# Assessment of national-scale tracking of commercially important fish species

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In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

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# Abbreviations

| | |
|---|---|
| AFMA | Australian Fisheries Management Authority |
| AODN | Australian Ocean Data Network |
| FRDC | Fisheries Research and Development Corporation |
| IMOS | Integrated Marine Observing System |
| IMOS ATF | IMOS Animal Tracking Facility |
| RPN | Fisheries and Aquaculture Research Providers Network |
| SIMS | Sydney Institute of Marine Science |
| TEPS | Threatened, Endangered and Protected Species |

# Executive Summary

The Integrated Marine Observing System (IMOS, www.imos.org.au) provides a national scale ocean observing system around Australia's coasts, providing information on biotic and abiotic variables. Since 2007 the IMOS Animal Tracking Facility (IMOS ATF) has provided a coordinated national database and a network of acoustic receiver installations that enable animals to be tracked as they move around Australia's coasts. In this FRDC project, over 2018-2019, a team from IMOS ATF in coordination with state and federal agencies and the Fisheries and Aquaculture Research Providers Network (RPN) met. They systematically reconfigured the IMOS ATF national network to improve the servicing of information needs for state and federal fisheries managers of Australia's commercial and recreational fish species and for Threatened, Endangered and Protected species.

Over the last decade, the IMOS ATF has collected data on commercially and recreationally important and threatened fish species, using a series of permanent IMOS ATF acoustic receiver installations and project-scale, researcher-funded deployments. Over 8000 transmitters have been deployed on 135 marine species and tracked over a range of scales from 100's m to thousands of km. Much of this work has derived from, or been driven by, state fisheries agencies' needs. However, despite considerable investment in the IMOS ATF infrastructure, there had not yet been a systematic, coordinated national-scale approach to fish tracking developed in conjunction with state and federal management agencies. This approach was needed to optimise use of this data to specifically serve agencies' needs. In consultation with IMOS, the RPN agreed there was both an opportunity and a need to use these data to provide updated, dynamic fish movement data to fishery managers. As marine environments continue to change, understanding the occurrence and movement of fish and fish stocks will be crucial to effective and sustainable management.

In 2018, the RPN identified the need for sustained observing of marine species of national relevance and produced an agreed list of key marine species for which movement and residency data would improve current understanding of populations and stock structure. Accordingly, this project aimed to assess the utility of the IMOS ATF national dataset for informing spatial management of the commercially and recreationally important fish species, as well as threatened, endangered or protected species, identified by the RPN.

The primary objectives of this project were to:

1. Use existing national acoustic telemetry data to examine movement patterns and connectivity of priority species identified by the RPN;
2. Determine where the national IMOS acoustic telemetry array can be improved to produce data for use by regional and national fisheries managers;
3. Provide a national-scale update on telemetry data for priority species and a proposal to improve the network to increase fisheries benefits of the national tracking scheme.

This project had three phases, a workshop to review the current state of the network and discuss potential analyses, a second stage where the proposed reconfiguration of the IMOS acoustic receiver array and analysis started at workshop one would be completed and matured, and a final workshop where state agencies would be consulted about implementing programs using the reconfigured network. In addition, analyses of existing data holdings were completed to determine national scales of movement of tracked individuals and examine connectivity of populations among receiver installations based on network analysis.

The application of network analysis to the national-scale IMOS acoustic telemetry data successfully enabled the assessment of population connectivity and stock structure of a variety of exploited and threatened marine species around Australia. This novel approach provided strong support for current models of stock discrimination, but also revealed previously unknown population structure based on the capacity to detect movements among fishery jurisdictions. We identified that the combination of acoustic telemetry and network analysis can provide information that is not available using other means as well as providing support for stock discrimination derived from standard approaches that typically require lethal sampling (e.g. otolith or vertebra chemistry) or can be limited by sample size.

We consulted with a national expert team on how to optimise national-scale data collection using the current IMOS acoustic receiver network, and how we might reconfigure the network to more closely target species of interest from the RPN and identify gaps in the current network. Following these discussions, the IMOS Board approved funding of additional receiver installations in Victoria, South Australia, New South Wales and Queensland (with the potential for additional receivers off Western Australia) to better capture data required to inform fisheries management.

Results of national-scale analyses for priority species were presented to key stakeholders, including state fisheries representatives as well as the RPN. There was unanimous agreement on the need for a coordinated national program to track movements of key priority species around Australia.

IMOS is now looking toward the next phase of this effort, an important component includes generating funding to support a coordinated national tagging program of priority species that generates data on spatial dynamics and stock structure, and implications of climate change, currently required to inform dynamic management strategies.

The revised IMOS ATF network is designed to cover areas of coast likely to be used by priority species identified by the RPN, including chokepoints previously not covered. The priority species are all subject to management by state and federal agencies and if these agencies undertake tagging of the relevant species, they should have significantly improved data upon which to base their decision making.

We propose a multi-year, nationally coordinated, tagging program to capitalise on the significant additional investment in acoustic telemetry infrastructure that IMOS has provided as part of this project. With co-investment from state fisheries agencies, we plan to tag and collect much needed data on movements and connectivity of priority species across jurisdictions. This information will feed directly into dynamic spatial management and stock structure assessments for these nationally important fish species.

**Keywords**

Stock structure, network analysis, acoustic telemetry, Integrated Marine Observing System, Fisheries and Aquaculture Research Providers Network, priority species, spatial dynamics, Snapper, *Chrysophrys auratus*, Yellowtail Kingfish, *Seriola lalandi*, Sand Flathead, *Platycephalus endrachtensis*, *Platycephalus bassensis*, Bluespotted Flathead, *Platycephalus caeruleopunctatus*, Black Bream, *Acanthopagrus butcheri*, Yellowfin Bream, *Acanthopagrus australis*, Spanish Mackerel, *Scomberomorus commerson*, Southern Bluefin Tuna, *Thunnus maccoyii*, Tiger Shark, *Galeocerdo cuvier*, White Shark, *Carcharodon carcharias*, Bull Shark, *Carcharhinus leucas*, School Shark, *Galeorhinus galeus*.

# Introduction

Over the last decade, the Integrated Marine Observing System's Animal Tracking Facility (IMOS ATF, www.imos.org.au) has been collecting data on commercially and recreationally important and threatened fish species, with a series of permanent IMOS receiver installations and project-scale, researcher-funded receiver deployments tracking over 8000 transmitters deployed on 135 marine species over a range of scales. Much of this work has derived from, or been driven by, state fisheries agencies' needs.

Despite considerable investment in the IMOS ATF infrastructure, there has not yet been a coordinated national-scale approach in conjunction with state and federal management agencies to optimise use of this resource to specifically serve agencies' needs. Since 2015 IMOS has been coordinating with the Fisheries and Aquaculture Research Providers Network (RPN) to identify how it may serve this purpose.

In 2018, the RPN identified the need for sustained observing of marine species of national relevance to Australia and produced a list of key marine species for which movement and residency data could be used to improve the current understanding of populations and stock structure (Table 1). Inclusion in this list was based on the following criteria:

- their current exploitation (i.e. commercial, recreational);
- their conservation importance (i.e. threatened, endangered or protected);
- their distribution across multiple jurisdictions;
- their movement ecology (i.e. migratory, resident);
- their trophic ecology (i.e. pelagic, demersal, coral reef associated).

In addition, their current stock status as defined by Status of Australian Fish Stocks (SAFS) reporting (i.e. sustainable, recovering, depleted, undefined) is also included.

National-scale data generated by the IMOS ATF were analysed for the first time in 2018 as part of a 'Task Team' of national experts commissioned by IMOS. This process revealed the potential to provide data essential to management. With IMOS, the RPN agreed there was both an opportunity and a need to use these data to inform the national telemetry approach as well as provide updated, dynamic fish movement data to fishery managers. As marine environments continue to change, understanding the occurrence and movement of fish stocks will be crucial to effective and sustainable management.

This project aimed to assess the utility of the IMOS ATF national dataset in informing spatial management of commercially and recreationally important fish species, as well as threatened, endangered or protected species (TEPS), identified by the RPN. The first phase of the project consisted of analysing the entire national dataset available for these priority species. In the second phase, the IMOS ATF presented results of these analyses to the RPN and consulted with state fisheries agencies to re-organise and enhance IMOS ATF infrastructure network to better capture data on priority species and inform stock structure and spatial management.

Table 1: List of priority species identified by the RPN, including additional information on life history parameters, status and current understanding of stock structure.

| Name | Rationale for inclusion | $L_\infty$[1,2] | Habitats | Exploited | Stock status[3] | Stock structure[4] |
|---|---|---|---|---|---|---|
| Snapper (*Chrysophrys auratus*) | Coastal demersal, Stocks fished across multiple states, commercially and recreationally important | 130 cm TL | Inshore and offshore | Commercial, recreational | Primarily sustainable | Complex stock structure, with genetic studies indicating multiple stocks around Australia |
| Yellowtail kingfish (*Seriola lalandi*) | Pelagic, migratory, Stocks fished across multiple states, recreationally important | 250 cm TL | Inshore and offshore, occasionally estuarine | Commercial, recreational | Primarily undefined | Genetic research indicates separate east and west coast populations in Australia |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sand flathead<br>(*Platycephalus bassensis*) | Coastal demersal, Stocks fished across multiple states, commercially and recreationally important | 46 cm TL | Inshore | Commercial, some recreational | Transitional – depleting | Stock structure not studied in detail, some evidence for regional subpopulations |
| Bluespotted flathead<br>(*Platycephalus caeruleopunctatus*) | Coastal demersal, Stocks fished across multiple states, commercially and recreationally important | 45 cm TL | Inshore, and occasionally estuarine and offshore | Commercial, recreational | Fully fished[4] | Unknown |
| Black bream<br>(*Acanthopagrus butcheri*) | Coastal demersal, Stocks fished across multiple states, commercially and recreationally important | 60 cm TL | Estuarine and inshore | Commercial, recreational | Sustainable | Sustainable in WA, NSW and TAS. In VIC, western and eastern estuary stocks are sustainable, Gippsland Lake stocks are depleting. In SA, marine stocks are sustainable but the Lakes and Coorong Fishery is depleted |
| Yellowfin bream<br>(*Acanthopagrus australis*) | Coastal demersal, Stocks fished across multiple states, commercially and recreationally important | 66 cm FL | Estuarine and inshore | Commercial, recreational | Sustainable | Genetic analysis indicates only one population, however conventional tagging suggests possibility of separate populations |
| Spanish mackerel<br>(*Scomberomorus commerson*) | Pelagic, migratory, Stocks fished across multiple states, commercially and recreationally important | 240 cm FL | Inshore and offshore, including coral reefs | Commercial, recreational | Sustainable | Genetic evidence suggests three biological stocks, but otolith microchemistry, parasite analyses and limited tagging suggest smaller stocks than indicated at genetic level. Each jurisdiction is likely to have multiple biological stocks within its boundaries |
| Southern bluefin tuna<br>(*Thunnus maccoyii*) | Pelagic, migratory, internationally commercially important (RFMO), increasing recreational catch | 245 cm FL | Offshore | Commercial, recreational | Recovering | Single, highly migratory biological stock that spawns in the north-east Indian Ocean and migrates throughout the temperate southern oceans, supporting a number of international fisheries (Evans et al. 2012, Patterson et al. 2008, Proctor et al. 1995) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Tiger shark (*Galeocerdo cuvier*) | TEPS, Large scale movements, interactions with humans | 600 cm TL | Inshore and offshore, including coral reefs | Commercial bycatch, recreational, shark control | Sustainable | Genetic study shows panmictic distribution in the Pacific and Indian Oceans, suggesting a large, single Indo-Pacific population (Holmes et al. 2017) |
| White shark (*Carcharodon carcharias*) | TEPS, large scale movements, interactions with humans | 640 cm TL | Inshore and offshore | | Depleted | Two stocks hypothesised: east coast and west of Bass Strait |
| Bull shark (*Carcharhinus leucas*) | TEPS, Large scale movements, interactions with humans | 400 cm TL | Estuarine, inshore, and offshore, coral reefs | Commercial bycatch, recreational, shark control | Sustainable | Acoustic tracking showed evidence for large-scale movement on the east coast (Heupel et al. 2015). A genetic study has suggested some reproductive philopatry in northern Australia (Tillett et al. 2012). Complex stock structure with likely natal philopatry to birth river |
| School shark (*Galeorhinus galeus*) | Demersal, south-east Australian distribution, commercially important, Conservation Dependent (EPBC) | 195 cm TL | Inshore and offshore | Bycatch | Depleted | Several hypotheses. Biological stock status: depleted. |

[1] For fish, this is the average maximum length of Australian records from FishBase (http://www.fishbase.org), unless otherwise indicated

[2] TL = Total length; FL = Fork Length

[3] For fish, this is summarised from Status of Australian Fish Stocks (http://fish.gov.au), unless otherwise indicated. For sharks, stock status was obtained from Simpfendorfer et al. (2017; http://www.sharkreportcard.org)

[4] For New South Wales, from Stewart et al. 2015.

