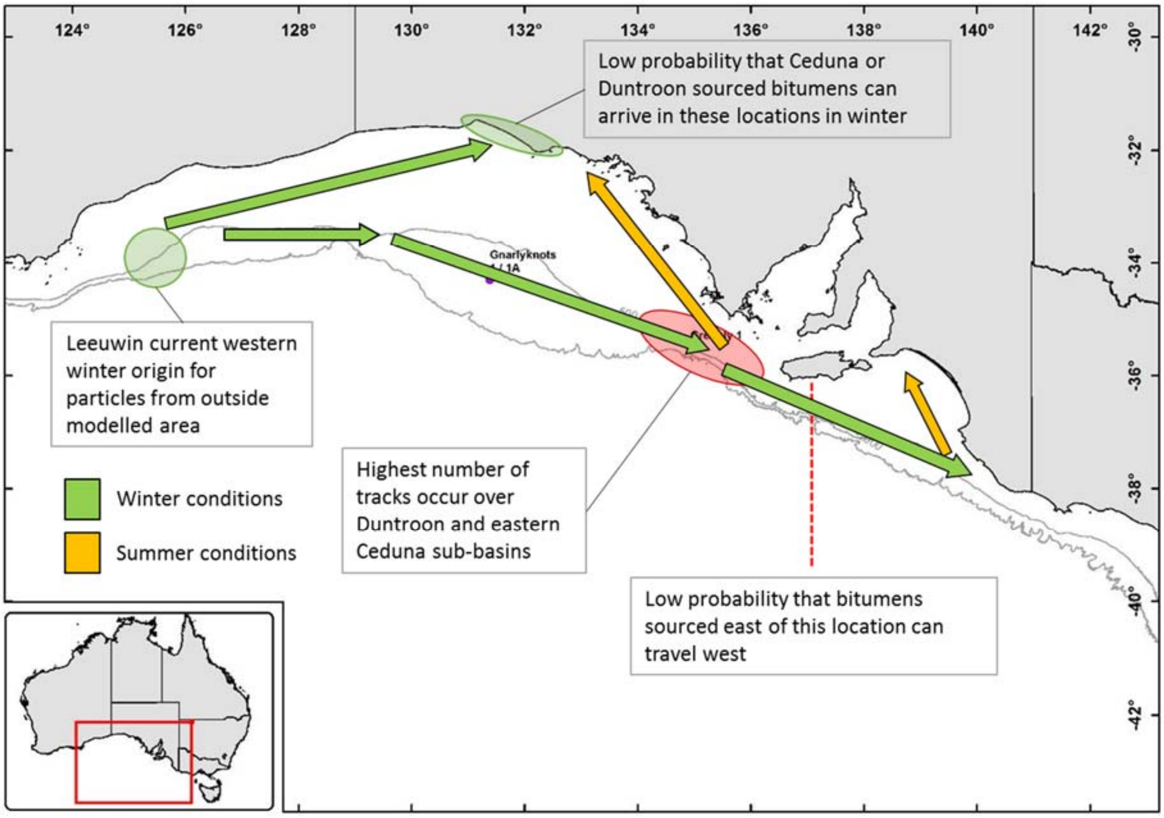


Figure 41. Key observations from oceanographic forward and backtrack models incorporating Stokes drift.

Table 2. Grains with Oil Inclusions results from this study.

Well	CSIRO No	Depth (MMD)	Count Protocol	Grains with oil inclusions	Total grains counted	GOI (%)
Borda-1	134500	2678-81 m	RG	4	6819	<0.1%
Borda-1	134501	2774-77 m	RG	0	2272	0.0%
Duntroon-1	134502	1855-60 m	RG	2	2160	<0.1%
Duntroon-1	134503	2150-55 m	RG	7	2253	0.3%
Duntroon-1	134504	2505-10 m	RG	12	3316	0.4%
Duntroon-1	134505	3025-30 m	RG	1	2718	<0.1%
Duntroon-1	134506	3235-40 m	RG	2	3840	<0.1%
Duntroon-1	134507	3345-50 m	RG	1	4015	<0.1%
Greenly-1	134508	3275-80 m	RG	6	3326	0.2%
Greenly-1	134509	3753-56 m	RG	2	2298	<0.1%
Greenly-1	134510	4110-13 m	RG	14	6661	0.2%
Greenly-1	134511	4377-80 m	RG	15	8520	0.2%
Greenly-1	134512	4530-33 m	RG	20	6192	0.3%
Greenly-1	134513	4809-12 m	RG	16*	1425	1.1%
Gnarlyknots-1A	134514	2170-80 m	RG	10	3360	0.3%
Gnarlyknots-1A	134515	2535-40 m	RG	8	2540	0.3%
Gnarlyknots-1A	134516	2865-70 m	RG	7	3648	0.2%
Gnarlyknots-1A	134517	3175-80 m	RG	5	3878	0.1%
Gnarlyknots-1A	134518	3760-65 m	RG	11	4994	0.2%
Gnarlyknots-1A	134519	3770-75 m	RG	6	3775	0.2%
Gnarlyknots-1A	134520	3930-40 m	RG	20	4778	0.4%
Gnarlyknots-1A	134521	4135-40 m	RG	19	4352	0.4%
Gnarlyknots-1A	134522	4390-95 m	RG	9	4143	0.2%
Gnarlyknots-1A	134523	4400-05 m	RG	12	7594	0.2%
Gnarlyknots-1A	134524	4410-15 m	RG	29	7027	0.4%
Gnarlyknots-1A	134525	4520-25 m	RG	6	6353	<0.1%
Gnarlyknots-1A	134526	4605-10 m	RG	19	5954	0.3%
Gnarlyknots-1A	134527	4705-10 m	RG	13	8046	0.2%
Jerboa-1	134718 + 134719	2470-75 m + 2475-80 m	RG	0	517	0.0%
Jerboa-1	134720	2490-95 m	RG	0	345	0.0%
Platypus-1	134528	9560-70 ft	RG	3	3720	<0.1%
Platypus-1	134529	9640-50 ft	RG	3	2700	0.1%
Platypus-1	134530	11090-100 ft	RG	0	201	0.0%
Potoroo-1	134721 + 134722	1778-82 m + 1782-86 m	RG	34	21384	0.2%
Potoroo-1	134531 + 134532	2398-2402 m + 2402-06 m	RG	3	2352	0.1%
Potoroo-1	134533	2730-34 m	RG	2	500	0.4%

GOI rounded to nearest 0.1% except for values between 0.01 and 0.09% which are reported as <0.1%. Rectangle Grid (RG), Point Grid (PG), Square Grid (SG or Random). * Excludes of oil inclusions in carbonate cement.

