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Implications of current spatial management measures for AFMA ERAs for habitats

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Contents

Tables

Figures

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A steering committee with membership comprising AMFA staff and CFA members provided valued guidance and feedback to the project.

The CERF Marine Biodiversity Hub provided the initial collation and mapping of national environmental variables; collation of many of the regional scale demersal biological surveys; and development of the approach used to predict and map assemblages. The NERP Marine Biodiversity Hub Project 2.3.2 originally developed the approach applied here for quantifying exposure of assemblages to trawling.

Updated ocean colour data was sourced from the Integrated Marine Observing System (IMOS), which is supported by the Australian Government through the National Collaborative Research Infrastructure Strategy and the Super Science Initiative.

The sources of biological survey datasets as listed in Appendix 3 are acknowledged.

Executive Summary

In this project, CSIRO researchers implemented the first Australia-wide spatial approach to quantifying the exposure of mapped seabed assemblages to the footprints of Commonwealth demersal trawl fisheries, as well as their spatial protection in areas closed to trawling. These outputs are assisting AFMA in understanding the contributions of existing spatial management measures to environmental sustainability, and to identify and prioritise any remaining needs for addressing risks to habitats. The focus provided by these priorities is intended to reduce the costs of environmental assessments, ultimately having outcomes including reduction of the ecological risks posed by trawling and enhanced environmental sustainability. Trawling footprints were mapped from fishery effort data for recent years. Protection provided by current spatial management included fishery closures, the Commonwealth Marine Reserve system (CMRs), and some other Marine Protected Areas (MPAs). Seabed assemblages — as surrogates for broad habitats — were defined and mapped using a single consistent method that had not been possible previously, but was now enabled by new advances in analyses and the availability of new data & knowledge. The overlaps of each assemblage with trawl footprints, and with areas closed to trawling, were calculated to quantify trawl exposure and spatial protection.

Background

To date, ecological risk assessments (ERAs) for Australian trawl fisheries have largely focussed on bycatch and by-product species — and management responses (ERM) have focused on species assessed as being at high risk. However, research has demonstrated that towed demersal fishing gears can impact seabed habitats, which consequently may be at risk. Most fisheries lack adequate data for habitat ERAs, but in some Commonwealth fisheries, initial ERAs identified the nature & diversity of habitats and potential risks from different fishing gears, though could not map spatial extent of habitats and were interim in nature. Subsequently, new management has been implemented — including effort reductions and closures — that may have reduced the level of potential risk. Thus, AFMA has identified the need to extend the ERAs covering habitats, and to take into account the recent management. Specifically, AFMA's stated priority was a gap analysis to determine the extent to which individual fishery ERAs, and hence ecological risk management (ERM), need to address habitats considering other fishery management measures now in place and following the finalisation of the CMRs network. It is this priority that this project addressed, utilizing new data and spatial mapping methods, for all Commonwealth demersal fisheries that use towed bottom-contact gear (trawls, dredges) in Australian continental shelf and slope waters.

Aims

The project aimed to quantify the overlap of mapped seabed assemblages with trawl footprints, and with areas of spatial management that exclude trawling, by building on previously collated data and assemblage mapping — as well as data for Commonwealth demersal trawling effort, fishery closures and marine reserves. These trawl exposure and protection estimates provide information that AFMA can use to focus on priorities or gaps, regarding the needs for any future for habitat ERAs, in their progress towards ecosystem based management.

Methods

Most fisheries lacked data for seabed habitats *per se*. Hence, as surrogates for habitats at meso-scales, assemblages were defined where each represented an area having similar environmental conditions and expected to have a similar mix of fish & invertebrate species. This process built on the foundation provided by significant previous investment in a number of completed and other current projects, but also required collation of additional biological survey datasets and environmental layers, as well as additional data for trawl effort distribution and intensity, and for fishery closures, CMRs and other MPAs. The multiple biological survey datasets were analysed with the environmental layers to quantify the magnitude of change in demersal species composition along the environmental gradients (as predictors). This information was then used to predict and map the distribution of demersal assemblages on a 0.01° grid. Trawled-area footprints were estimated from logbook or VMS effort data for a 3–5 year period post-2007 (after significant restructuring had been implemented in several fisheries) and mapped on the 0.01° grid, as were fishery closures and CMRs. The overlap of each assemblage with trawling and closed areas was then quantified by area and as a percentage. All CMRs were assumed to exclude trawling, although most CMR management plans were under review. The fisheries assessed were: Southeast Commonwealth Trawl Sector, Bass Strait Central Zone Scallop (dredge) Fishery, Great Australian Bight Trawl Fishery, Western Deepwater Trawl Fishery, Northwest Slope Trawl Fishery, Northern Prawn Fishery, and Torres Strait Prawn Fishery. Each fishery was analysed separately within its respective management jurisdiction boundary, subject to a maximum depth of 1500 m for fish trawl fisheries and 150 m for prawn and scallop.