# Objectives

This project aimed to:

1. Use existing national acoustic telemetry data to examine movement patterns and connectivity of priority species identified by the RPN;
2. Determine where the national array can be improved to produce data for use by regional and national fisheries managers;
3. Provide a national-scale update on telemetry data for priority species and a proposal to improve the network to increase fisheries benefits of the national tracking scheme.

# Methods

## 1. Analysis of the movement, connectivity and stock structure of priority species

The national-scale Australian IMOS acoustic telemetry network was initiated in 2007. To date 9518 acoustic receivers have been deployed at 158 locations (installations) around the country ranging from 113.6° to 159.3°E and 11.8° to 43.1°S (Fig 1). Receiver installations include backbone IMOS ATF infrastructure (i.e.14 fixed receiver installations, 200-250 receivers, see Steckenreuter et al. 2016, Brodie et al. 2018) as well as receiver arrays maintained by independent researchers who contribute data to the IMOS ATF. The national network has to date recorded detections from 8184 transmitters deployed on 135 species and is supported by a central, open, database that collates and facilitates extraction and exchange of national-scale movement data (https://animaltracking.aodn.org.au).

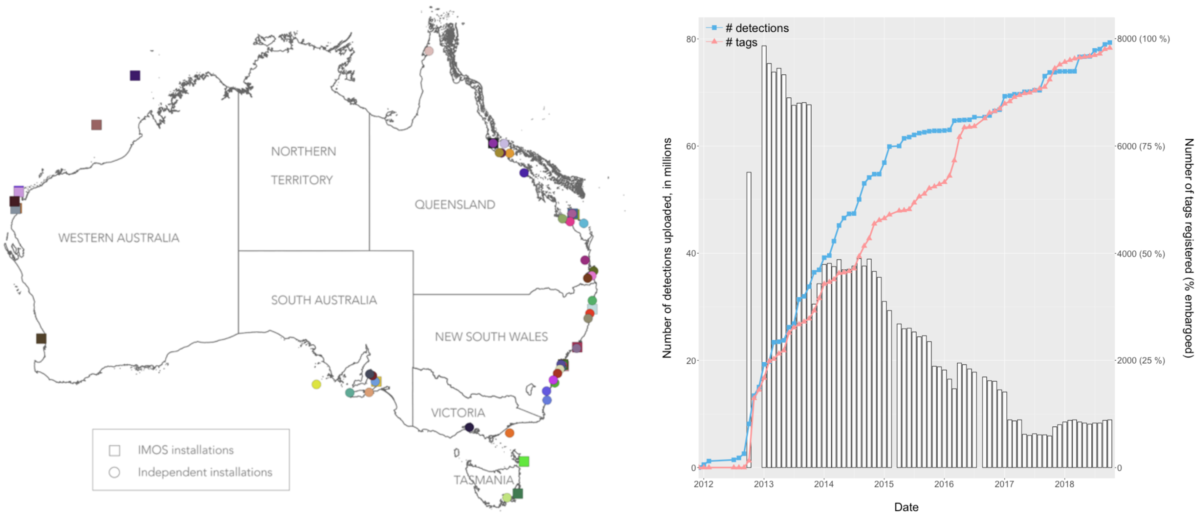


Figure 1: Locations of receiver infrastructure deployments comprised as part of the national IMOS acoustic tracking network (left panel), including backbone IMOS infrastructure (squares) and researcher-contributed receiver deployments (circles). Colours denote different receiver installations. Number of acoustic telemetry detections (blue) and tags (pink) stored in the national IMOS acoustic tracking database (right panel). Bars denote the proportion of the dataset embargoed over time.

In this study, we extracted acoustic telemetry detection data for the RPN priority species from the IMOS acoustic tracking database. Data were quality-controlled using procedures described in Hoenner et al. (2018), therefore eliminating erroneous detections using specific rules that interrogate each data point in light of spatio-temporal patterns in detection and known species ranges. Only detections identified as valid by the purpose-built IMOS ATF quality control (QC) procedures (i.e. QC flag of 1 or 2, Hoenner et al. 2018) and from individuals with more than 10 detections were used in subsequent analyses. The resulting dataset included transmitter IDs, detection timestamps, geographic coordinates of receivers, and associated tag metadata (e.g. species).

### a. Calculation of standardised movement metrics for marine species in the IMOS ATF national database

All species were tracked using the same technology (i.e. Vemco, Canada, www.vemco.com) and movement metrics for space-use were computed for all tagged individuals using the same standardised approach (Udyawer et al. 2018). Standardising methodology provides a powerful approach for accurate cross-taxa comparisons of movement, space use, dispersal and allometric scaling (Udyawer et al. in review).

Detection data were used to calculate standardised metrics of activity space and dispersal using the Animal Tracking Toolbox functions within the R package *'VTrack'* (Campbell et al. 2012; Udyawer et al. 2018), which allowed for direct comparison across species and sites. For each tagged individual, activity space included the area within the 95% contour of a Brownian bridge kernel utilisation distribution (KUD) for all detections (Horne et al. 2007). Dispersal capacity was calculated as the maximum step distance between consecutive detections across the full tag life for each individual.

### b. Application of network analysis to national-scale acoustic telemetry data for priority species

Networks representing the number of individuals moving between installations were created for each species using methodology described in Lédée et al. (in review). Briefly, the number of individuals moving between installations were stored in an adjacency matrix for each species. Species adjacency matrices were divided by the number of individuals within each species to enable species comparison. To determine whether the patterns observed were significant, networks were tested for random patterns by link permutation using a bootstrap approach (n = 10000, Croft et al. 2011). Observed links were randomly shuffled between installations and new networks were generated using the same degree distribution as the original network. For each randomised network, network metrics (i.e. number of installations, paths, subgraph and isolate, path weight, average path length, clustering coefficient, density, and diameter) were calculated and compared to those from the observed network using a coefficient of variation and likelihood ratio tests ($\chi^2$, $p<0.05$). Networks were analysed using *sna* (Butts 2013) and *igraph* (Csárdi & Nepusz 2006) packages in the R environment (R Core Team 2017).

## 2. Engagement with state fisheries agencies, Research Providers Network and other stakeholders for improved data collection and use

**Workshop 1:**

A group of national telemetry experts (see Appendix 1) were consulted about priorities and potential re-configuration of the IMOS ATF network during a workshop held at the Sydney Institute of Marine Science on the 7th-11th of October 2018. The aim was to discuss analysis results as well as how the IMOS ATF network could be re-configured to better capture data on priority species at a national scale. A number of scenarios were discussed with varying levels of investment required from IMOS (e.g. acoustic receivers) and partners who would need to commit to servicing them. Scenario discussions revolved around where installations could be established to increase scientific value and with particular reference to addressing data needs for the priority species identified by the RPN. A network analysis approach was agreed upon.

**RPN meeting:**

We presented the results of these analyses to the RPN and consulted with state fisheries agencies to re-organise the IMOS ATF infrastructure network in order to better capture data on priority species and inform stock structure and spatial management. Subsequently, a proposal was submitted to the IMOS Board for funding to undertake the reconfiguration. State agencies were consulted and co-investment from these agencies for servicing and supporting the new infrastructure secured.

**Workshop 2:**

Representatives from each of the state fisheries agencies, the Australian Fisheries Management Authority (AFMA) and the FRDC were invited to attend a one-day workshop held at the Institute of Marine and Antarctic Studies, University of Tasmania, Hobart, on the 22nd of August 2019. The workshop participants (see Appendix 1) were consulted about priority species and the potential for coordinated efforts to exploit the new receiver configuration of the IMOS ATF network.

# Results, Discussion & Conclusion

## 1. Analysis of the movement, connectivity and stock structure of priority species

### a. Calculation of standardised movement metrics for marine species in the IMOS ATF national database

In total, passive acoustic telemetry data of 1634 individuals from 71 marine species within 4 broad taxonomic groupings (i.e. teleost fish, sharks, rays, reptiles) were collated, including data for 9 of the 13 priority species identified by the RPN. The large geographic footprint of the IMOS ATF receiver network alongside the sheer number of observations across a decade of passive monitoring, provided reasonable activity space and dispersal values for priority species and enabled the use of a consistent analytical method across species and individuals (Fig 2).

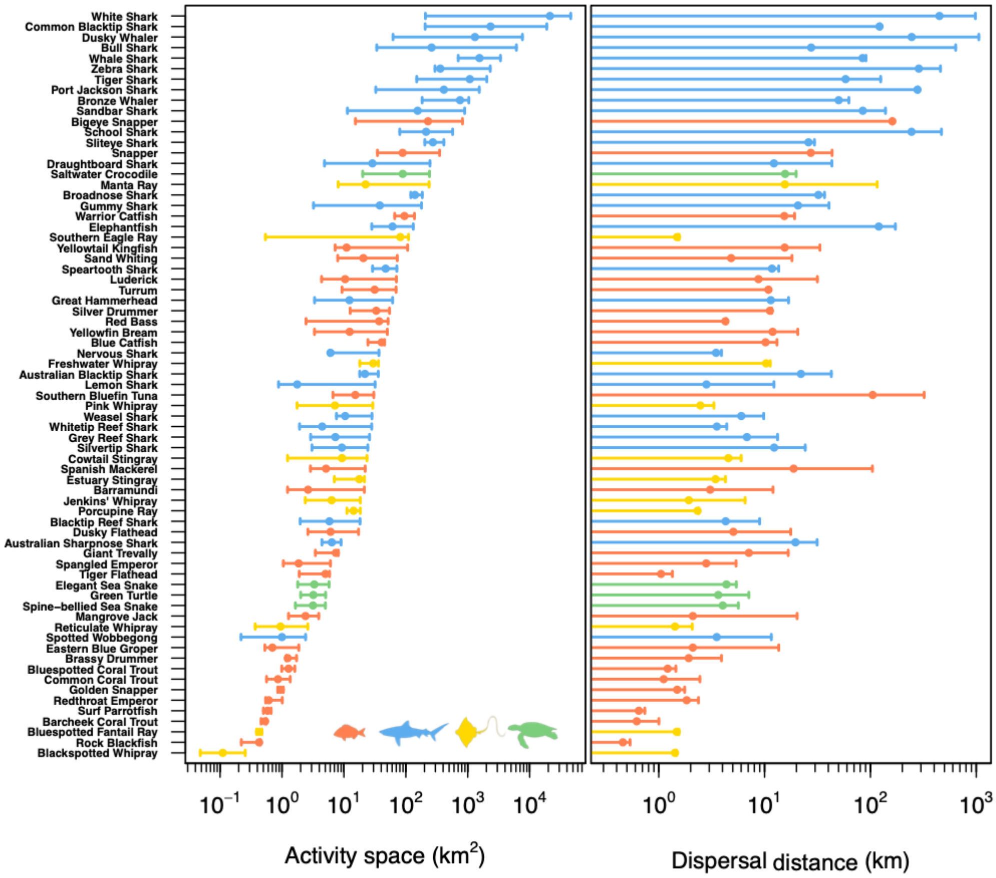


Figure 2: Summary plot of log-transformed dispersal distance (i.e. the maximum distance moved from tagging site) and activity space (i.e. the local area within which tagged individuals moved as part of their routine activities) metrics for species tracked on the IMOS ATF network. Bars represent range of metrics with points representing mean values. Colours indicate taxonomic grouping for teleosts, sharks, rays and marine reptiles. Figure courtesy of Udyawer *et al.* (in review).