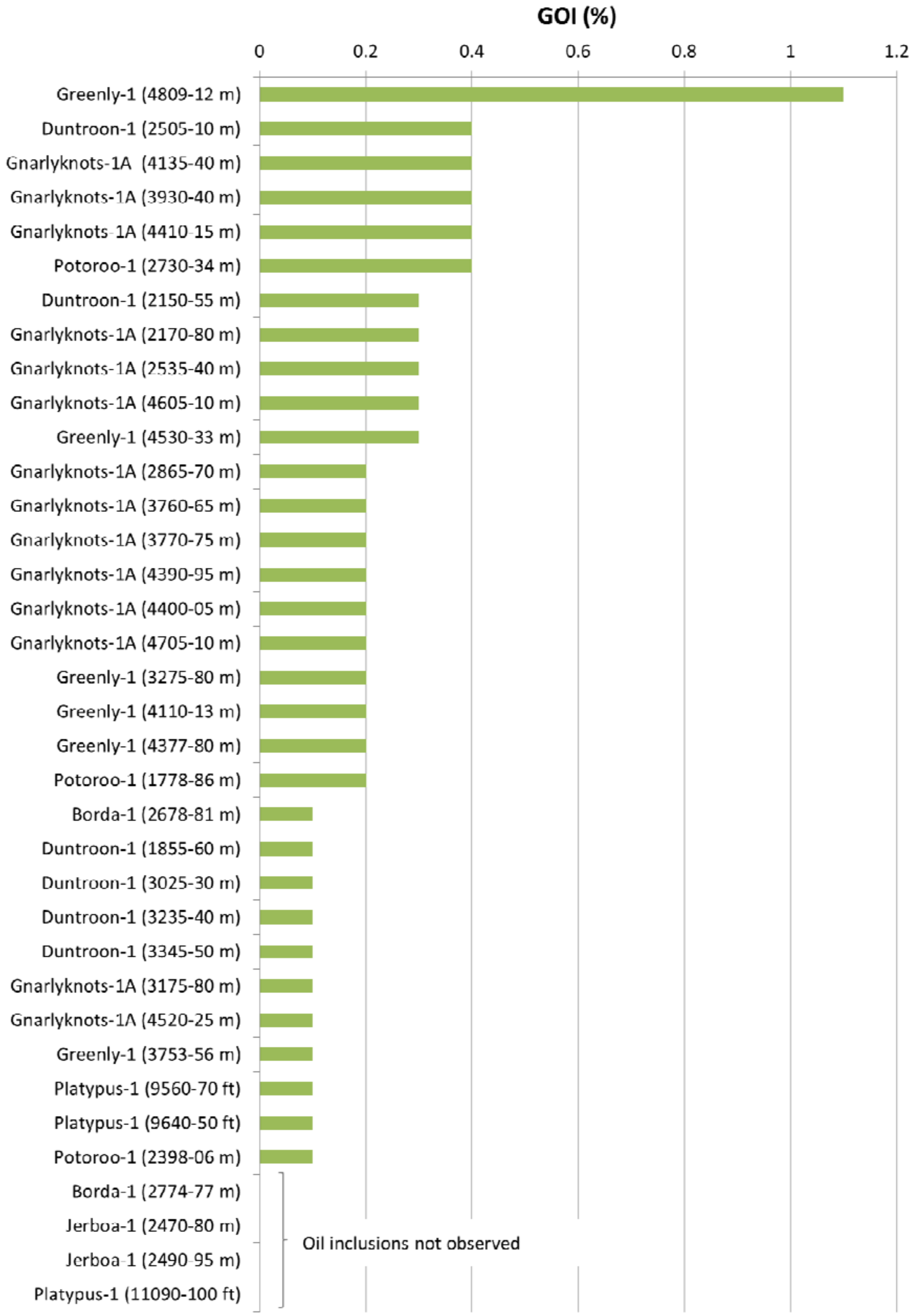


Figure 42. Grains with Oil Inclusions results ranked by GOI number.

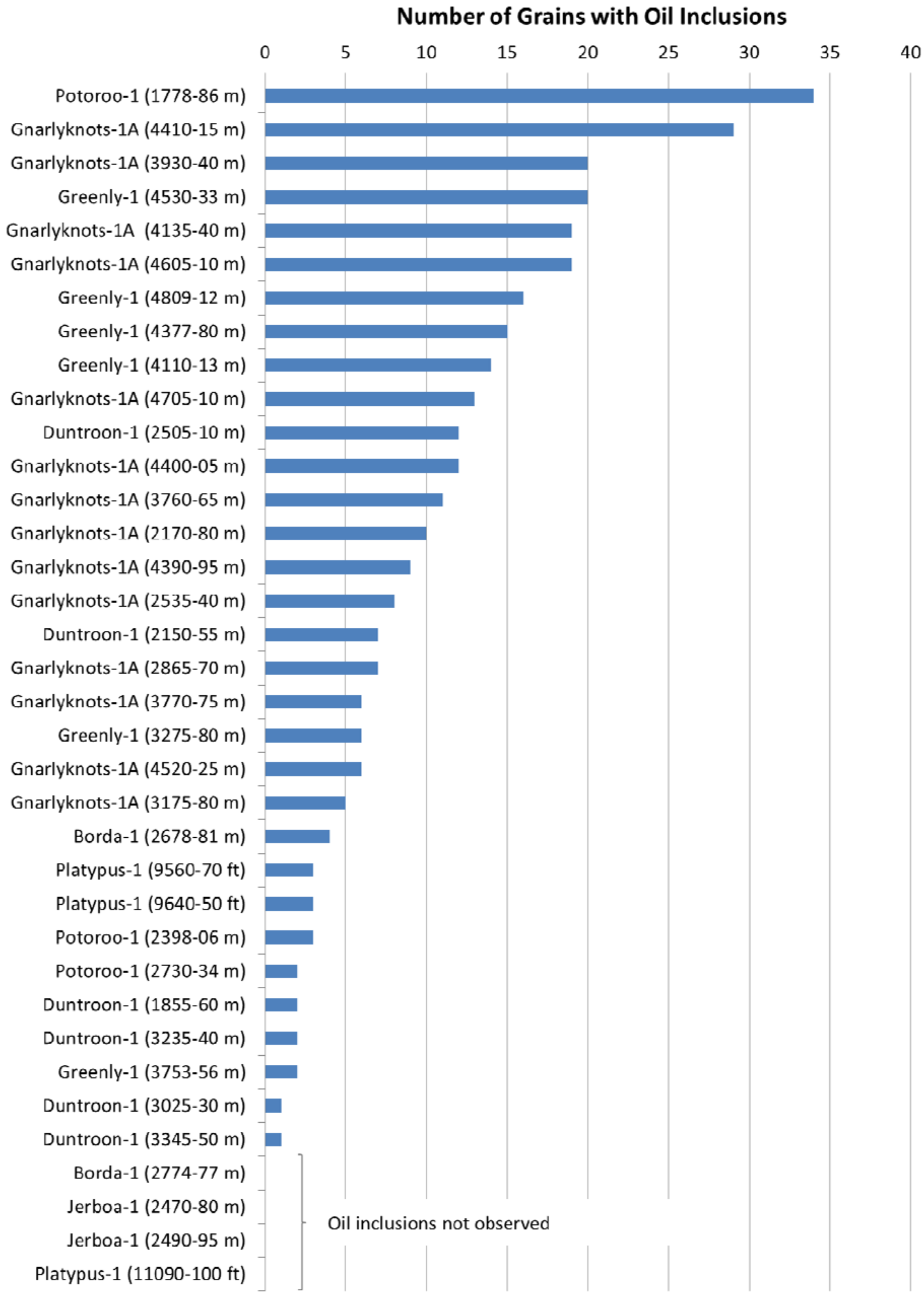


Figure 43. GOI results ranked by number of grains with oil inclusions.