Key findings

The majority of the 106 seabed assemblages defined and mapped had little or no exposure to trawling by the Commonwealth trawl fisheries assessed. These assemblages with low trawl exposure included a large number with little or no protection in closed areas, in addition to those with high levels of protection in closures. Across all fisheries, there were relatively few assemblages that had both high exposure to trawling and low protection by closed areas. Several more highly exposed assemblages also had substantive inclusion in closed areas. For example, five assemblages had >20% annual trawl footprint exposure (maximum annual footprint = 43.7%), of which two had >20% protection in areas closed to trawling. Those assemblages with both high exposure and low protection may be considered higher priority for future AFMA habitat ERA focus, whereas those with low exposure and high protection may receive less ERA focus. The identification of these assemblages does not necessarily imply actual risk to habitat, but rather, information on the extent of any vulnerable habitats or biological components in the higher priority assemblages is required to make such a risk assessment.

Implications for stakeholders

It is likely that the majority of demersal assemblages within these Commonwealth trawl fishery jurisdictions are not subject to substantive risk from these fisheries, due to their low exposure, and this is largely independent of whether assemblages have high or no protection. The relatively few assemblages within these jurisdictions that have higher exposures to trawling may have potential for risk to vulnerable habitats if such habitats occur in these areas. Thus, the limited resources for future habitat ERAs can be focussed on the small number of more highly exposed assemblages, particularly those with lower levels of protection, to assess whether vulnerable habitats are present and whether they are at substantive risk from demersal trawl or dredge fishing. This focus will enable more efficient application of resources on environmental risk assessments for habitats. Ultimately, expected benefits include reduction in environmental risks due to trawling, and hence AFMA meeting requirements of legislation regarding environmental sustainability, and improved social licence for fisheries.

Recommendations

Decisions regarding the final priorities for future habitat risk assessments should include further discussions with AFMA, industry associations and industry members of relevant fisheries, AFMA's consultative management and scientific committees, and researchers. The discussions should also include potential methods that may be suitable for determining whether sensitive habitats or habitat-forming biological components are present in the priority assemblages, and for assessing whether they are at substantive risk from trawling. The priorities for future habitat ERAs need to account for the uncertainties inherent in mapping assemblages and trawl footprints.

The project scope was Commonwealth trawl & dredge fisheries only — it did not map assemblages outside of these jurisdictions or address the footprints of State bottom-trawl fisheries. This may be significant because, although State trawl fisheries generally occur outside Commonwealth jurisdictions, some assemblages extend outside of these jurisdictions and may be exposed to State trawl fisheries. In addition, some State fisheries operate within the jurisdictional boundaries of some Commonwealth trawl fisheries. This may affect the relative priorities of assemblages determined by this project. Further, it is now feasible to apply the approach used in this project to all Australian fishery jurisdictions and cover State managed fisheries, to provide a single consistent national assessment of the exposure of assemblages to trawling, with an ultimate expected outcome of leading to achievement and demonstration of habitat sustainability for all Australian demersal trawl fisheries.

Keywords

ecological risk assessment; ERA; bottom trawling; effects of trawling; trawl impacts; seafloor damage; trawl footprints; seabed assemblages mapping; marine protected areas; marine parks.

1 Introduction

Australia is a world leader in ecosystem based management of fisheries; nevertheless, addressing the environmental sustainability of fishing continues to be a major strategic challenge. Australian fisheries must meet legislative requirements under the Environmental Protection & Biodiversity Conservation (EPBC) Act and regular environmental reviews assessed by the Department of Environment (DoE). In response to the EPBC Act, related regulations and international obligations, the Australian Fisheries Management Authority (AFMA) has for some time been moving beyond target species to take an ecosystem-based approach to managing Commonwealth fisheries, aiming for broader environmental sustainability including for bycatch species, habitat and communities. Typically, a risk assessment approach is being taken for this purpose.