### b. Application of network analysis to national-scale acoustic telemetry data for priority species

Movement data were examined for 1491 individuals from 14 shark and teleost species, including 11 of the 13 priority species identified by the RPN, tracked throughout the IMOS acoustic telemetry network between 2007 and 2018. A total of 166 of these individuals did not meet criteria (< 10 detections) and were removed from further analyses.

Individuals used in the analysis were tracked for varying periods with fish monitored for mean periods of 104 – 427 days while sharks were monitored for mean periods of 64 – 659 days.

For 9 out of the 11 priority species examined, the application of network analysis to the national-scale IMOS acoustic telemetry data successfully enabled the assessment of population connectivity and stock structure of a variety of exploited and threatened marine species around Australia. This novel approach provided strong support for current models of stock discrimination, but also suggested previously unknown population structure based on the capacity to detect movements among fishery jurisdictions. Consequently, the combination of acoustic telemetry and network analysis can provide information that is not available using other means. Data from network analysis can also be used to provide support for stock discrimination derived from standard approaches (e.g. otolith or vertebra chemistry; McMillan et al. 2018).

In general, network analysis showed sharks were detected at more installations, had greater numbers of paths, moved more broadly (>path weight), and used more space (i.e. produced larger networks - >diameter) than teleost species (Fig 3 & 4, Table 2). In contrast, networks for teleost species included more clusters and subgraphs, longer average path lengths (APLs), and were denser than for sharks (Fig 3 & 4, Table 2). These results reveal the differences in mobility among the tracked species and their potential for connectivity across broad areas.

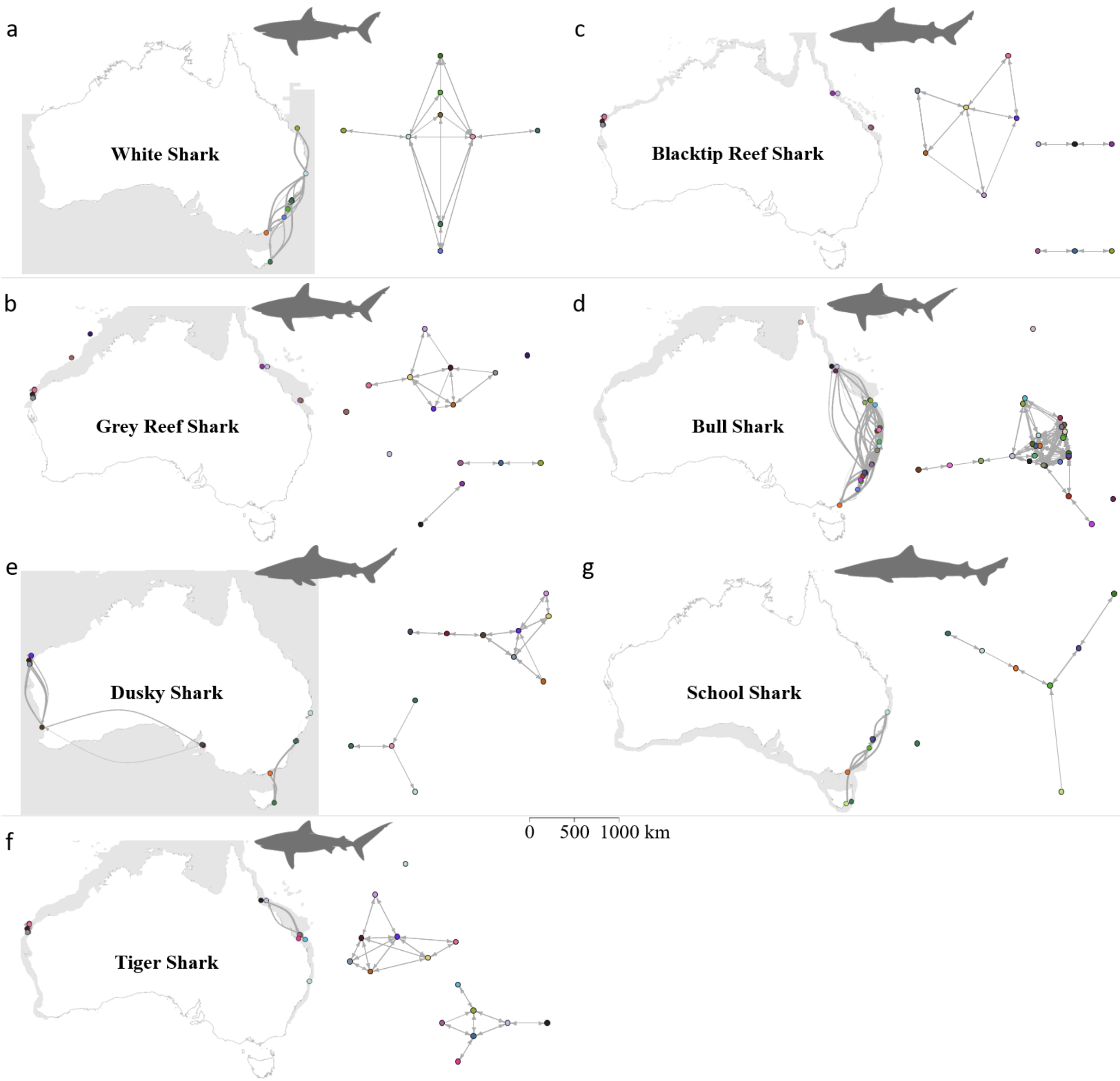


Figure 3: Species networks of seven elasmobranch species tagged in Australia between 2007 and 2018 overlaid on Australian stock distribution. Nodes (coloured circles) symbolise installations and edges (lines) represent the movement of an individual within the study area. Arrows indicate the direction of movement. Size and colour of edges represents frequency of movement between installations (thicker the line and arrow the more frequently it is used). Networks for each species are displayed using geographic coordinates (left panels) and Multidimensional scaling layout (right panels). Figure courtesy of Lédée et al. (in review).

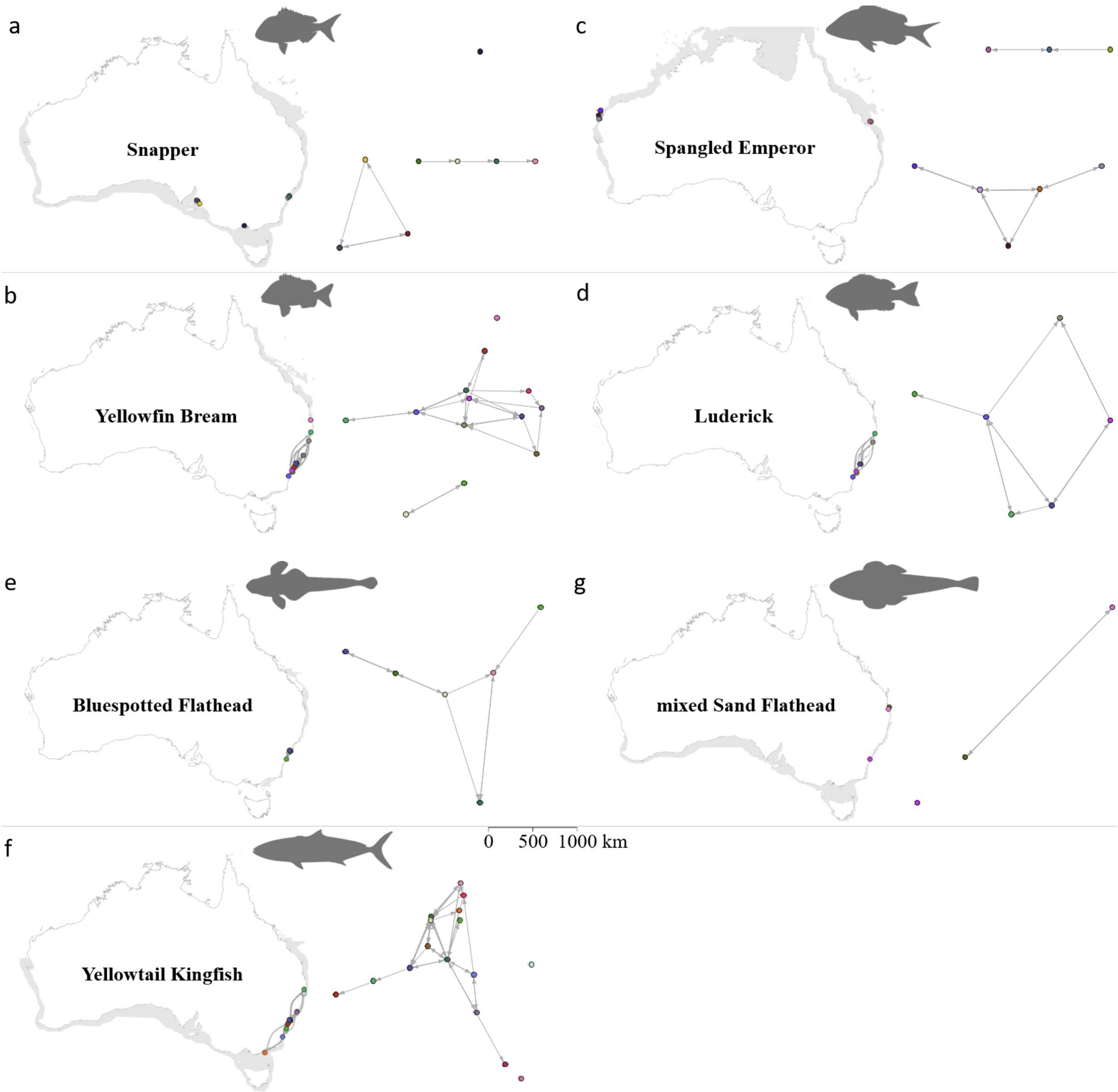


Figure 4: Species networks of seven teleost species tagged in Australia between 2007 and 2018 overlaid on Australian stock distribution. Nodes (coloured circles) symbolise installations and edges (lines) represent the movement of an individual within the study area. Arrows indicate the direction of movement. Size and colour of edges represents frequency of movement between installations (thicker the line and arrow the more frequently it is used). Networks for each species are displayed using geographic coordinates (left panels) and Multidimensional scaling layout (right panels). Figure courtesy of Lédée et al. (in review).

Table 2: Network metrics for the eleven priority species tagged in Australia between 2007 and 2018.

| Species | N | No | Installation | Path | Path weight | Diameter | CC | APL | Density | Subgraph | Isolate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| White shark | 233 | 214 | 11 | 42 | 4937 | 306 | 0.45 | 1.85 | 0.35 | 1 | 0 |
| Snapper | 169 | 142 | 8 | 14 | 1489 | 290 | 0.6 | 1.5 | 0.22 | 2 | 1 |
| Bull shark | 149 | 138 | 27 | 210 | 16796 | 255 | 0.67 | 1.81 | 0.29 | 1 | 2 |
| Yellowfin bream | 124 | 112 | 13 | 38 | 2484 | 275 | 0.30 | 2.20 | 0.22 | 2 | 1 |
| Bluespotted flathead | 61 | 48 | 6 | 15 | 514 | 100 | 0.38 | 1.56 | 0.42 | 1 | 0 |
| Yellowtail kingfish | 48 | 44 | 15 | 54 | 1705 | 122 | 0.48 | 1.88 | 0.24 | 1 | 1 |
| Tiger shark | 48 | 42 | 15 | 56 | 1155 | 91 | 0.57 | 1.62 | 0.25 | 2 | 1 |
| School shark | 29 | 15 | 9 | 19 | 255 | 87 | 0.00 | 2.51 | 0.23 | 1 | 1 |
| Sand flathead (mixed) | 17 | 7 | 3 | 5 | 18 | 2 | 0.00 | 1.00 | 0.56 | 1 | 1 |
| * Southern bluefin tuna | 83 | 25 | 5 | 6 | 112 | 21 | 0.00 | 1.00 | 0.24 | 1 | 3 |
| * Spanish mackerel | 20 | 16 | 2 | 3 | 20 | 2 | 0.00 | 1.00 | 0.75 | 1 | 0 |

*N represents the total number of individuals tagged per species. No is the total number of individuals used in the analysis. Installation indicates the number of nodes in the network. Path represents the number of routes (link between nodes) in the network. Path weight is the number of times an individual used the same route in the network. Diameter indicates the size of the network. CC (clustering coefficient) indicates local density within network. Average path length (APL) represents separation within the network. Density is a measure of route selection (ranging from 0 to 1 with 1 meaning all installations in network are connected to each other). Subgraph and isolate represent the number of unconnected subnetwork and installations (nodes) within the network respectively. Species marked with an * indicate priority species for which the networks produced were random and therefore these species were removed from further analyses.*

Shark networks varied substantially between species (Fig 3). The network structure for tiger sharks (*Galeocerdo cuvier*) produced distinct networks reflecting use of coral reef habitats on the east and west coasts of Australia but displayed connectivity along the length of the Great Barrier Reef (GBR) reflecting their broader movement patterns. Bull shark (*Carcharhinus leucas*) movement data reveal high connectivity along almost the entire east coast including coastal and reef habitats (Fig 3). Bull shark networks had more routes (path), moved more often (path weight), and had more local density (CC) within their network than any other species (Table 2). Altogether, these metrics reflect high mobility of this species and connectivity of temperate and tropical habitats. The white shark network revealed connectivity along the southeast coast but lacks data from individuals in the west and southwest (Fig 3). White shark networks were nonetheless denser than any other shark network, highlighting their connectivity across a wide range of regions and receiver installations (Table 2). Similarly, school shark (*Galeorhinus galeus*) data were only obtained from individuals captured in Tasmania (Fig 3). Nonetheless, school sharks were detected on more installations, had larger networks (diameter), and more separation (high APL), higher route selection (density), and more subgraphs and isolates in their networks (Table 2) than any other species. While these individuals represent connectivity along the east coast, they do not reflect the full extent of known movement for this species, possibly due to the restricted location of transmitter deployments (Tasmania) and the extent of the national receiver network which is limited along the south coast of Australia.