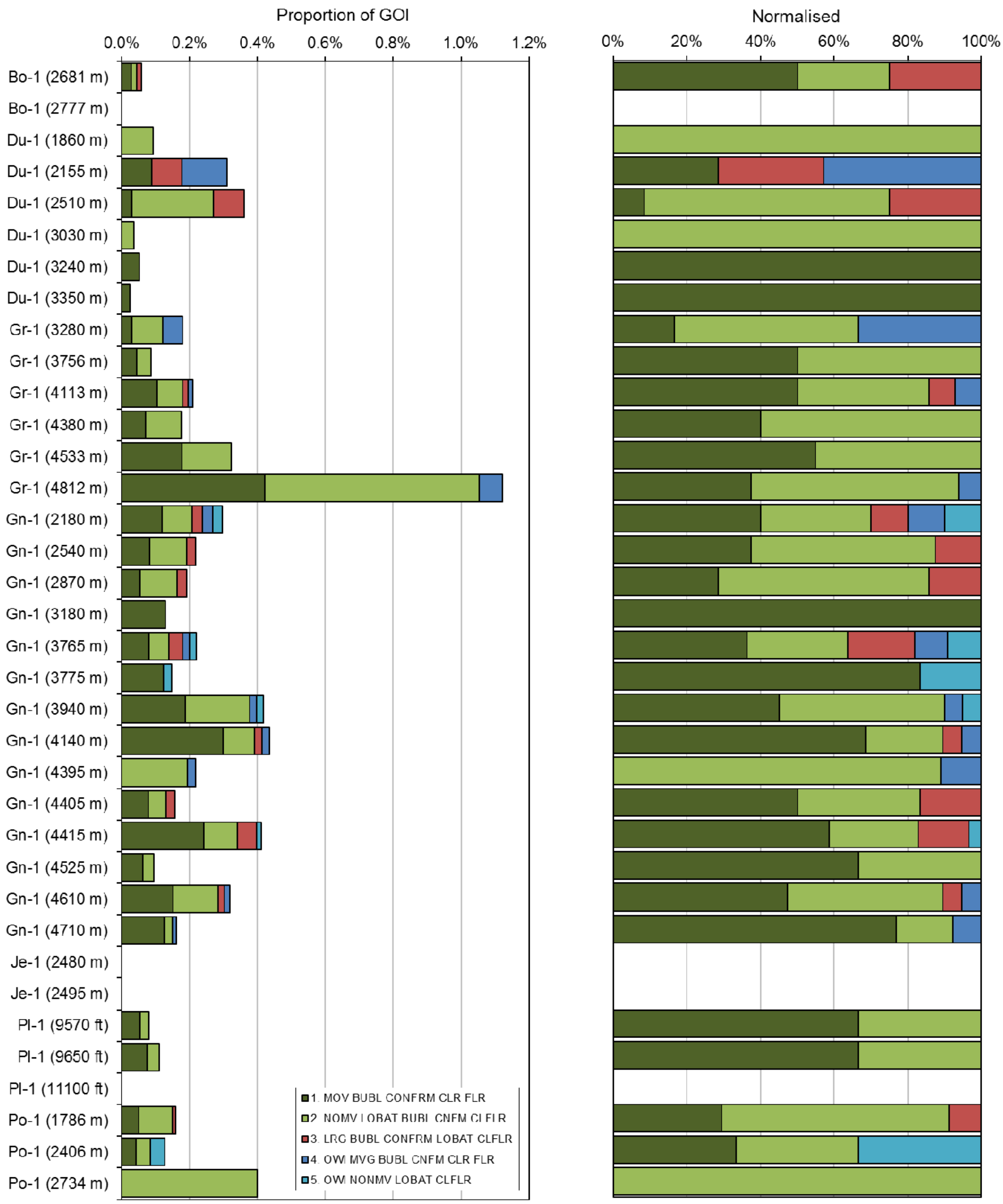


Figure 44. Bar chart of oil inclusion descriptions for GOI–all samples. For oil-bearing inclusions counted in GOI only. Well annotations shortened to first two letters of name. Depth = base of cuttings interval.

SOCIO-ECONOMIC ANALYSIS

The key objective of the Socio-economic Analysis Theme was to establish social and economic baselines and analytical tools for the region. The Theme consisted of three projects. The first project documented the socio-economic status of the regional communities and identify concerns about the development of an oil industry in the region, focusing on the Eyre Peninsula and the West Coast regions (Beer and Thredgold 2017). The second project provided a regional economic baseline, identified the range and relative importance of the different industries to employment, income and the processes currently driving development (O'Neil *et al.* 2017). The project also developed a series of regional models that can be used for subsequent analysis of economic impacts. The third project focused on the fisheries and aquaculture industries in the GAB (Pascoe and Innes 2017a). As well as determining the current economic status (e.g. gross value of production, profitability and contributions to the regional economy) of the different fisheries and aquaculture businesses in the region, the project also undertook a qualitative assessment of the potential impacts of the development on? the region's fisheries (Pascoe and Innes 2017b).

Socio-economic baseline

The Eyre Peninsula and West Coast (EPWC) region consists of 11 Local Government Areas (LGAs) and the unincorporated west coast. The total population was 56,286 people in 2011, 3.5 per cent of the South Australian population. Approximately 64 per cent of the EPWC region's population resided in the City of Whyalla (22,088) and City of Port Lincoln (14,086). A total of 635 people live on the unincorporated west coast. Almost 83% of the region's population was born in Australia; over 5.5 per cent (3,162) identified as an Aboriginal person at the 2011 census. The Nauo (south western Eyre), Barngarla (eastern Eyre), Wirangu (north western Eyre), and Mirning (far western Eyre) are the Aboriginal Nations present when Europeans arrived and maintain traditional ties to Country in the study area.

The social baseline study identified that the region is characterised by a small and sparsely distributed population and highly dependent on primary industries (agriculture, fishing, aquaculture). Opportunities outside these sectors are limited. There is general net outward migration of younger residents to larger centres and Adelaide for employment and education. The age profiles of the population and workforce in the EPWC are older than the rest of South Australia. There is a strong attachment to place in the region, with the pristine coastal and marine environment a key factor underlying this attachment (Figure 45). Attitudes to the development in the region were largely positive, with expectations of alternative employment opportunities

generated directly (by the oil industry) and indirectly through increased population in the region (Figure 46). Concerns about potential environmental damage, were also raised by residents.

Economic modelling

The results of the economic baseline study largely confirmed those of the social survey, namely that primary industries were the dominant sectors in terms of gross regional product and employment. Unemployment in the region was generally lower than the State average, although this was partially an artefact of the outward migration from the region of those seeking employment. The study also highlighted that there was a broad skills shortage in the region, and that potential direct employment opportunities from an oil and gas development would result in an influx of workers. Infrastructure in the region is also relatively poor, and improvements in infrastructure as a result of any development would be of benefit to the existing sectors. An economic model was developed for the region that could be used to assess the impacts of future developments against the baseline conditions.

Fishing and aquaculture

Total gross value of production (GVP) from South Australia's fishing and aquaculture industries has remained relatively constant over the last decade in nominal terms, generally ranging between $400-$500 million per annum, although in real terms has declined by around one third. Most of the inter-annual variation occurs in aquaculture production, with the wild caught fisheries being relatively stable in terms of GVP. Similarly, most of the reduction in GVP in real terms since 2000-01 has been in aquaculture, with this sector declining in value by 50% over this period.

The fishing and aquaculture industries in the GAB consists of three main components: State managed fisheries that comprise most of the wild catch; a relatively small number of Commonwealth managed fisheries; and an aquaculture industry in inshore and coastal waters. Most of the value from wild-caught fisheries is derived from the South Australian State managed fisheries. The aquaculture industry is largely based on grow-out (or ranching) of juvenile SBT initially taken from the Commonwealth fishery. The tuna ranching activity contributes around two thirds of the value of aquaculture production in South Australia. The Pacific Oyster industry has also developed into a major aquaculture industry, with South Australia now the major producer of Pacific Oysters in Australia.

Synthesis

The projects identified a range of potential positive and negative impacts of the development of an oil industry in the region. Lack of appropriate infrastructure was identified as major constraint to development in the region, with both social and economic consequences for the region. Many participants in the focus groups and surveys had expectations that the development of an oil industry would contribute to the improved development of infrastructure such as roads, rail, port facilities and airports. This in turn would have spin-off effects for tourism (through better access) and the exporting industries, as well as contributing to safety (through better roads) and better access to health services. Further, better airport infrastructure would also facilitate the increase in fly-in-fly-out workers, with possible benefits in terms of being able to expand the mining industry in the region. Expectations of an improved helipad in the western GAB was also believed to contribute to safety for the fisheries sector, as well as the region as a whole though an enhanced rescue facility.

Expectations of a range of alternative employment opportunities were seen as potential positive impacts from the development. While it was recognised that much of the labour associated with development would most likely be specialised, the increase in population in the region would increase the demand for support services. Population decline in the region is a particular concern, with many of the younger generations leaving the region in search of employment in the major centres. An influx of workers associated with the development of the oil industry would not only increase the population directly, but may also contribute to the retention of young people who may otherwise leave.

Concern was raised in the social baseline study about the potential environmental consequences of the proposed development, and the effect that this may have on fisheries (both commercial and recreational) and other marine life (particularly whales). The pristine marine environment was a key factor underlying the attachment to the region for many participants. Given the importance of ecotourism to the region, any environmental damage was also considered to have potential negative economic consequences. From a fisheries perspective, the major potential threat was an oil spill. Qualitative modelling of different oil spill scenarios suggested that coastal aquaculture was particularly at risk of an oil spill; albeit the likelihood of such a spill is considered to be low. Despite these environmental concerns, the regional communities were largely supportive of the development, with the identified perceptions of the benefits exceeding the perception of the potential negative aspects.