CSIRO, among others, has been supporting AFMA and other management agencies to meet these requirements for several years. For example, with ecological risk assessments (ERAs) for species, bycatch, habitats and communities (e.g. Stobutzki et al. 2000, 2001; Pitcher et al. 2007ab; Pitcher 2013, 2014, 2015; Hobday et al. 2011ab; Zhou et a. 2009). Much of this effort has been focussed on bycatch, and ERAs for bycatch species have been conducted for most Commonwealth fisheries. However, research has demonstrated that demersal towed fishing gears can impact seabed habitats and communities (e.g. Burridge et al. 2003; Pitcher et al. 2016), which consequently are considered potentially at risk. Accordingly, ERAs for habitats have been completed, at a qualitative level, for some Commonwealth fisheries (e.g. Williams et al. 2011). Nevertheless, largely due to inadequate data for most fisheries, most habitat ERAs were non-spatial (i.e. the spatial extent of risk was unknown) and interim in nature.

More recently, new data and methods have become available that permit an advancement of these assessments; and further, new management has been implemented — including effort management, fishery closures and the Commonwealth Marine Reserve system (CMRs) — that may change the spatial extent of potential risk to habitats from trawling. Thus, AFMA has identified a need to extend the ERAs covering habitats and communities, taking into account the new management, information and methods. In particular, AFMA has specified a priority requirement for a gap analysis to determine the extent to which individual fishery ERAs, and hence ecological risk management (ERM), need to address habitats considering other fishery management measures now in place — including effort reductions & closures — and following the finalisation of the CMRs network. It is this priority need that this project was specifically developed to address.

In addition to the new management, the project also took into account the new data & knowledge, and new advances in methods, to implement a consistent national-scale assemblage mapping approach that had not been possible previously, and applied it to Commonwealth demersal trawl fisheries. The scope included Australian continental Commonwealth demersal fisheries that use towed bottom-contact gear in shelf and mid/upper-slope waters. These fisheries included: the Southeast Commonwealth Trawl Sector (SET), the Great Australian Bight Trawl Fishery (GABTF), the Western Deepwater Trawl Fishery (WDTF), the Northwest Slope Trawl Fishery (NWSTF), the Northern Prawn Fishery (NPF), the Torres Strait Prawn Fishery (TSPF) and the Bass Strait Central Zone Scallop (dredge) Fishery (BSCZS). Each fishery was analysed separately within its respective management jurisdiction boundary, subject to a maximum depth of 1500 m for fish trawl fisheries and 150 m for Prawn (NPF, TSPF) and Scallop (BSCZS) (see Appendix 1).

2 Objectives

Build on recently collated data and mapped distributions of predicted demersal assemblages — as well as data for Commonwealth demersal fishing effort, fishery closures and marine reserves — to provide:

- quantification of the overlap of current fishing effort and intensity with each mapped assemblage,
- quantification of the overlap of each mapped assemblage with areas of spatial management that exclude fishing, such as fishery closures and marine reserves,
- a gap analysis and prioritisation of which mapped assemblages, and in which fisheries, may require future focus for AFMAs fishery ERAs.
- qualitative assessment of the potential risk implications for any habitat forming biota (if/where data available) in mapped assemblages with high exposure to fisheries, given current spatial management.

3 Methods

The project built on the foundation provided by significant previous investment in a number of completed and current projects that provided: the underpinning methods for high-resolution regional-scale quantitative risk assessments of assemblages and habitats (e.g. the "GBR Seabed Biodiversity Project", Pitcher et al. 2007a); a comprehensive database of available demersal biodiversity survey datasets and environmental data layers with national coverage, new methods for predicting patterns of biodiversity composition at regional scale from multiple disparate inputs, and maps of predicted assemblages for each large marine planning region nationally (the CERF Marine Biodiversity Hub "Prediction Program", Pitcher et al. 2011); updated biological survey and environmental datasets and revised regional maps of predicted seabed assemblages (CERF Transition Program "New data layers", McLeod & Pitcher 2011); compilations of Commonwealth fishing effort and closures information, and development of the assemblages overlap approach to be used in this project (NERP Marine Hub Project 2.3.2 "Landscape approach to supporting management of benthic biodiversity in the Southeast Marine Region", Pitcher et al. 2015). These existing data, including fishing effort, had already been mapped to a common 0.01° (~1.11 km) grid and were re-used by this project.