Networks from fish species were highly variable and showed a range of patterns (Fig 4). Bluespotted flathead (*Platycephalus caeruleopunctatus*) was the only species to produce a single connected network revealing movement along the central coast of New South Wales (NSW). Yellowtail kingfish (*Seriola lalandi*) had the largest fish network and it was well connected with more routes (path) and movements (path weight) within the network than any other fish species (Table 2), but also revealed an isolate which was distinct from the rest of the movement locales (Fig 4). Yellowfin bream (*Acanthopagrus australis*) included three separate components: two sub-networks and an isolate (Fig 4), thus reflecting their highest separations within the network (APL; Table 2). All networks were present in coastal NSW and as such may represent connectivity among nearby estuaries in the region. Snapper data revealed three distinct networks in NSW, South Australia, and Victoria which likely represent three distinct stocks that do not mix (Fig 4). Finally, sand flathead (*Platycephalus bassensis*) were detected on more installations, had more route selection (density) and more subgraphs and isolates in their network than any other fish species (Table 2). This result is likely based on the small number of individuals in the sample.

Delineation of population or stock sub-units across jurisdictional boundaries and defining key processes occurring in these units are important for effective management (Begg & Waldman, 1999), as management decisions in one jurisdiction can have flow-on effects in another. While geographic distributions are known for many species, the level of connectivity within this distribution is difficult to quantify (e.g. Figs 3 and 4). Quantifying networks of connectivity (i.e. number, strength, and directionality of connections) is especially important in identifying and describing cross-jurisdictional linkages, or connections between key habitats which are highly relevant to management decisions.

Within the distribution of a single stock, network analysis can show the importance of key areas beyond residency, highlighting where animals might be more vulnerable by revealing where nodes have strong levels of connectivity and more heavily weighted pathways. Within the yellowtail kingfish network, some nodes clearly had much stronger pathways and more connections. These areas could be considered more important and central to these species than less well-connected areas. Identification of these locations could help researchers and managers identify key features in the habitat or environment that may be crucial to the resource needs of the species.

Increasingly, resource assessment has been shifting from a regional to a national or international perspective (e.g. Flood et al. 2016), which is essential for species whose stock structure transcends jurisdictional boundaries. Such assessments obviously require knowledge of stock structure and connectivity, but this information is still lacking for a large number of exploited species (Flood et al. 2014). The power of acoustic telemetry and associated network analysis lies in its ability to detect stock structure and connectivity at scales relevant to contemporary fisheries management and assessment. This is primarily due to the temporal scale at which movements are recorded – at the ecological rather than the evolutionary scale of techniques such as genetics. Genetic tools reflect the broad connectivity of populations which occurs over multiple generations and may be facilitated by the movement of a small number of individuals (Lowe & Allendorf 2010). While this information is valuable for understanding the species, it may be less relevant for management decisions if the majority of the population remain resident within a location or region. Fisheries management would best reflect the behaviour of the species in the timescale of the management cycle, and as such may be better informed by telemetry data on movement and connectivity than evolutionary timescale connections. Additionally, exploring population-level patterns of habitat use will require population-level sampling, which often appears to be outside the scope of most studies.

# 2. An approach for re-configuration of the national IMOS acoustic telemetry array

A group of national telemetry experts were consulted about priorities and potential re-configuration of the IMOS acoustic telemetry network during a workshop held at the Sydney Institute of Marine Science (SIMS) on the 7-11th October 2018. A number of scenarios were discussed with varying levels of investment required from IMOS (e.g. acoustic receivers) and partners who would need to commit to servicing the new installations. Scenario discussions revolved around where installations could be established to increase scientific value and with particular reference to addressing data needs in terms of movement patterns, dispersal, habitat use, residency and connectivity for the priority species identified by the RPN (Table 1). The proposed scenarios are outlined in the IMOS Network Reconfiguration Plan provided as supplementary material (see Appendix 5).

Briefly, the group considered the scenarios detailed below (see the IMOS Network Reconfiguration Plan in Appendix 5 for more information):

- ***Status Quo:*** The current IMOS ATF receiver network as shown in Figure 5. It was noted at the workshop that current installations are biased to the east coast of Australia and off Ningaloo Reef with gaps apparent in several other regions. Despite the lack of infrastructure in the north, it was determined that there is not currently enough capacity to expand the network into this region at this time. In addition, it is not a critical area relative to the majority of the priority species identified by the RPN.

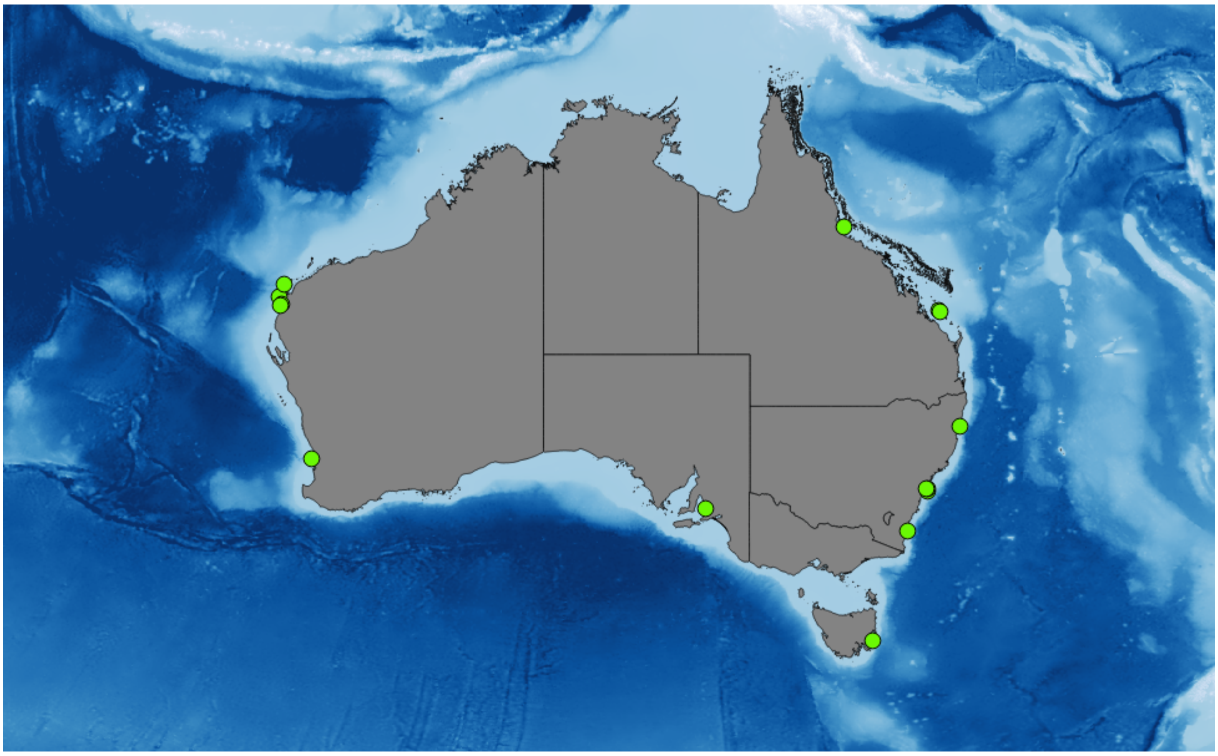
Figure 5: *Status Quo* – the current IMOS ATF infrastructure deployed around Australia as indicated by green circles.

- ***Scenario 1:*** The first scenario represents the lowest cost option (i.e. no new capital required) and is deemed to provide limited benefit relative to the majority of the priority species. The scenario involves the relocation of some existing infrastructure and deployment of receivers that are not currently in use. Relocation would involve removal of the central line in the Ningaloo Reef network (n = 8 receivers), Glenelg Line (n = 2) and the Orpheus Island Array (n = 18 receivers) for redistribution. Receivers from these locations would be used to establish two new installations, both of which would increase effective receiver coverage, but only in close proximity to currently surveyed areas (Figure 6).

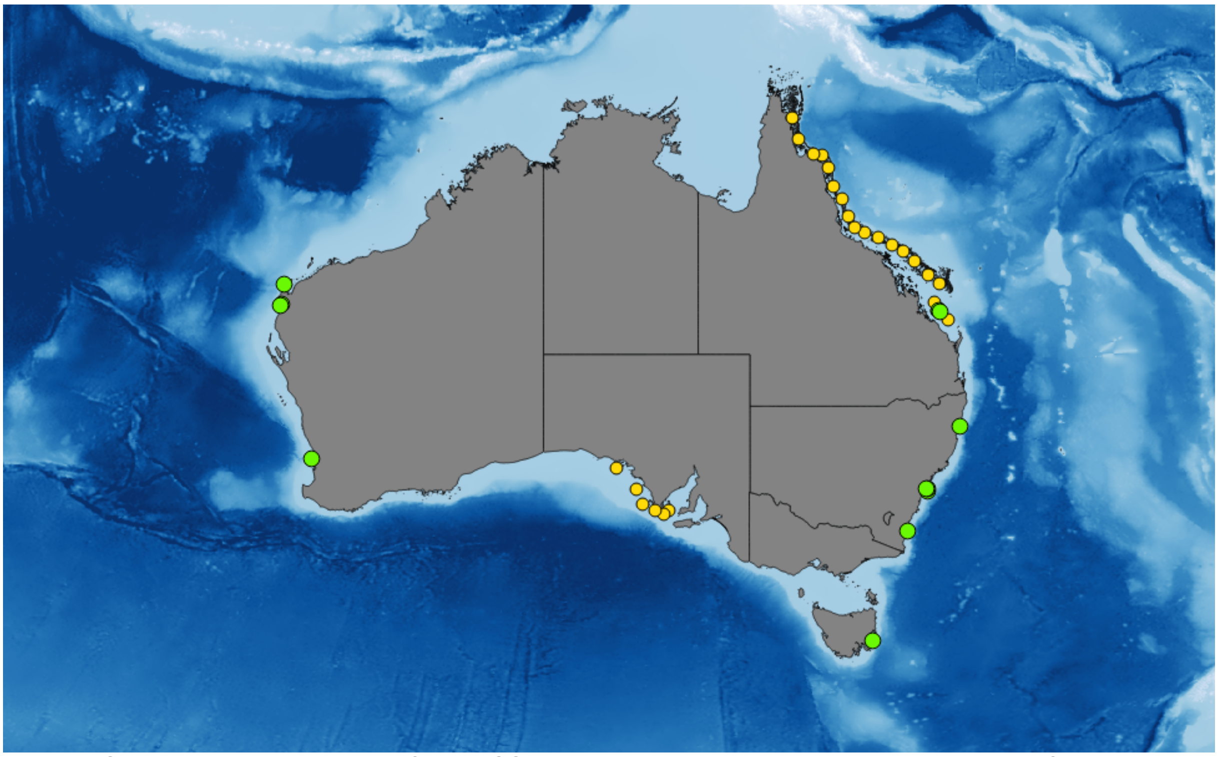

Figure 6: Scenario 1 – enhancement of the IMOS ATF acoustic receiver network through the use of existing receiver infrastructure and high potential for co-investment to support equipment servicing. Existing installations (Scenario 0) are indicated by green circles and new installations (Scenario 1) are indicated by yellow circles.