Key findings and legacies

The Socio-economic Analysis Theme undertook the first targeted socio-economic assessment of the Eyre Peninsula. It developed an understanding of key issues associated with the development, including recognition of the economic benefits of oil/gas development and concerns about impacts on environment and social values. The GABRP established a socio-economic baseline for the coastal communities of the GAB and demonstrated the importance of fishing and aquaculture to the region. Importantly, an economic model was established for the region that can be used in future assessments of the economic impacts of future developments which represents a significant legacy for the GABRP.

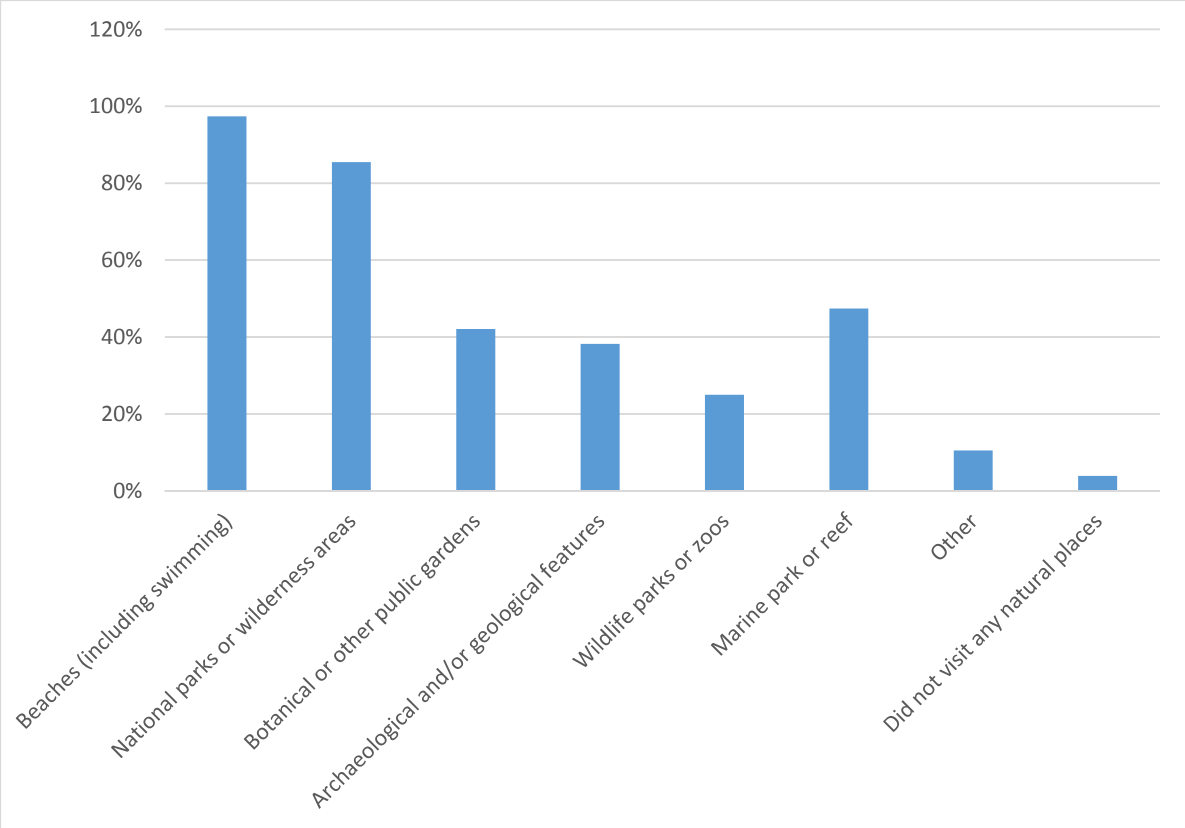


Figure 45. In the last 12 months have you, or anyone in your household, visited any of the following natural places?

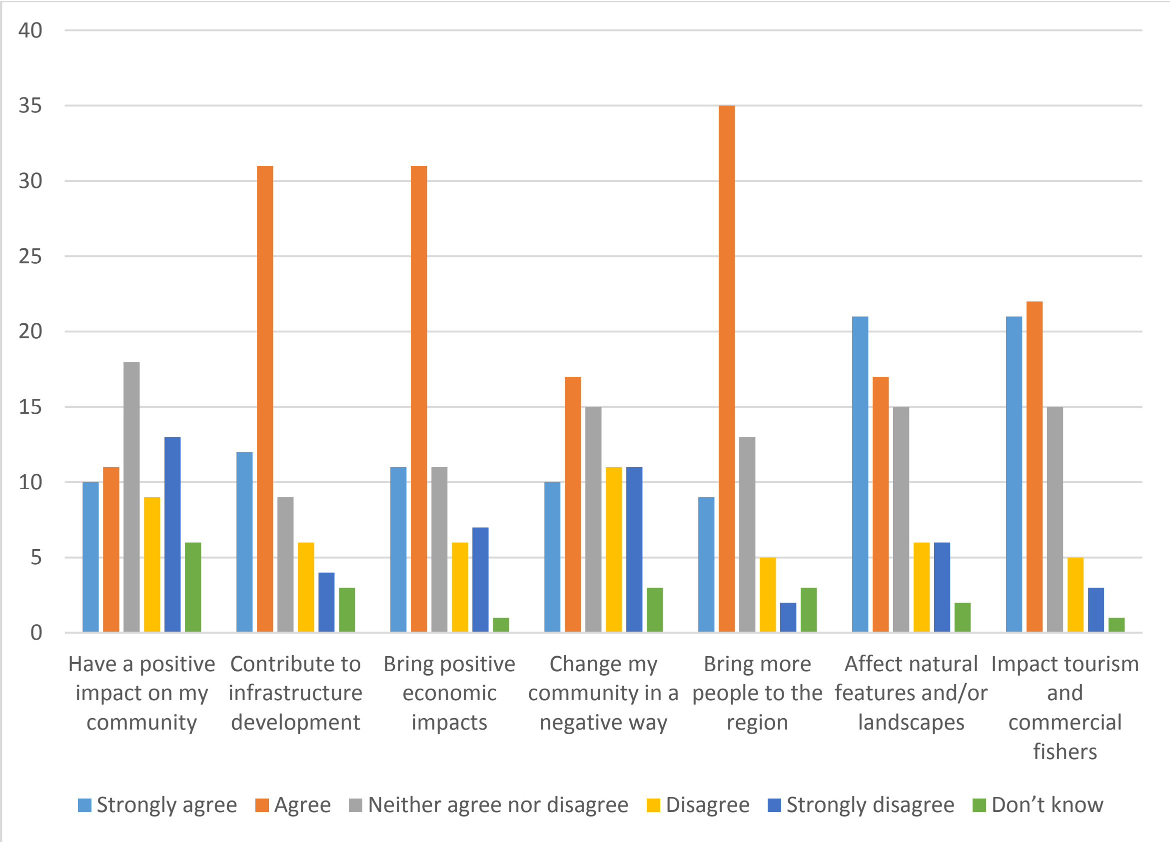


Figure 46. Offshore exploration and drilling, and possible subsequent onshore development, will:

MODELLING AND INTEGRATION

The Modelling and Integration Theme had two objectives. The first was to establish trophodynamic (*Ecopath with Ecosim, EwE*) and whole-of-system (*Atlantis*) models for the GAB and use them to a) evaluate the vulnerability of key species, trophic pathways, habitats and assemblages to potential ecosystem stressors, including climate change, fisheries, aquaculture and oil spills and b) assess the synergistic, cumulative and potential impacts of multiple stressors and identify socio-economic and ecological trade-offs associated with future multiple use of the GAB (Fulton *et al.* 2017). The second was to synthesise information from the GABRP (this document).