The existing predicted large marine region (LMRs) assemblage maps (e.g. Ellis & Pitcher 2009abc, 2010, 2011; Pitcher et al. 2011), fishing effort data and closures information from these projects provided the basis for the assessments reported here. However, the specific purposes of the current project — i.e. assemblage maps that matched each fishery jurisdiction specifically (rather than the LMRs) to ensure that assessments were appropriate and valid to relevant stakeholders — required re-assembly of datasets and re-analysis. In addition, the earlier coarse-resolution NASA-sourced ocean colour data were updated with a higher resolution (0.01°) product provided by the Integrated Marine Observing System (IMOS); and a number of additional biological survey datasets were acquired and included in analyses. The assemblage maps provided meso-scale surrogates for habitats, given the lack of data for seabed habitats *per se* in most fisheries. Each assemblage represents an area expected to have a similar mix of species that differs from neighbouring assemblages and increasingly to more distant assemblages.

3.1 Datasets

3.1.1 Biological survey datasets

Many existing biological datasets (about 20) for large scale surveys suitable for the project were available from previous projects (e.g. collated the CERF Marine Hub *Prediction Program*, Pitcher et al. 2011, see Appendix 2). These primarily include fish trawls comprising mostly larger species of fishes. For parts of Australia, there are also prawn trawl surveys that include smaller species of fishes and mobile invertebrates. In some regions there were also epibenthic sled datasets that include mobile and sessile invertebrates. A few regions also had infaunal grab data (e.g. Gulf of Carpentaria).

Additional biological survey datasets collated recently and/or by this project include:

- Museum Victoria Bass Strait Survey (epibenthic sleds and grabs: Wilson & Poore 1987; O'Hara 2002);
- Western Australian Department of Fisheries Shark Bay and Exmouth Gulf Biodiversity survey (prawn trawls: Kangas et al. 2007);
- SARDI Eastern Great Australian Bight Benthic Protection Zone surveys (epibenthic sleds and grabs: Ward et al. 2003; Currie et al. 2007, 2008);
- CSIRO Western Australian Slope Voyage of Discovery (beam trawls, sleds & grabs: Alan Williams et al, unpubl.);
- Northern Territory Fisheries Groundfish Stock Survey, 1990 & 1992 (fish trawls: Ramm 1997).
- SET and GAB Fishery Independent Survey (FIS) datasets (Ian Knuckey et al. unpubl., Fishwell Consulting/AFMA).

These datasets were checked, cleaned and re-formatted to be compatible with existing survey datasets and with the analyses procedures.

A full list of biological survey datasets used by the project is shown in Appendix 3.

3.1.2 Mapped environmental predictors

About 26 environmental variables were collated and mapped at 0.01° for the Australian EEZ by the CERF Marine Biodiversity Hub, for the purpose of biodiversity distribution analysis and prediction (Huang et al. 2011; Pitcher et al. 2011; see variables #1–26 in Appendix 4). Subsequently, additional variables were collated (#27–40) as part of the CERF Hub Transition program (McLeod & Pitcher 2011) and/or the NERP Marine Hub (Pitcher et al. 2015). The original 0.1 degree seabed stress layer was replaced by higher resolution national data layer from the CSIRO 'Ribbon Model' (#8).

The Ocean Colour derived variables (#21–34, Appendix 4), originally from NASA sources at ~0.1 degree, were updated to higher resolution 0.01° products from IMOS for variables #21–30 (Appendix 4). From these, the data for the Australian EEZ were extracted and the 'climatological' annual average & seasonal range were calculated, as well as the further derived variables #31–34 (Appendix 4). Updated maps for these Ocean Colour variables are shown in Appendix 6.

A complete list of mapped environmental variables used by the project is shown in Appendix 4, including full definitions, abbreviations and sources.