- ***Scenario 2*** was designed to provide infrastructure at key locations relative to data needs for the priority species and to improve national coverage. This scenario maintains the changes highlighted in Scenario 1 and expands beyond that proposal (Figure 7). Additional installations in Scenario 2 include (from east to west): Stradbroke Island (QLD), Port Stephens (NSW), Portland (Vic), Esperance (WA) and Shark Bay (WA). These suggested deployments were not given equal weight by the workshop team. All these installations would require purchase of additional receivers (IMOS support) and co-investment support to service receivers.

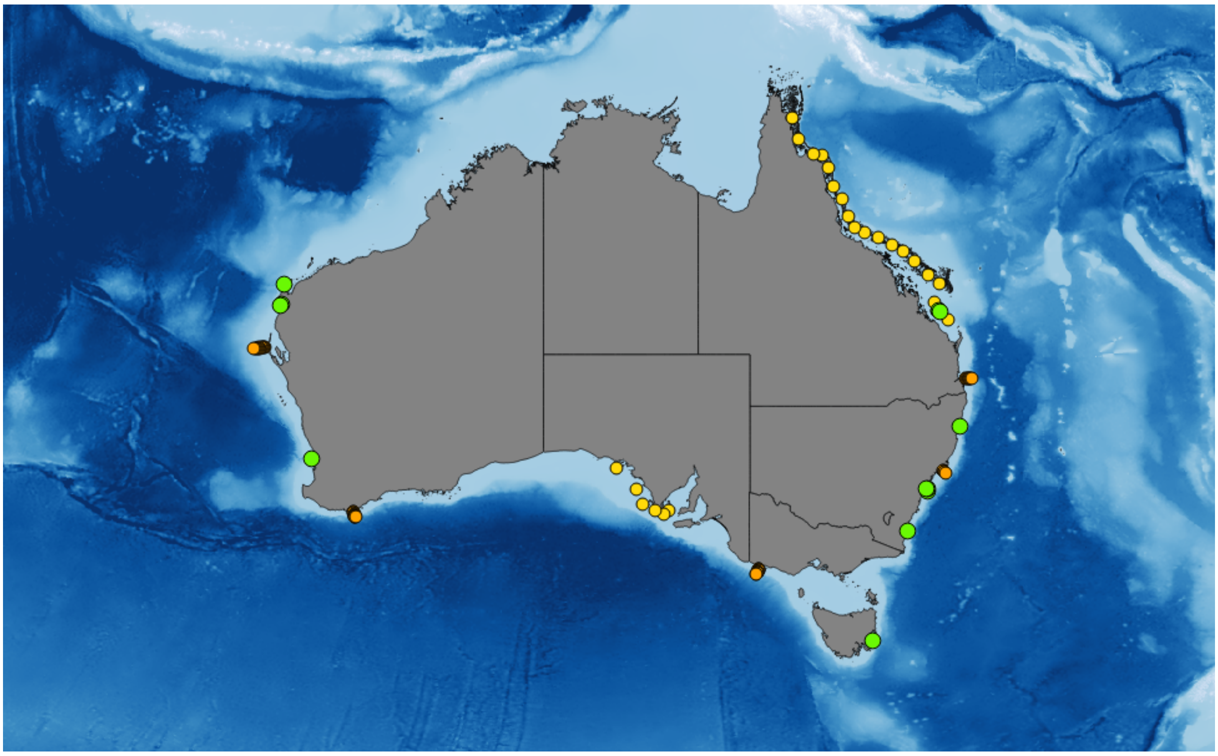

Figure 7: Scenario 2 – expansion of the IMOS ATF acoustic receiver network to include installations in locations that are likely key to addressing questions related to priority species. Installations are indicated by green (Scenario 0), yellow (Scenario 1) and orange (Scenario 2) circles.

- ***Scenario 3*** (the most expensive scenario) was developed as an optimal national array design (within the context of limited scope to expand in the north). This scenario maintains the changes highlighted in Scenarios 1 and 2 and includes additional expansion of the IMOS ATF network (Figure 8). Additional installations in Scenario 3 include, from east to west: the west coast of Tasmania, Cape Jervis (SA), and Kangaroo Island (SA). All of these installations would require purchase of additional receivers and co-investment support to service receivers.

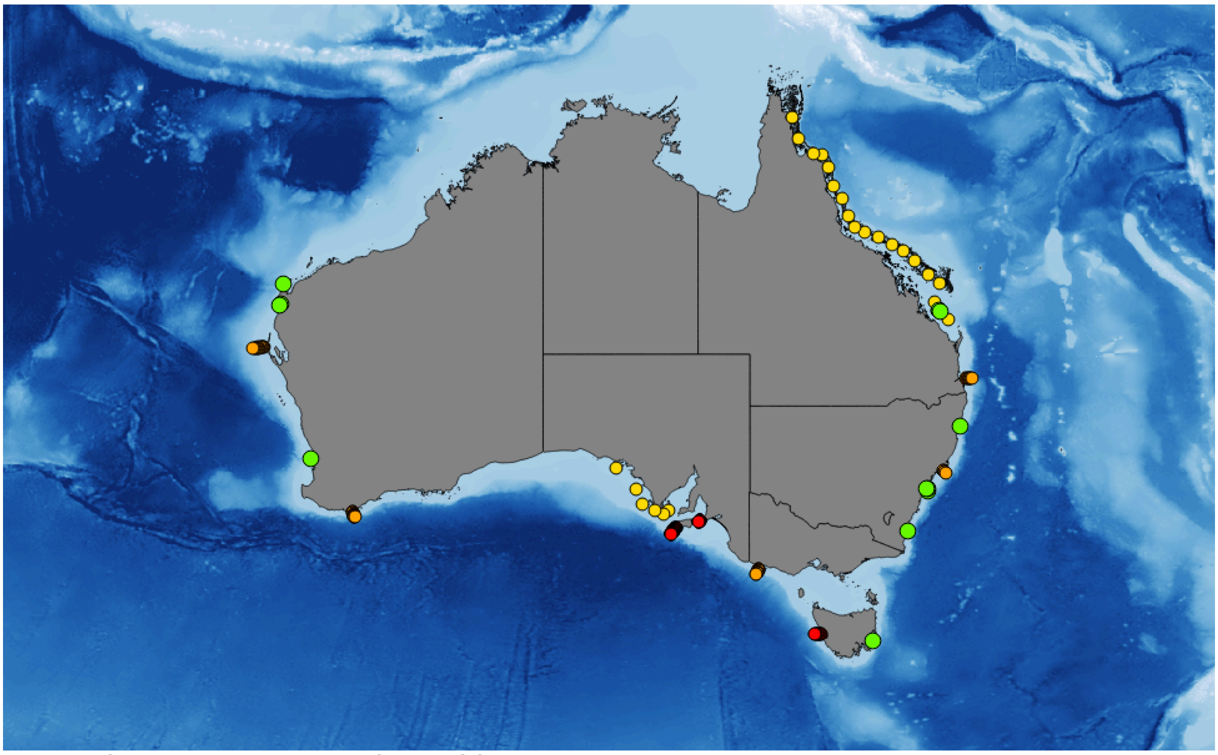

Figure 8: Scenario 3 – expansion of the IMOS ATF acoustic receiver network to include installations that provide enhanced national coverage. Installations are indicated by green (Scenario 0), yellow (Scenario 1), orange (Scenario 2) and red (Scenario 3) circles.

The workshop team of acoustic telemetry experts concluded that the bare minimum change required to the national network is captured in Scenario 1, which provides minor expansion to the network without requiring additional equipment while creating the potential to integrate into existing work plans without requiring significant additional co-investment. The team, however, agreed that Scenario 2 provided a stronger, more comprehensive network to address questions relevant to the ecology, management, and conservation of a variety of species within Australian waters. Scenario 2 required capital investment in infrastructure from IMOS as well as co-investment from partners to facilitate equipment servicing. If sufficient partner commitment and co-investment could not be secured, this Scenario may not be viable. However, because installations are independent, it was recognised that some individual components of this scenario may be more feasible than others and all options should be explored to help enhance the national infrastructure even if Scenario 2 could not be implemented in its entirety. It was recognised that Scenario 3 represented a greater challenge given the significant infrastructure investment required and large co-investment from the broader community. As with Scenario 2 though, if partners were interested in components of this scenario these should be explored in the interest of improving the national infrastructure as much as possible. At this point in time, there is little acoustic tracking research conducted in marine coastal waters of northern Australia as well as insufficient potential co-investment from local research agencies. As such, the northern Australian coastline was not considered as part of this network re-configuration.

In November 2018, after careful consideration, the IMOS Board approved to fund part of Scenario 2 which included the following new IMOS receiver installations (from east to west): Stradbroke Island (QLD), Port Stephens (NSW) and Portland (VIC). Installations in WA are still being considered as part of consultation with partners in the region. Subsequently, the first of the new IMOS receiver arrays was successfully deployed off Portland, Victoria, in June 2019. This installation extends from Cape Bridgewater to the 10m isobath marking the edge of the continental shelf in this area, thereby closing a critical gap in receiver coverage along the southern coast. The remaining two installations are scheduled to be deployed off Stradbroke Island (QLD) and Port Stephens (NSW) before the end of 2019.

# 3. Presentation of results to the RPN and other relevant stakeholders and end users

On 22nd August 2019, results from this project were presented to representatives from Australian state fisheries agencies, and the RPN, during a meeting held at the Institute for Marine and Antarctic Science in Hobart, Tasmania. The first aim of this meeting was to provide key stakeholders with an update on Objectives 1 and 2 and their implementation. The second, critical aim of the meeting was to work with stakeholders to develop a plan to optimize tagging data collection for priority species.

The meeting participants welcomed the national momentum to monitor priority species created by this project funded by FRDC and led by IMOS. Subsequent discussions revolved around: 1) which priority species should be tracked at a national scale to aid management; and 2) the creation of a coordinated tagging effort of priority species across jurisdictions to facilitate collection of data required to inform stock structure at a national scale, with in-principle agreement that all data derived from this program would be centralised in the IMOS ATF national acoustic tracking database.

It was noted that each jurisdiction has a differing list of priority species (Table 3). However, discussions amongst the meeting participants highlighted that some species are common to most, if not all, states as species of high interest for future monitoring. This provides an opportunity to extend our approach to these species and inform management by collecting much needed data on their spatial dynamics and stock structure.

As part of these discussions, it was recognised that the development of a simultaneous, coordinated tagging program in conjunction with the IMOS receiver network expansion is crucial to the success of this initiative. Therefore, now that the IMOS ATF acoustic receiver network is reconfigured and expanded, investment in acoustic transmitters is required to optimise information requirements over the next few years. This likely will need to come from funding outside of IMOS, which currently does not support purchase of acoustic transmitters. Regardless of the source, an optimised array requires development of a suitable tagging program established as part of a nationally coordinated tracking program. This approach would be designed to overcome locational biases in the national dataset.