Ecosystem modelling

Ecopath describes the static state energy flow of an ecosystem at a particular point in time; *Ecosim* is used for dynamic simulations that forecast ecosystem response to environmental perturbations. The domain of the GAB EwE model is shown in Figure 47. Time series data from 2006 to 2015 were used to develop and calibrate the *Ecosim* model. The GAB *EwE* model was built around 75 functional groups including: mammals (7), birds (8), chondrichthyans (6), teleosts (24), farmed finfish and shellfish (2), cephalopods (3), other invertebrates (17), bacteria and microbes (2), autotrophs (4), detritus (1) and discards (1). Annual fishery landings and effort data for the GAB from 2006-2011 were obtained for 34 fleets (based on gear-type and target species). Discard rates were estimated from data obtained from independent surveys. Some commercial fish and iconic species were modelled as separate groups to aid scenario testing and facilitate assessment of impacts and drivers. Critical inputs for each trophic group of dietary information, biomass, consumption per unit of biomass, production per unit of biomass, and ecotrophic efficiency were obtained from a variety of sources.

The trophic flows between functional groups in the GAB EwE model are shown in Figure 48. The relative change in functional group biomasses between 2006 and 2015, estimated in the status quo GAB *EwE* model are presented in Figure 49. The greatest changes for vertebrates were a near doubling of SBT, and large increases for slope large demersal invertivores (60%), slope small demersal piscivores (>50%) and deep demersal sharks (>30%) (Figure 49). There were declines in shelf large pelagic piscivores and gannets (>70%), slope large demersal piscivores, snapper and offshore pelagic sharks (~50%) and garfish (~40%). For invertebrates, abalone increased by 60% and rock lobster decreased by over 90% (Figure 49).

The GAB EwE was used to examine the potential effects of several scenarios on functional groups and ecosystem indicators. Scenarios examined were climate change, reduced and increased fishing pressure, a sardine mortality event, high SBT recruitment and variations in food web structure.

Whole-of-system, or end-to-end, ecosystem models such as Atlantis incorporate habitats, hydrodynamic features, environmental drivers, trophic interactions, biological parameters, major human uses such as fisheries and socio-economic components. These models are used to investigate the function of marine ecosystems under various environmental conditions or resource management regimes. They also provide insights into the linkages and processes that occur in both natural and perturbed marine systems, beyond those which can be gained from studying a single species or impact.

The domain of the GAB Atlantis model was similar to the domain for the EwE model (Figure 45). Oceanographic data and dynamics (e.g. temperature, salinity, horizontal and vertical advection-diffusion) were obtained from hydrodynamic models developed in the Physical Oceanography Theme of the GABRP. The GAB Atlantis model consisted of 64 functional groups of species with similar size, diets, habitat preferences, migratory patterns, metabolic rates, and life history strategies that represent the entire food web, inshore and offshore, pelagic and demersal and from bacteria and phytoplankton up to top predators. Initial abundance estimates were obtained from published sources or model-derived where published data were unavailable. Data for other biological parameters, such as seasonal distribution, reproduction, growth and habitat preference – were obtained from a variety of sources, including other parts of the GABRP. Aquaculture groups representing juvenile SBT and (bivalve) molluscs were included separately. Annual fisheries landings and discard data from 2005 to 2016 were separated into 11 fisheries (fleets). Fisheries information was obtained from catch and effort data and recent stock assessments. The GAB-Atlantis model was forced using time-series data from a hydrodynamic model and parameterised using growth, life-history and diet information derived from the literature.

In the status quo model are shown, mesopelagic fishes had the highest biomass. The biomass of the majority of fishes remained stable through the projection period of the status quo model run. Annual or multi-year variation occurred in some groups, but most variations were within a stable band of biomasses. Instabilities in age structure (and thus biomass trajectories) were shown for shallow piscivores, herbivorous fishes and non-migratory mesopelagic fishes, likely due to interactions between their relative sizes, prey and predator fields.

A spatio-temporal simulation of the GAB ecosystem was undertaken to examine the ecological consequences (changes in trophic linkages and biomass flow) of scenarios involving changes in temperature, fishing pressure, stock abundances, spatial management or a shipping oil spill. Scenarios of high fishing had the greatest negative impact on relative biomasses of individual functional groups, while scenarios of ocean warming had the largest impacts on the indicators of ecosystem structure and integrity (Figure 51). Oil spills caused by potential off-shore shipping accidents would have greatest impacts on seabirds, pelagic fishes and marine mammals with flow on effects to the whole ecosystem (Figure 52).

Key findings and legacies

The two ecosystem models developed for the GAB in the Modelling and Integration Theme, i.e. EwE and Atlantis, are important legacies of the GABRP. These models were used to integrate disparate datasets (including old and new knowledge) and test various development scenarios. These models will also be available to assist future management of the GAB's socio-ecological systems. EwE is particularly suited to evaluating tradeoffs among fishing and aquaculture activities. Atlantis is designed to support strategic assessments of the interactions among sectors and evaluation of the potential ecological, economic and social costs and benefits of development scenarios, including cumulative impacts.

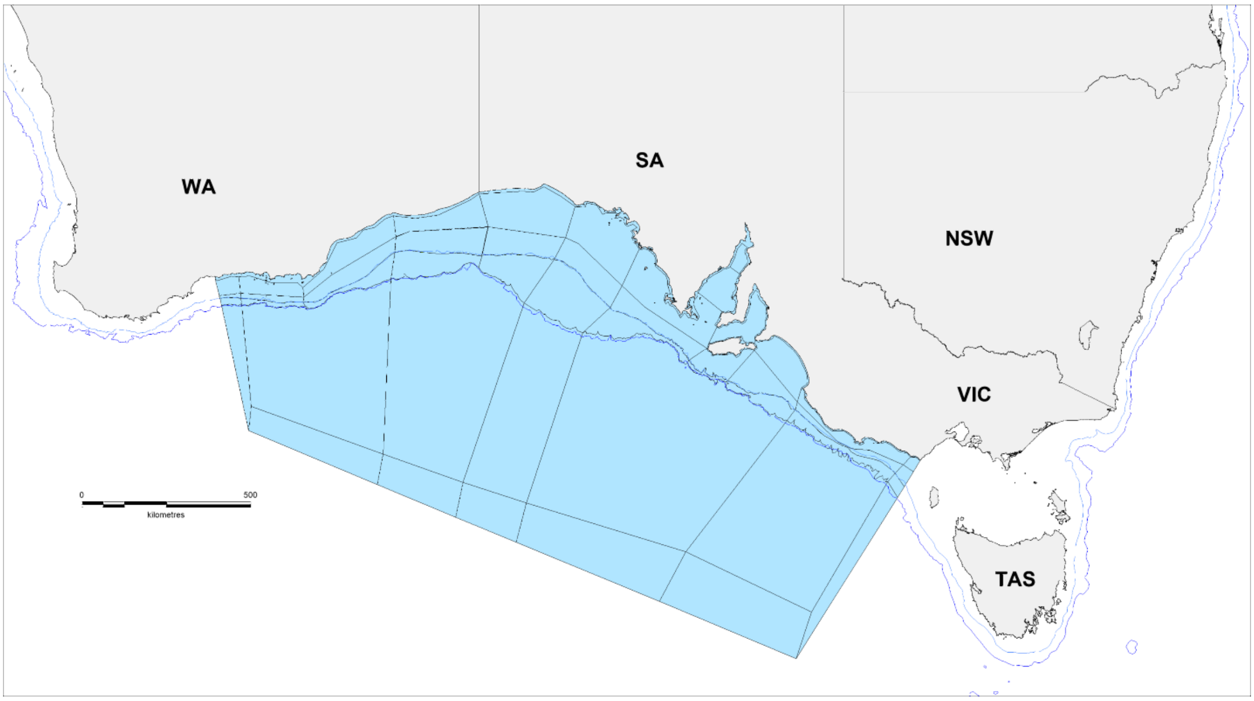


Figure 47. Area used to define the GAB ecosystem model domains (shaded blue). Atlantis model polygons with the domain area are indicated as are the 200 m and 2000 m contour.