3.1.3 Closures and Marine reserves

Data on SESSF permanent fishery closures, and Commonwealth Marine Reserves (CMRs), were largely available from previous recent projects (e.g. Pitcher et al. 2015). Additional data for closures (permanent only) in other Commonwealth fisheries (e.g. NPF, TSPF), and for other Marine Protected Areas, were collated by this project (see Appendix 5). All were mapped to the 0.01° 0–1500 m database and analysis grid to be used by this project (Figure 1).

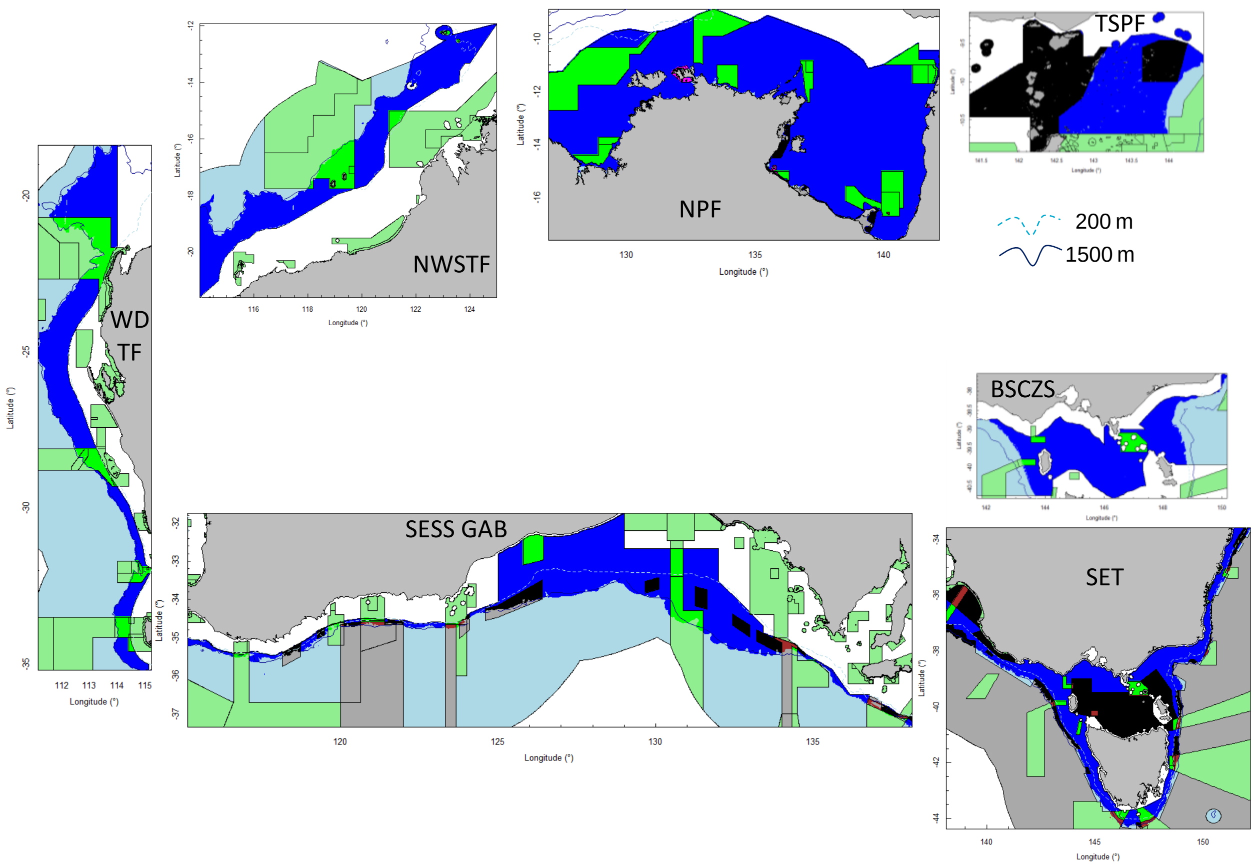


Figure 1 Commonwealth demersal fishery areas (blue), CMR's & MPA's (green) and closures (dark grey/black) for fish & prawn trawl and scallop dredge. Areas in-scope for study (<1500m/150m) in dark colours (blue, green, black, brown=CMR & Closure, magenta=MPA & Closure).