Table 3: Updated list of priority species based on feedback gathered during the consultation process with state and federal fisheries representatives. Colour shading indicates the level of priority (yellow: low, orange: medium, red: high) to each jurisdiction.

| | Species | QLD | NSW | VIC | TAS | SA | WA | Cwth | Comments |
|---|---|---|---|---|---|---|---|---|---|
| RPN listed | Snapper | | | | | | | | Important species for NSW but national stock structure seems reasonably well understood through tagging and otolith micro-chemistry and internal structure. Fairly high site-fidelity. NSW SAFS status is Sustainable. In VIC - need a better understanding of movement of snapper between Port Phillip Bay and south-east SA - are snapper in south-east SA spill over from the Victorian population or do they return to Port Phillip Bay to spawn? Confirming the extent of movement of snapper between eastern Victoria and NSW, and eastern Victorian and Tasmania is required. |
| RPN listed | Yellowtail kingfish | | | | | | | | Iconic recreational species, subject of fisheries enhancement program. NSW commercial harvest has declined from ~550 t (1980's) to ~150 t (1990's), currently around 60 t and recreational catch estimated at 120-145 t/yr. In NSW, kingfish are an identified species for a harvest strategy case study through MEMA, FRDC and RFSWT projects. Current FRDC proposal under development by NSW to investigate national priorities and knowledge gaps for kingfish. Need a better understanding of connectivity and migratory dynamics between NSW, VIC and SA. Is the Victorian fishery largely dependent on seasonal migration and transient residency of juveniles originating from NSW? |
| RPN listed | Bluespotted flathead | | | | | | | | TAC species in NSW (NSW only species), little known of stock structure. Catch is currently ~100 t Commercial and ~200 t Recreational. No understanding of population structure, are stocks in bays/inlets largely isolated from each other, is there movement through coastal waters of adults/juveniles? |
| RPN listed | Southern sand flathead | | | | | | | | Minimal NSW catch |
| RPN listed | Yellowfin bream | | | | | | | | Important recreational and commercial species, many complicating factors like hybridisation, different spawning strategies. Considerable tagging work already done. |
| RPN listed | Spanish mackerel | | | | | | | | Sustainable species with good knowledge of stock structure (existing genetic evidence of 3 biological stocks, but otolith micro + parasite analyses + limited tagging indicates smaller stocks than indicated at genetic level). Current food safety issues with ciguatera poisoning of fish, thought to have accumulated toxin in northern waters; |

| | Species | QLD | NSW | VIC | TAS | SA | WA | Cwth | Comments |
|---|---|---|---|---|---|---|---|---|---|
| RPN listed | Southern bluefin tuna | | | | | | | | Key recreational fishery in VIC, improved understanding of how the fish targeted in VIC relate to other fishery regions is required. |
| RPN listed | Tiger shark | | | | | | | | Shark Management Strategy species, but limited success tagging in NSW waters. QRAC priority (rejected) concern over stock declines / shark control impacts |
| RPN listed | White shark | | | | | | | | Human interactions. Shark Management Strategy species, and contemporary issues well recognised. |
| RPN listed | Bull shark | | | | | | | | Human interactions - are they moving south? Shark Management Strategy species, and contemporary issues well recognised. Is the subject of reasonably comprehensive tagging work, but some data gaps could still be addressed particularly southward penetration |
| RPN listed | School shark | | | | | | | | Minimal harvest (<10 t) or conservation concern in NSW. |
| | Australian salmon | | | | | | | | Stocks are sustainable however there are two species, each with a single biological stock stretching across state boundaries. Western Australian Salmon are found in WA, SA and VIC. Eastern Australian Salmon are found in NSW, VIC and TAS. The impacts of climate change on the movements, timing of migrations and overall distributions are currently uncertain. |
| | Mulloway | | | | | | | | General poor understanding of population structure and movements between States. Stock structure within NSW uncertain. SAFS status: NSW - Depleted; Qld - Undefined; SA -Sustainable; WA - Sustainable. |
| | Pearl perch | | | | | | | | Stock structure needs work; not genetically defined but based on limited distribution on east coast and pelagic larvae, most likely a single stock. |
| | Grey morwong | | | | | | | | Stock structure needs work - not genetically defined but based on limited distribution on east coast and pelagic larvae. So, likely single stock. NSW and Commonwealth commercial catch ~20 t each (declining); NSW Recreational catch declined ~150 t (2000-01) to 29 t (2013-14). Minor catch in QLD. |
| | King George whiting | | | | | | | | Poor understanding of movements of adult fish across state boundaries, particularly SA and VIC. Do fish that recruit in VIC bays migrate back to spawning regions in SA? |
| | Hammerhead shark (Great & Scalloped) | | | | | | | | Conservation concern |

| | Species | QLD | NSW | VIC | TAS | SA | WA | Cwth | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Satellite tagging more appropriate | Mako shark (Shortfin) | | | | | | | | Highly Migratory (High Seas / ABNJ and regional), bycatch of commercial fisheries, recreational/game target. Current focus of a recreational fishing licence funded project, poor understanding of migratory dynamics etc. |
| | Cobia (Black kingfish) | | | | | | | | |
| | Silver trevally | | | | | | | | Contrasting stock structure issue between NSW and Commonwealth, at least for east coast stocks. Small tagging study in NSW indicating restricted adult movement and sub-structuring of east coast stocks (Fowler et al in prep) - essentially this finding led to a split in the SAFS assessment into jurisdictions with the NSW assessment classified as Depleting and Commonwealth as Sustainable. In NSW, Silver Trevally are also an identified species for a harvest strategy case study through MEMA, FRDC and RFSWT projects. |
| | Sea mullet | | | | | | | | Uncertainty regarding connectivity between QLD and NSW. |
| | Mahi mahi | | | | | | | | Important recreational species, but previous tagging work shows limited results. |
| | Redfish | | | | | | | | Stock structure needs work; not genetically defined but based on limited distribution on east coast and pelagic larvae, most likely a single stock. |
| | Blue-eye trevalla | | | | | | | | Stock structure reasonably well known (a lot of work recently - Williams et al 2017). Genetic, otolith micro-chemistry, phenotypic variation in age and growth indicate substantial stock structuring on east coast and seamounts. The 2018 assessment has not taken this structure into consideration yet. |
| Satellite tagging more appropriate | Striped marlin | | | | | | | | Important recreational species, but large gamefish tag recapture database already collected |
| Satellite tagging more appropriate | Swordfish | | | | | | | | Primarily occurs off the shelf - unlikely to be picked up on existing array infrastructure |
| | Bastard trumpeter | | | | | | | | Important in TAS |
| | Striped trumpeter | | | | | | | | Important in TAS |

| | Species | QLD | NSW | VIC | TAS | SA | WA | Cwth | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Black jewfish | | | | | | | | Important in QLD |
| | King threadfin | | | | | | | | Important in QLD |
| | Narrow sawfish | | | | | | | | Important in QLD |
| | Tailor | | | | | | | | Important in QLD |

# Implications

The revised IMOS ATF network is designed to cover areas of coast likely to be used by priority species identified by the RPN, including chokepoints previously not covered. These species are all subject to management by state and federal agencies and if these agencies undertake tagging of the relevant species, they should benefit from the significantly improved data upon which to base their decision making. For a relatively modest outlay, management agencies and their funding bodies could tag target species and track their movements using the existing IMOS ATF network. The federal government with co-investment partners invests approximately $50 million/annum in IMOS (see Appendix 6). The research community has benefited immensely from this investment, as have many other stakeholders, but fisheries management agencies could exploit this resource to greater advantage, especially given the new reconfiguration designed to serve their needs. A nationally coordinated tagging program would maintain Australia's position as the leader in fish tagging research and management. In light of the rate at which species distributions are changing in Australia's waters (e.g. the intensification of the Eastern Australian Current) and records of multiple fish species off Tasmania not sighted in previous decades, evidence-based management needs to adopt these new and innovative techniques that can provide data on a national scale.

# Recommendations

The national IMOS acoustic tracking dataset provides valuable information on stock structure of priority species identified by the RPN. This information is important, but currently not being used to inform dynamic spatial management of these species. We have developed a novel approach to gain insight into spatial stock structure of important Australian fish species. Future stock assessments and management decisions about the species analysed here should take into consideration the information produced as part of this project.

We propose an FRDC supported multi-year, nationally coordinated, tagging program to capitalise on the significant additional investment in acoustic telemetry infrastructure that IMOS has provided as part of this project (see Appendix 6). With co-investment from state fisheries agencies, the plan is to tag and collect much needed data on movements and connectivity of priority species across jurisdictions. This information will feed directly into dynamic spatial management, and stock structure assessments, contribute to assessment of the status of stocks (e.g. SAFS) and identify impacts of climate change for these nationally important fish species.

# Extension and Adoption

Results from this work will be communicated to both data providers and end users including the RPN, fishery managers, IMOS leadership and IMOS ATF partner institutions. It will provide detailed information to regional management agencies (via their delegates) on how telemetry can be used to monitor species stock structure, movements and range changes, and on how the new strategic deployment of receiver arrays can further improve that knowledge.

# Project materials developed

**Scientific articles:**

UDYAWER, V., CAMPBELL, H., HARCOURT, R., HOENNER, X., HUVENEERS, C., JAINE, F., SIMPFENDORFER, C., TAYLOR, M., BARNETT, A., BROWN, C., BRUCE, B., BUSCOT, M.J., BUTCHER, P., CURREY, L., DREW, M., ESPINOZA, M., FOWLER, A., LEE, K., LLOYD, M., LOWRY, M., MATLEY, J., McAULEY, R., MEEKAN, M., MILLS, K., PEDDEMORS, V., SEMMENS, J., SMOOTHEY, A., SPEED, C., HEUPEL, M. (in review) Scaling of space use in marine organisms across latitudinal gradients. *The American Naturalist*.

LEDEE, E., HEUPEL, M., TAYLOR, M., HARCOURT, R., HUVENEERS, C., UDYAWER, V., CAMPBELL, H. JAINE, F., BABCOCK, R., HOENNER, X., BARNETT, A., BRACINI, M., BRODIE, S., BUTCHER, P., CADIOU, G., DWYER, R., ESPINOZA, M., FERREIRA, L., FETTERPLACE, L., FOWLER, T., HARBORNE, A., KNOTT, N., LOWRY, M., McAULEY, R., MEEKAN, M., MILLS, K., PEDDEMORS, V., PILLANS, R., SEMMENS, J., SMOOTHEY, A., SPEED, C., VAN DER MUELEN, D., SIMPFENDORFER, C. (in review) National-scale acoustic telemetry and network analysis provide new insights into stock structure. *Fish and Fisheries*.

**Business Plans:**

HARCOURT, R., HEUPEL, M., JAINE, F. (2018) IMOS ATF Acoustic Receiver Reconfiguration Proposal. *Integrated Marine Observing System.*

# Appendices

1. List of participants to Workshops #1 and #2
2. References
3. IMOS ATF Acoustic Receiver Reconfiguration Proposal
4. IMOS Letter of Support

# Appendix 1: List of Participants

**Workshop #1: Assessment of national-scale tracking of commercially important fish species**
*Sydney Institute of Marine Science, Mosman, NSW*
*7th-11th October 2018*

| Participant | Affiliation(s) |
|---|---|
| Babcock, R. | Commonwealth Scientific and Industrial Research Organisation (CSIRO) |
| Campbell, H. | Charles Darwin University |
| Harcourt, R. | Integrated Marine Observing System (IMOS), Animal Tracking Facility<br>Macquarie University |
| Heupel, M. | Integrated Marine Observing System (IMOS), Animal Tracking Facility<br>Australian Institute of Marine Science (AIMS) |
| Hoenner, X. | Integrated Marine Observing System (IMOS), Australian Ocean Data Network |
| Huveneers, C. | Flinders University |
| Jaine, F. | Integrated Marine Observing System (IMOS), Animal Tracking Facility<br>Macquarie University |
| Lédée, E. | Carleton University<br>James Cook University |
| Simpfendorfer, C. | James Cook University |
| Taylor, M. | NSW Department of Primary Industries (NSW DPI), Fisheries Research |
| Udyawer, U. | Australian Institute of Marine Science (AIMS) |

**Workshop #2: National-scale tracking of priority fish species**
*Institute for Marine and Antarctic Studies, University of Tasmania, TAS*
*21st-23rd August 2019*

| Participant | Affiliation(s) |
|---|---|
| Gaughan, D. | WA Department of Primary Industries and Regional Development (WA DPIRD) |
| Hamer, P. | Victorian Fisheries Authority, Management and Science |
| Harcourt, R. | Integrated Marine Observing System (IMOS), Animal Tracking Facility |
| Heupel, M. | Integrated Marine Observing System (IMOS) |
| Jaine, F. | Integrated Marine Observing System (IMOS), Animal Tracking Facility |
| Jebreen, E. | QLD Department of Agriculture and Fisheries, Fisheries |
| Moltmann, T. | Integrated Marine Observing System (IMOS)<br>Fisheries and Aquaculture Research Providers Network |
| Rogers, P. | SA Primary Industries and Regions, South Australian Research and Development Institute, Finfish Fisheries |
| Semmens, J. | Institute for Marine and Antarctic Studies, University of Tasmania |
| Smith, D. | Fisheries and Aquaculture Research Providers Network |
| Taylor, M. | NSW Department of Primary Industries, Fisheries Research |

# Appendix 2: References


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# Appendix 3: IMOS Acoustic Receiver Reconfiguration Proposal

**Background**
The Integrated Marine Observing System Animal Tracking Facility (IMOS ATF) is comprised of a series of permanent national installations supported by IMOS and project-scale deployments supported by researchers (Brodie et al. 2017; Figure 1). In 2017 a Task Team synthesised and undertook comparative analyses of the large amount of telemetry data collected via this national-scale collaborative infrastructure. The team also explored whether the current receiver network could play a stronger national role in management and conservation efforts.