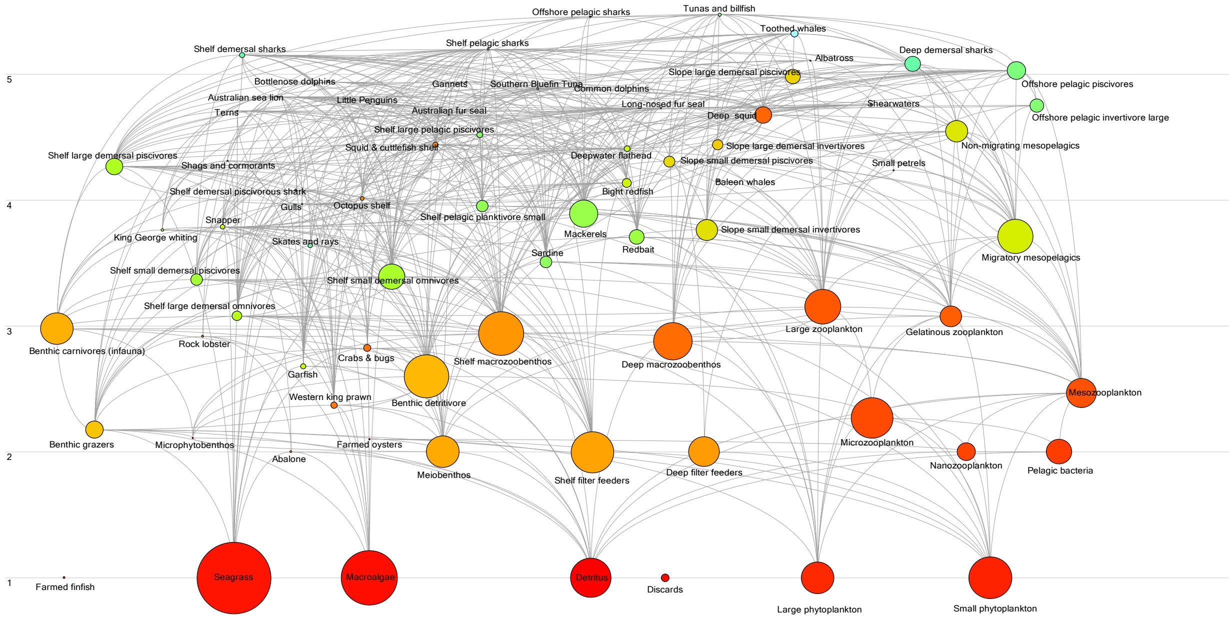
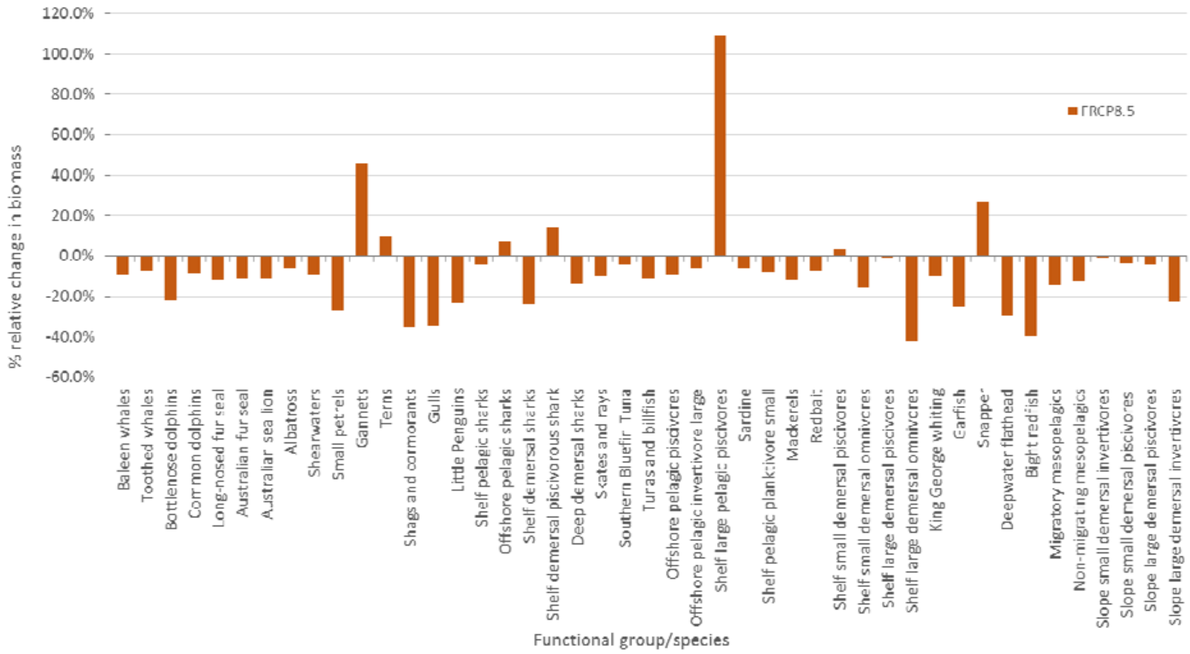


Figure 48. Flow diagram expression of the trophic flows between functional groups in the GAB ecosystem. Trophic levels are on the y axis, the x-axis groups are arranged to allow the best visual representation of the foodweb. Functional groups are represented by a circle; the size of the circle is proportional to its biomass and the colour of circles is unrelated to any parameter.

a)



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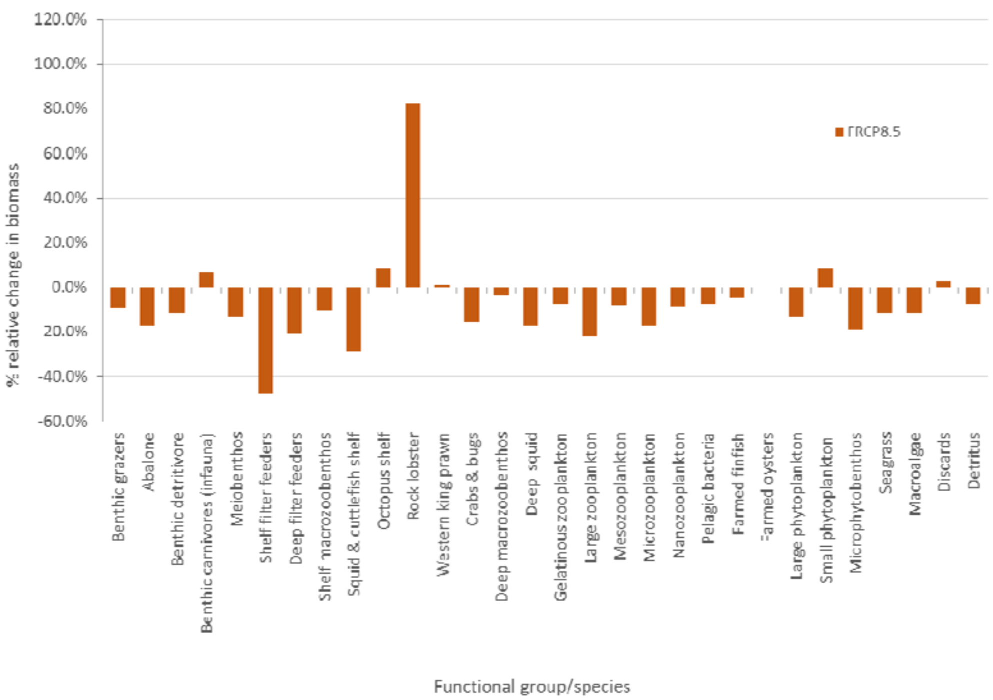
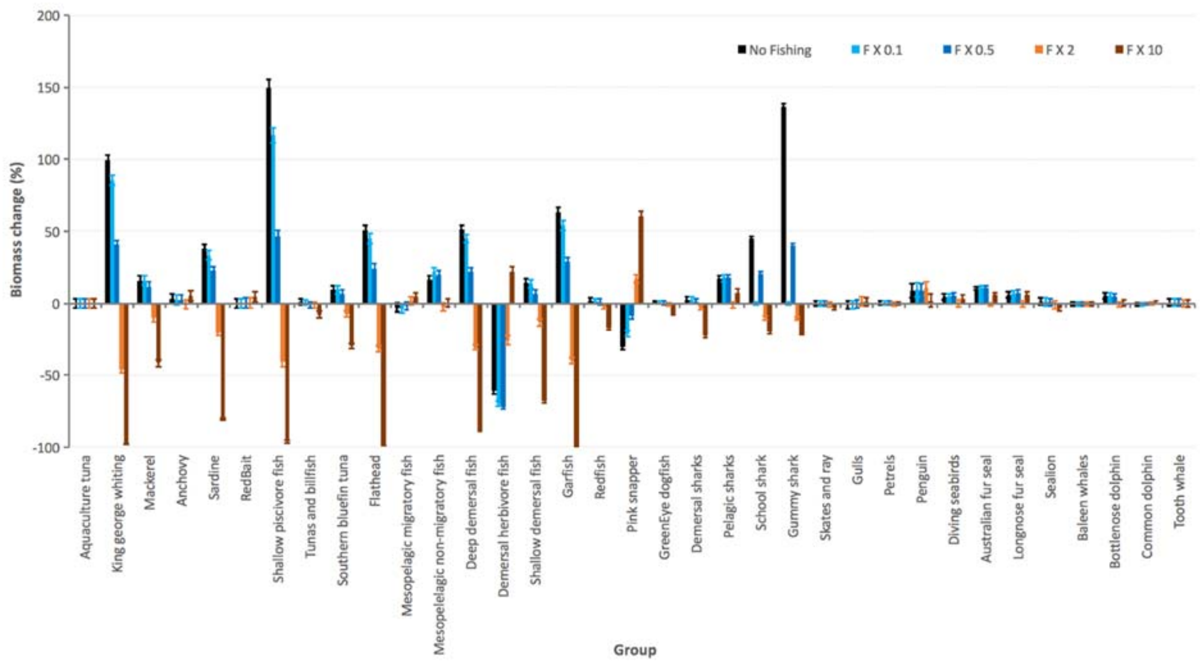