All CMRs were assumed to exclude trawling, as intended when boundaries were declared. We note that management plans within CMR boundaries (except southeast) are currently under review, and permitted activities within CMRs were not finalised during this project.

3.1.4 Trawl effort data

Data on annual trawl effort gridded at 0.01° were available from previous recent projects, where they were sourced from logbook records or VMS data, as available for each fishery (see Appendix 5), linear interpolated between tow start-end positions or successive trawl polls and aggregated to grids. For this project, effort data were extracted for each fishery for a recent period of 3–5 years, typically post-2007, to account for significant recent management changes in several fisheries. In all fisheries, trawl effort and footprints had been greater in previous years; however, only current effort levels were within the project scope. Effort in various metrics (hours, metres, number of tows, etc) were all converted to swept-area per grid-area ratio, to standardise for different gear sizes and tow speeds. The annual average for each grid was taken to define the typical spatial distribution of trawl intensity for recent years in each fishery. The effort data was joined to the gridded environmental variables for each fishery and mapped.

The current footprints for each fishery were estimated (Table 1). These show the total area of each fishery within the specified depth-range, the total area of 0.01° grid cells with trawling recorded in recent years, the total swept-area of all trawls annually, the footprint area accounting for overlapping effort in grid cells with swept-area ratio >1 assuming trawling is conducted uniformly at 0.01° scale, and the footprint area accounting for overlapping effort *within* grid cells assuming trawling is conducted randomly at sub-0.01° scale. The random <0.01° estimates the annual average footprint. However, among years the fine distribution of trawling at 10–100 m scales is not exactly the same, and over multiple years the footprint tends to approximate the uniform footprint. The estimated annual footprints range from <1% to ~8% of the managed area of each fishery within the specified depth range, whereas the multi-year footprints typically are about 25% larger. Both estimates account for the aggregated nature of trawling at ~1–10 km scales.

Table 1 Footprints (km²) of Commonwealth demersal trawl fisheries, for depth range 0–1500 m (or 0–150 m).

FISHERY	TOTAL GRID AREA	TOTAL WITH TRAWL	TOTAL SWEPT AREA	UNIFORM @ 0.01° (%)	RANDOM < 0.01° (%)
SET Fishery	227,255	71,633	33,403	21,356 (9.4)	17,312 (7.6)
NPF Fishery	749,629	67,949	19,913	15,012 (2.0)	12,175 (1.6)
GAB Fishery	157,335	24,218	10,195	7,745 (4.9)	6,042 (3.8)
TSPF Fishery (0–150m)	36,168	4,690	2,682	1,773 (4.9)	1,414 (3.9)
NWST Fishery	180,977	8,579	1,018	992 (0.5)	855 (0.5)
WDT Fishery	154,655	3,385	300	294 (0.2)	243 (0.2)
BSCZ Fishery (0–150m)	75,084	680	24	24 (<.1)	22 (<.1)

3.2 Analyses

The approach for producing the assemblage maps is now established; it involves quantifying the magnitude of change in species composition along environmental gradients (predictors) and using this information to predict distribution patterns of demersal biodiversity. The method, called “Gradient Forest" (Ellis et al. 2012), is an extension of Random Forest (Breiman 2001), which fits an ensemble of bootstrapped regression tree models (a ‘forest’ — of 500 trees in our case) between each individual species abundance and environmental variables. The many branches (or 'splits') in the tree models are fitted recursively along the environmental gradients at locations on variables where the most deviance in species response is explained (fit 'improvement'). Each tree is fitted to a different random sample of ~⅔ of the data (in-bag) and fit performance is tested on the ~⅓ of data held out-of-bag (OOB). The influence of each variable was assessed by randomly permuting each variable in turn and quantifying the degradation in prediction performance on the OOB data ('predictor importance'). Models were fitted for every species with adequate occurrence in every available biological survey dataset.