In 2018 an FRDC-funded project was established to determine whether existing data for a suite of priority species (Table 1) could be used to inform management. This study included an assessment of whether stock structure of these priority species can be defined using dispersal distance and connectivity of species derived from the IMOS ATF acoustic network. A second component of this project was to examine scenarios for reconfiguring or enhancing the acoustic receiver array to better address fisheries management needs for priority species.

Consideration of network functionality also requires consideration of tracking capacity. This means consideration must be given to development of a simultaneous tagging program in conjunction with receiver expansion. Therefore, if the IMOS ATF acoustic receiver network is reconfigured and expanded, an additional investment in acoustic transmitters would be required to optimise output. This likely needs to come from funding outside of IMOS which currently does not support purchase of acoustic transmitters (e.g. FRDC, fisheries agencies). Regardless of the source, an optimised array requires development of a suitable tagging program established as part of a nationally coordinated tracking program. This approach would be designed to overcome locational biases in the national dataset.


*Figure 1. The IMOS ATF national acoustic receiver array. Black squares indicate IMOS infrastructure and grey circles indicate co-invested collaborator (researcher) installations. From Brodie et al. 2017.*

**Table 1.** List of priority species provided by the Fisheries Research Provider Network (RPN), on the basis of fisheries or conservation importance i.e. Threatened, Endangered and Protected Species (TEPS).

| Species | Rationale |
|---|---|
| Snapper | Coastal demersal, Stocks fished across multiple states, commercially and recreationally important |
| Kingfish | Pelagic, migratory, Stocks fished across multiple states, recreationally important |
| Flathead (Sand, Bluespotted) | Coastal demersal, Stocks fished across multiple states, commercially and recreationally important |
| Bream (Black, Yellowfin) | Coastal demersal, Stocks fished across multiple states, commercially and recreationally important |
| Spanish mackerel | Pelagic, migratory, Stocks fished across multiple states, commercially and recreationally important |
| Southern bluefin tuna | Pelagic, migratory, internationally commercially important (RFMO), increasing recreational catch |
| Tiger shark | TEPS, Large scale movements, interactions with humans |
| White shark | TEPS, Large scale movements, interactions with humans |
| Bull shark | TEPS, Large scale movements, interactions with humans |
| School shark | Demersal, south-east Australian distribution, commercially important, Conservation Dependent (EPBC) |

**Approach**

A group of national telemetry experts were consulted about priorities and potential configurations of the IMOS ATF network during a workshop held at the Sydney Institute of Marine Science 7-11 October 2018. A number of scenarios were discussed with varying levels of investment required from IMOS (e.g. acoustic receivers) and partners who would need to commit to servicing them. Scenario discussions revolved around where installations could be established to increase scientific value and with particular reference to addressing data needs for the priority species identified by the RPN (Table 1). Agreed scenarios are outlined below.

***Scenario 0***

The current IMOS ATF receiver network is shown in Figure 2. It was noted at the workshop that current installations are biased to the east coast of Australia and off Ningaloo Reef with gaps apparent in several other regions. Despite the lack of infrastructure in the north, it was determined that there is not currently enough capacity to expand the network into this region at this time. In addition, it is not a critical area relative to the majority of the RPN priority species.

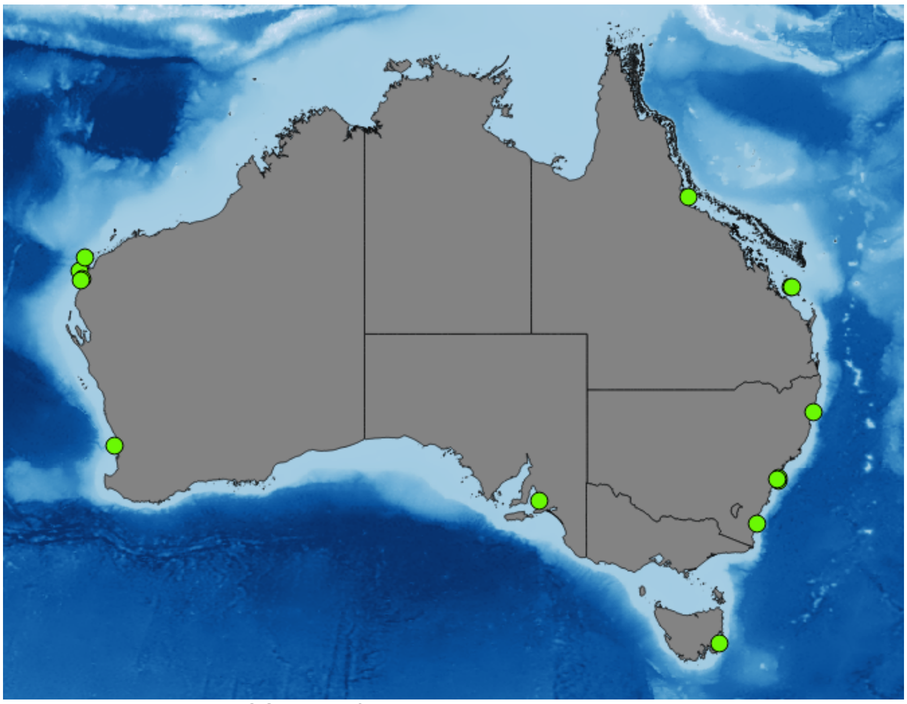

*Figure 2. Scenario 0 – the current IMOS ATF infrastructure deployed around Australia as indicated by green circles.*

***Scenario 1***
The first scenario is the lowest cost option (no new capital) and is deemed to provide limited benefit relative to the majority of the priority species. The scenario involves the relocation of some existing infrastructure and deployment of receivers that are not currently in use. Relocation would involve removal of the central line in the Ningaloo Reef network (n = 8 receivers), Glenelg Line (n = 2) and the Orpheus Island Array (n = 18 receivers) for redistribution. Receivers from these locations would be used to establish two new installations, both of which would increase effective receiver coverage, but only in close proximity to currently surveyed areas (Figure 3).

The first of these new installations would be in QLD to form a backbone of receivers along the Great Barrier Reef. The intent of this installation would be to integrate acoustic monitoring with the Reef Integrated Monitoring and Reporting (RIMReP) field work. A total of 46 VR2W receivers are available for this installation. If agreed by RIMReP research providers, receivers could be swapped out during routine field work alleviating the need for additional funding support for receiver servicing. Some support would be required to ensure receivers are ready for deployment by RIMReP teams and to offload data from recovered receivers, but this could be managed within the workload of the Facility.

The second addition would be around offshore islands and on existing infrastructure (e.g. moorings) off the coast of South Australia (SA) and include 15 VR2W receivers. These deployments aim to expand coverage while increasing ease of deployment and retrieval. This installation would expand capacity in SA but requires co-investment from a partner agency to service the deployed equipment. Flinders University and SARDI have been identified as potential co-investment partners who could support and service the equipment deployed at this installation.

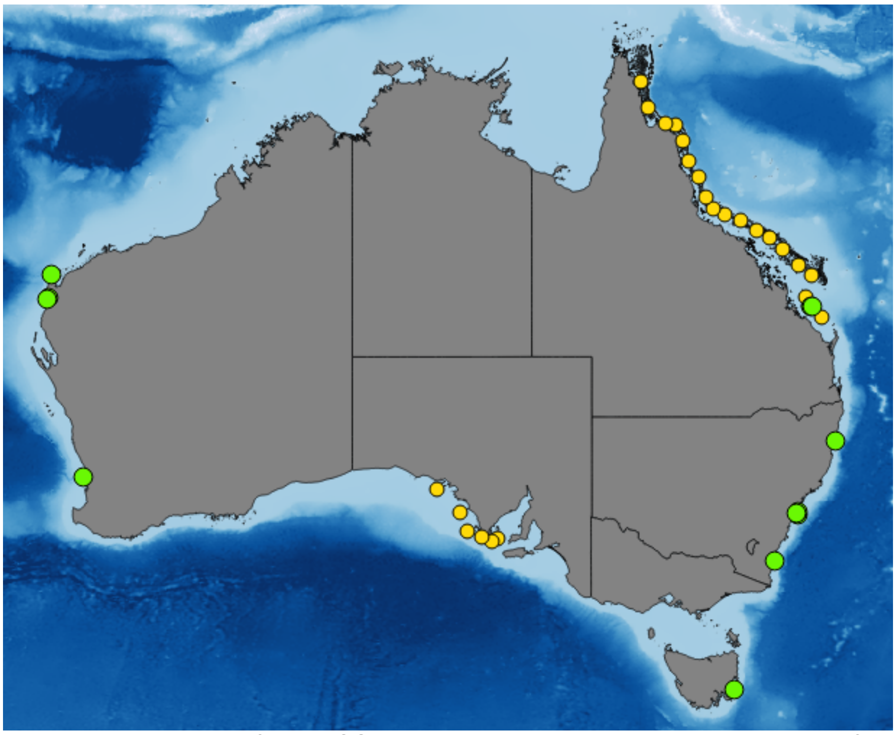

*Figure 3. Scenario 1 – enhancement of the IMOS ATF acoustic receiver network through use of existing receiver infrastructure and high potential for co-investment to support equipment servicing. Existing installations (Scenario 0) are indicated by green circles and new installations (Scenario 1) are indicated by yellow circles.*

***Scenario 2***
The second scenario is designed to provide infrastructure at key locations relative to data needs for the priority species and improve national coverage. This scenario maintains the changes highlighted in Scenario 1 and expands beyond that proposal (Figure 4). Additional installations in Scenario 2 include (from east to west): Stradbroke Island (QLD), Port Stephens (NSW), Portland (Vic), Esperance (WA) and Shark Bay (WA). These suggested deployments were not given equal weight by the workshop team (see Table 2). Descriptions of the deployments (in order of priority) are listed below. All these installations would require purchase of additional receivers (IMOS support) and co-investment support to service receivers.

Scenario 2 is estimated to require an initial capital investment in receiver infrastructure of approximately \$500k. Furthermore, the use VR2-AR (acoustic release receiver) units requires two VR100 manual receivers to program receiver releases, for which an additional \$50k infrastructure investment is needed.