Figure 49. Relative changes (%) in the total biomasses of (a) vertebrates and (b) invertebrate functional groups under the ocean warming scenario in EwE– calculated relative to the status quo simulation.

a)



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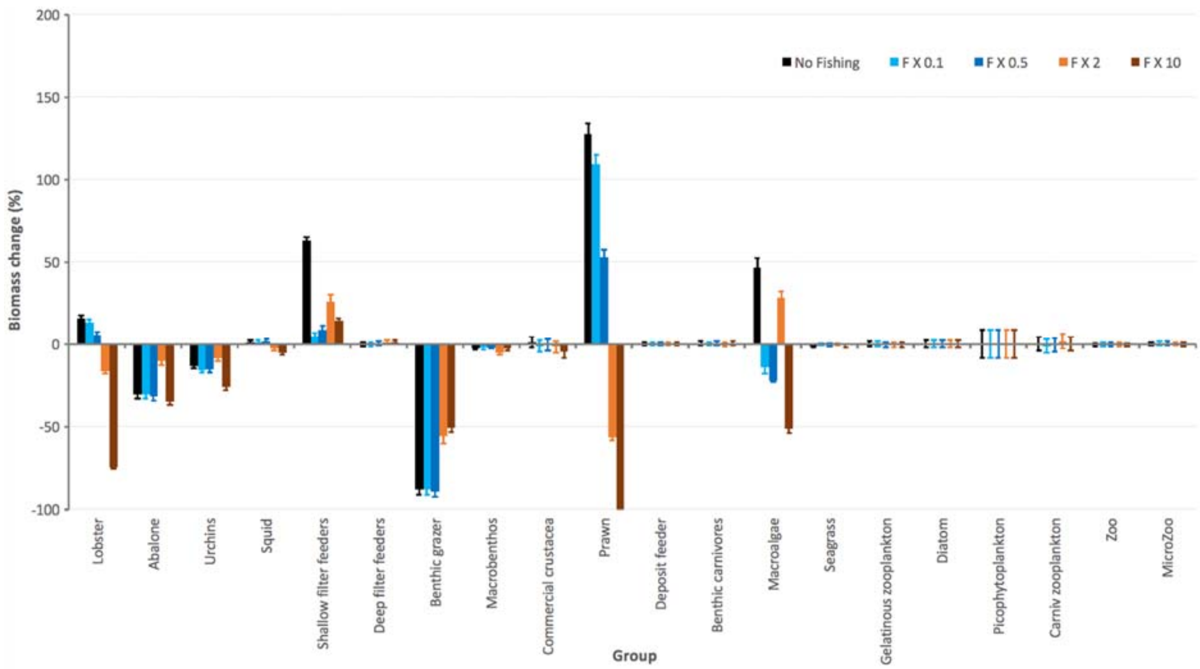


Figure 50. Relative changes (%) in the total biomass of (a) vertebrates and (b) invertebrate functional groups under the fishing scenarios in Atlantis – calculated relative to the Status Quo. Note that the biomass change axis is to a different scale to the fishing and shipping related scenarios.