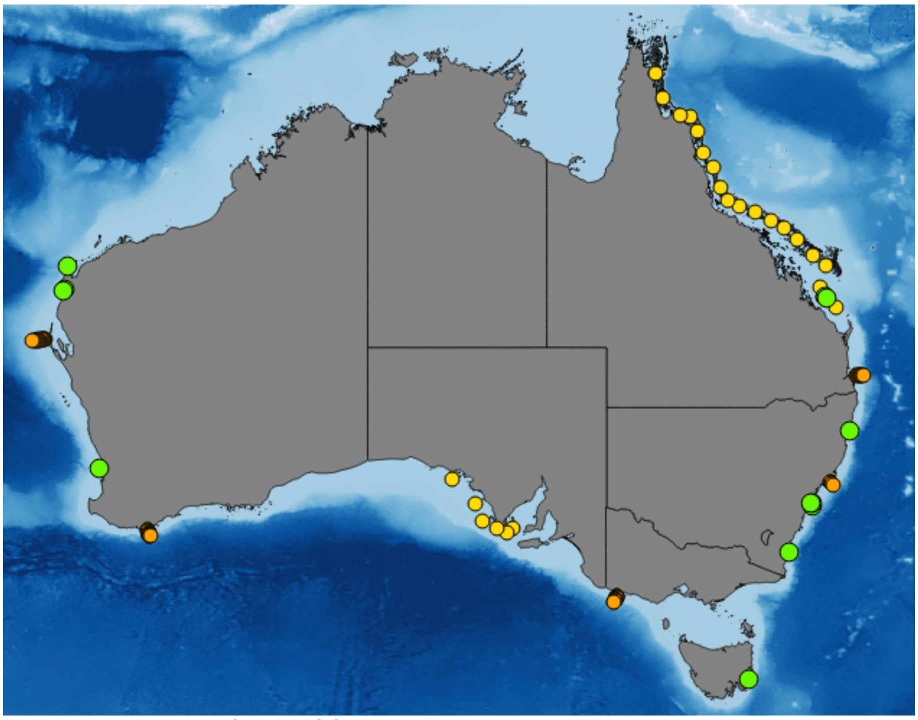

*Figure 4. Scenario 2 – expansion of the IMOS ATF acoustic receiver network to include installations in locations that are likely key to addressing questions related to priority species. Installations are indicated by green (Scenario 0), yellow (Scenario 1) and orange (Scenario 2) circles.*

Portland (Vic) – 10 VR2-AR receivers. This line off the Victoria coast is considered a high priority based on the capacity to define cross-jurisdictional movement and population links near and through Bass Strait, to expand infrastructure to the south coast, and based on the distribution of several priority species occurring in this region. Deakin University has been identified as a partner to conduct servicing of this installation. Initial conversations with Deakin indicate they may be willing to play this role.

Stradbroke Island (QLD) – 5 VR2-AR receivers. This installation provides capacity to define cross-jurisdictional population links between QLD and NSW and also serves as a link between NSW arrays and the proposed RIMReP deployment. It is also strategically placed to reduce the amount of equipment required and to complement other IMOS biophysical datasets (i.e. National Reference Station). The IMOS ATF may be able to conduct receiver servicing at this location due to the small number of units, proximity to a research station and access to the CSIRO vessel. This would be facilitated by time savings from removal of the Ningaloo central line.

Esperance (WA) – 15 VR2-AR receivers. This installation serves as a link between the south and west coasts while increasing capacity to monitor species that occur in the southwest. Placement of this installation is based on the width of the shelf in this region and proximity to population centres which can provide access to vessels. This installation would require co-investment from a partner to conduct servicing. WA Fisheries has been identified as a potential partner who could service this equipment, but this has not yet been discussed with anyone from WA Fisheries.

Shark Bay (WA) – 10 VR2-AR receivers. This installation serves to increase capacity to capture broad-scale movements along the west coast. Placement of this installation is based on position in the region, midway between northern and southern existing installations. This strategic location was also chosen due to potential future studies in Shark Bay that could leverage off and enhance a deployment in this area. WA Fisheries has been identified as a potential partner who could service this equipment, but this has not been discussed with anyone from WA Fisheries at this stage.

Port Stephens (NSW) – 5 VR2-AR receivers. This installation serves as a link between other NSW arrays and also occurs within a marine reserve. This small amount of equipment could provide significant additional information about movements along the coast of NSW, capitalising on the large number of species tagged in the region, as well as an indication of use of the marine reserve by exploited or threatened species. NSW Department of Primary Industries may be able to conduct receiver servicing at this location due to the small number of units and proximity to their main office.

***Scenario 3***
The third scenario was developed as an optimal national array design (within the context of limited scope to expand in the north). This scenario maintains the changes highlighted in Scenarios 1 and 2, and includes additional expansion of the IMOS ATF network (Figure 5). Additional installations in Scenario 3 include, from east to west: the west coast of Tasmania, Cape Jervis (SA), and Kangaroo Island (SA). Descriptions of the deployments (in order of priority) are listed below (also see Table 2). All of these installations would require purchase of additional receivers and co-investment support to service receivers.

Scenario 3 is the most expensive scenario expected to require an initial investment in receiver infrastructure estimated at approximately $250k in addition to the investment required for Scenario 2.

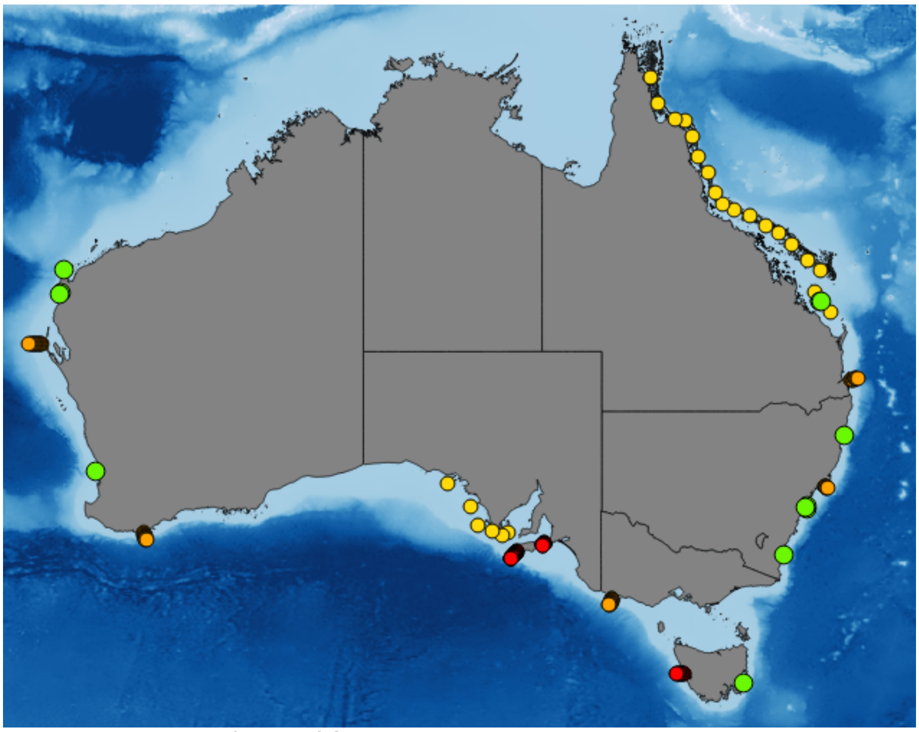

*Figure 5. Scenario 3 – expansion of the IMOS ATF acoustic receiver network to include installations that provide enhanced national coverage. Installations are indicated by green (Scenario 0), yellow (Scenario 1), orange (Scenario 2) and red (Scenario 3) circles.*

Cape Jervis (SA) – 15 VR2-AR receivers. This installation serves as a gate to capture movements along the southern coast. Placement of this installation is designed to take advantage of a pinch point between the coast and Kangaroo Island which could capture alongshore movements of priority species. South Australian Research and Development Institute (SARDI) and Flinders University have been identified as potential partners who could service this equipment, but this has not been discussed with anyone from either institution at this stage.

Kangaroo Island (SA) – 6 VR2AR receivers. This installation extends from Kangaroo Island toward the shelf edge to capture movements in deeper waters along the southern coast. Placement of this installation is designed to take advantage of Kangaroo Island to reduce the amount of equipment required. South Australian Research and Development Institute and Flinders University have been identified as potential partners who could service this equipment, but this has not been discussed with anyone from either institutions at this stage.

Western Tasmania (Tas) – 10 VR2-AR receivers. This installation would capture any movement of individuals along the west coast of Tasmania as opposed to travelling through Bass Strait. This installation serves to provide more complete coverage in southern Australia. It is acknowledged that this area is challenging to work in, with equipment deployment and maintenance a potential issue. A partner agency who would have capacity to service this installation has not yet been identified.

**Conclusions**
The workshop team of acoustic telemetry experts concluded that the bare minimum change required to the national network is captured in Scenario 1, which provides minor expansion to the network without requiring additional equipment and the potential to integrate into existing work plans without requiring significant additional

co-investment. The team, however, agreed that Scenario 2 provided a stronger, more comprehensive network to address questions relevant to the ecology, management, and conservation of a variety of species within Australian waters. Scenario 2 requires capital investment in infrastructure from IMOS as well as co-investment from partners to facilitate equipment servicing. If sufficient partner commitment and co-investment cannot be secured, this Scenario may not be viable. However, because installations are independent, individual components of this scenario may be more feasible than others and all options should be explored to help enhance the national infrastructure even if Scenario 2 cannot be implemented in its entirety. It was recognised that Scenario 3 represents a greater challenge given the significant infrastructure investment required and large co-investment from the broader community. As with Scenario 2 though, if partners are interested in components of this scenario these should be explored in the interest of improving the national infrastructure as much as possible.

**Next Steps**

1. Discuss Scenario options with David Smith and Tim Moltmann for input
2. Communicate and socialise scenarios with fisheries agencies (RPN?)
3. Contact potential partners to explore level of interest and capacity to co-invest in receiver management in their region
4. Hold a workshop to present scenario options to the research and management community for discussion and endorsement.
5. Report final conclusions and proposed network structure to FRDC and IMOS.

**Table 2.** Listing of proposed expansion deployments and infrastructure needs in order of priority. The amount of receivers required is indicative of the capital investment required for each installation.

| Priority | Scenario | Site name | Receiver needs | Potential co-investment partner |
|---|---|---|---|---|
| 1 | 1 | Great Barrier Reef | - | RIMReP providers |
| 1 | 1 | South Australian Islands | - | SARDI, Flinders Uni |
| 2 | 2 | VR100 | 2 VR100 | IMOS |
| 3 | 2 | Portland, Victoria | 10 VR2-AR | Deakin Uni |
| 4 | 2 | Stradbroke Island, Queensland | 5 VR2-AR | CSIRO |
| 5 | 2 | Esperance, Western Australia | 15 VR2-AR | WA Fisheries |
| 6 | 2 | Shark Bay, Western Australia | 10 VR2-AR | WA Fisheries |
| 7 | 2 | Port Stephens, New South Wales | 5 VR2-AR | NSW DPI |
| 8 | 3 | Cape Jervis, South Australia | 15 VR2-AR | SARDI, Flinders Uni |
| 9 | 3 | Kangaroo Island, South Australia | 6 VR2AR receivers | SARDI, Flinders Uni |
| 10 | 3 | Western Tasmania | 10 VR2-AR | Unknown |

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# Appendix 4: IMOS Letter of support

**IMOS** Integrated **Marine Observing** System

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16 August 2019

Christopher Izzo
Fisheries Research & Development Corporation
Locked Bag 222
Deakin West, ACT 2600

Dear Christopher,

**RE: FRDC Project 2018-091, Final Report**

This letter is intended to provide additional information in support of the findings and recommendations of FRDC Project 2018-091 – "Assessment of national-scale tracking of commercially important fish species". Since this project commenced, the IMOS consortium and other partners have committed significant new resources as follows:

- The IMOS Board approved $3.183M of ongoing funding for the Animal Tracking facility over four years (2018-22). At the request of Australian Government, IMOS is currently planning out to 2030 and we expect our animal tracking program to continue.
- The IMOS Board also approved new investment of $0.500M, including commencing redesign of the national network in response to input from the National Fisheries and Aquaculture Research Providers Network (RPN).
- Existing receiver arrays have been reconfigured, and new arrays approved at Portland (Victoria/SA), Stradbroke Island (Queensland) and Port Stephens (NSW). The new Portland receivers are already in the water – see here.
- There is potential for a further $0.250M of IMOS investment at Esperance and Shark Bay in WA, subject to resolution of historical issues around data sharing. Current discussions are very positive.
- Queensland Government have indicated that, subject to Ministerial decision, an additional $1.049M will be invested over four years to enhance the national Animal Tracking Network to inshore coastal waters in collaboration with the Queensland Shark Control Program.

This substantial, additional support provides confidence that the findings and recommendations of project 2018-091 can be successfully implemented, and opportunities identified can be realised. We hope the final report will be favourably received.

Yours sincerely,

T. Moltmann

**Tim Moltmann - IMOS Director**