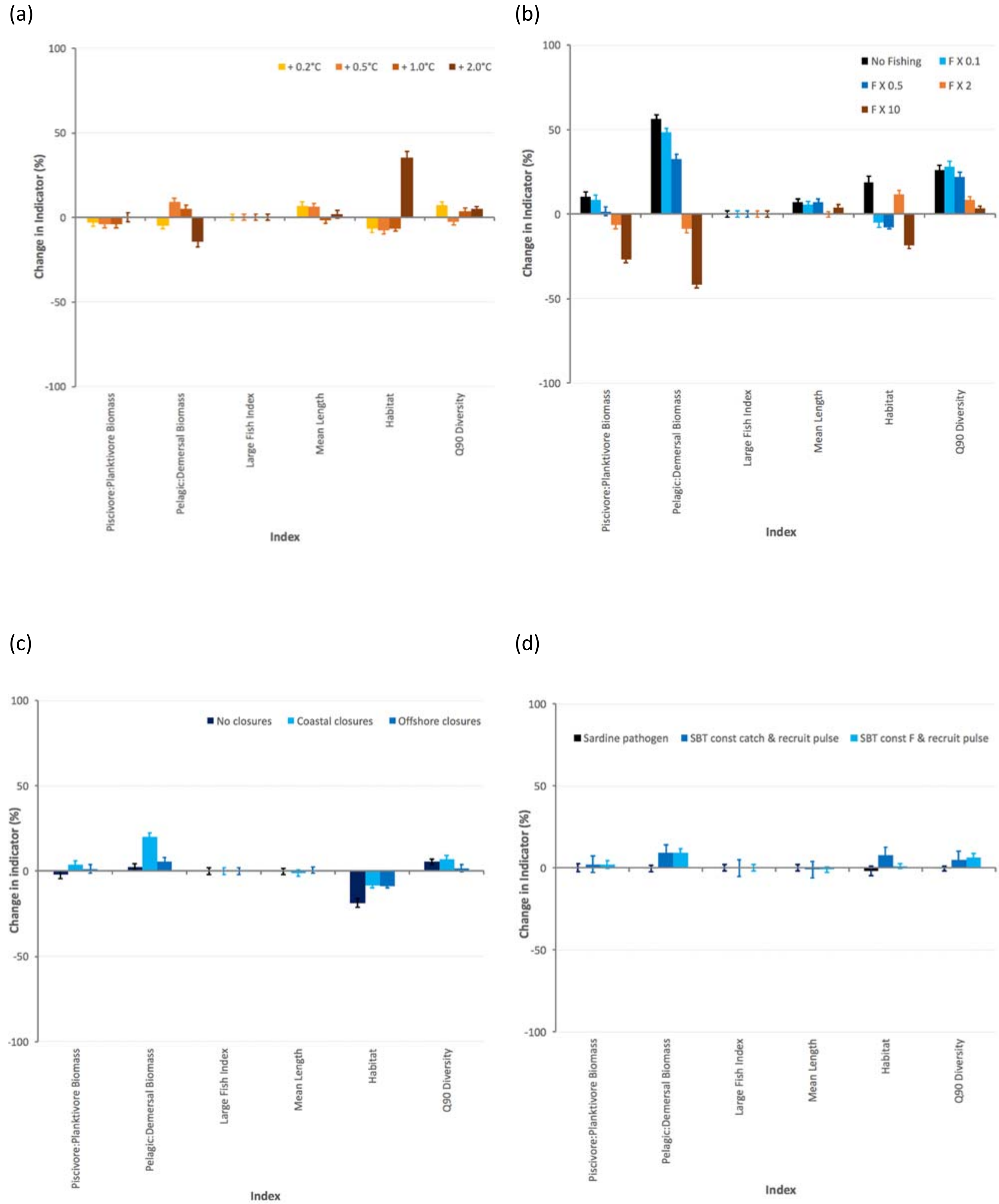
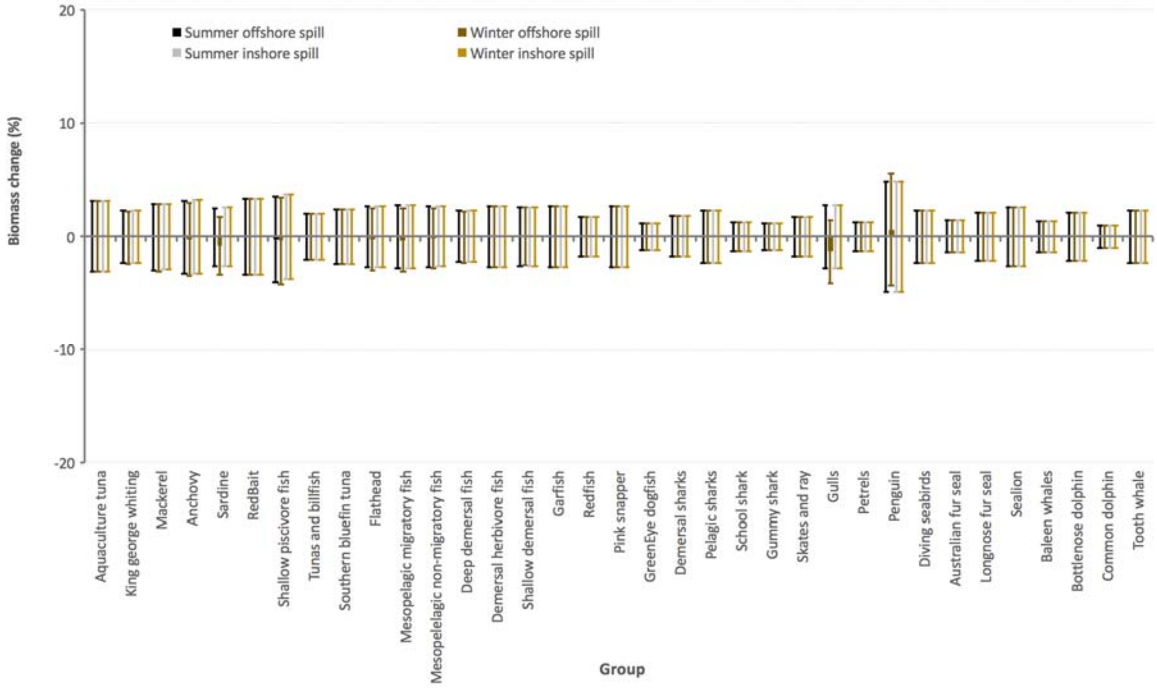


Figure 51. Relative changes in the ecosystem performance indicators for (a) ocean warming scenarios, (b) fishing scenarios, (c) spatial management scenarios, (d) sardine and SBT scenarios. All calculated compared to status quo.

(a)



(b)

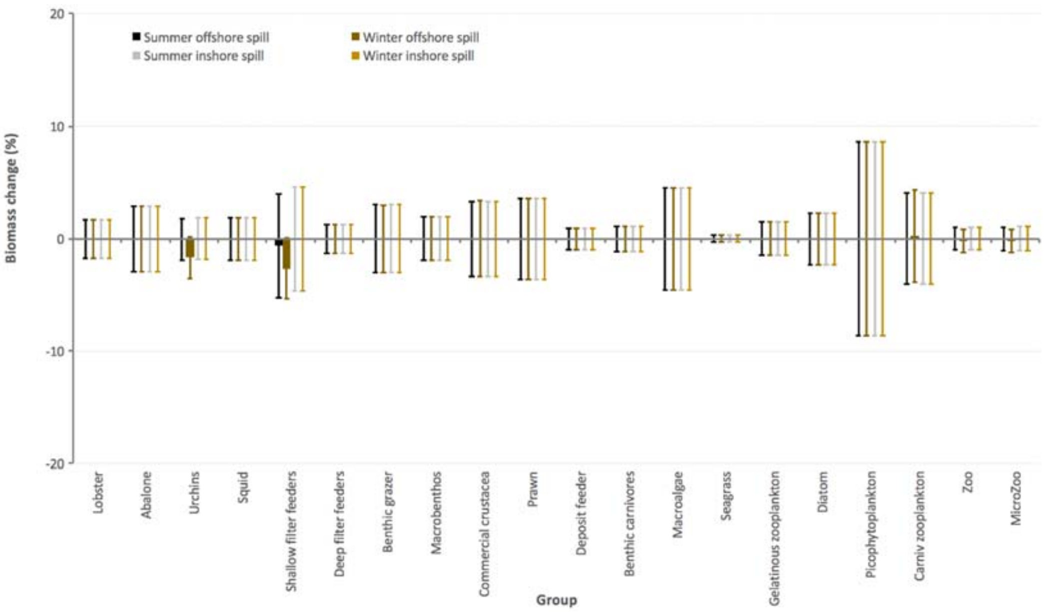


Figure 52. Relative changes (%) in total biomass of (a) vertebrates and (b) invertebrates functional groups under the ship collision and oil spill scenario(s) – calculated in comparison to the Status Quo scenario. Note the scale of the y-axis is much smaller than for the other scenarios reported in this chapter.

SYNTHESIS AND CONCLUSIONS

The GABRP was established to develop scientific knowledge, tools and baseline data to inform and support future use, development, management and conservation of the socio-ecological systems of the GAB. The program filled key knowledge gaps on the structure and function of the Bight's ecosystems; the nature and value of its marine industries, including its potential hydrocarbon reserves; and the dependence of the GAB's coastal communities on the amenities provided by the pristine marine environment.

Critical new scientific knowledge developed in the GABRP include:

- refined understanding of the hydrodynamic processes underpinning the ecosystem;
- new insights into factors driving pelagic productivity and supporting the region's rich pelagic communities, including its diverse assemblage of apex predators and iconic species;
- greater awareness of the region's pelagic and benthic biodiversity and endemism, especially in the deep ocean beyond the continental shelf;
- identification of at least 277 species that are new to science and almost 1000 species not previously reported in the GAB;
- improved understanding of the biology and ecology of the region's most valuable natural assets, especially its diverse assemblages of marine mammals, seabirds and sharks;
- improved understanding of the migratory and foraging patterns of southern bluefin tuna;
- confirmation of oil and gas migration in the GAB;
- collation of historical information of seismic activity in the GAB;
- improved understanding of the values and priorities of people living in the GAB's coastal region.

Valuable new scientific tools developed during the program that provide a significant legacy for future scientific studies, monitoring programs and management advice include:

- a nested suite of improved hydrodynamic models;
- a new tool for sampling pelagic ecosystems (acoustic and optical probe, PLAOS);
- a new tool for sampling benthic communities (multi-corer);
- habitat models and molecular identification tools for pelagic and benthic species;
- distribution and foraging habitat models for iconic species and apex predators;
- improved statistical methods for estimating the position of SBT from archival tags, and examining their feeding behaviour, habitat preferences and seasonal distribution patterns;
- a model for assessing the economic impacts of future developments;
- ecosystem models for evaluating future development scenarios.

The GABRP has transformed the deep water ecosystems of the GAB from one of Australia's least studied environments into one of the best known.

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