From the Random Forest models, Gradient Forest extracts each split value and deviance improvement. The split-improvements were aggregated and standardised by data density to quantify where species composition changes occurred along the gradients. Cumulative distributions of the splits on each predictor represent overall changes in the whole community, or compositional turnover, in standardised units of R^2 along the gradient of each predictor. These turnover curves are accumulated for the fishery region to provide empirical functions for transforming the multi-dimensional environmental gradients to common biologically-scaled axes that can be used to estimate the spatial pattern of species composition — or *assemblages* — associated with the environment and mapping in geographic space. Because these functions integrate biological information, they provide improved use of environmental variables as surrogates for predicting and mapping patterns of biodiversity. The method has been used to produce biodiversity and bioregional maps in Australia and overseas. Statistical details of Gradient Forest are described in Ellis et al. (2012), and example ecological applications are described in Pitcher et al. (2010, 2012); further information is available at http://r-forge.r-project.org/projects/gradientforest/.

After the multiple environmental gradients have all been transformed to a common biological scale, principal components analysis (PCA) is used to capture the majority of compositional variation associated with environmental gradients in as few dimensions as possible. A colour ramp is applied to the PCA ordination (e.g. red-green-blue in three dimensions, or a colour wheel around the first two dimensions) to allow visualisation of compositional patterns in 2-D PCA-space and in mapped geographic space. The visualisation in PCA-space may be called 'biological-space' — it is a 'bi-plot', with vectors showing the direction of the major environmental drivers, and provides a colour key for the corresponding geographic map to facilitate interpretation.

In this application, the continuous variation in composition in biological space was clustered to represent expected species-assemblage groups, which were also mapped in biological space and geographic space. Determining the most appropriate number of clusters, or predicted assemblages, for a region is non-exact — several guides have been trialled previously (Pitcher, Ellis & Dunstan 2011). This number should be guided by the original biological survey data as much as possible, although this is not straightforward for the case of several contributing surveys each having only partial coverage of a region. A two-step approach was taken. First, multivariate regression trees (MRT) were applied to each biological survey separately to obtain an objective number of clusters (i.e. terminal nodes) for sampled sites in each dataset by partitioning on environmental variables using cross-validation. The resulting number of terminal nodes sets a minimum constraint on the number of clusters in biological space; i.e. the number of clusters in the whole region must be sufficient to split each set of survey sites into at least the number of MRT terminal nodes. The second step assessed which regional clustering — over a plausible range of numbers of clusters — taken as a factor, accounted for most variation in the constituent biological survey datasets. This involved linking each candidate clustering back to the biological data using multivariate analysis of variance method (distance-based redundancy analysis, db-RDA, Legendre and Anderson 1999). The db-RDA provides a multivariate F-ratio test statistic, a large value of which would indicate evidence that a given clustering has captured structure in the survey sample data. The F-ratio for each survey in the region was obtained, and the geometric mean of these was used as the diagnostic. Subject to the step one minimum constraint, the clustering with the largest mean F-ratio was preferred on biological grounds.

3.3 Assessments

Each mapped assemblage provided the basic unit of assessment and after the assemblage maps and trawl effort & closures datasets were produced for each Commonwealth fishery jurisdiction, the quantitative overlap assessments comprised relatively straightforward spatial analyses. First, the various types of spatial management, including Commonwealth marine reserves, other marine protected areas, and fishery closures (Figure 1) were overlaid on the assemblage maps and the area of each mapped assemblage represented in each category of spatial management was quantified by area and as a percentage. Where possible, reserves were categorised using the IUCN framework. Second, the annual trawl footprint of each demersal fishery (see Table 1 ‘random’) was overlaid on the corresponding assemblage map, and the extent of footprint overlap on each assemblage was quantified by area and as a percentage. The multi-year footprint area (Table 1 ‘uniform’) was also estimated — these typically were about 25% larger than annual footprints. As an indicator of trawl effort intensity, the total swept area in each assemblage was also quantified by area and as a percentage. This information was tabulated for each assemblage in each fishery. The level of exposure of each assemblage to trawling, and protection in spatial management, was also plotted for each fishery in a format analogous to previous ERA presentations.

To provide an overall synthesis, all mapped assemblages were ordered by exposure to trawling and (inverse) overlap in fishery closures and reserves. This ordered list is provided to support prioritisation for AFMA decision making regarding the identity and requirement for any assemblages to be the focus of future ERAs for habitat.

The trawl footprint exposure of assemblages is an indicator of *potential* risk but is not directly an assessment of risk of trawl impacts on habitats *per se*. Where possible, for any assemblages that appeared to be of higher priority — if suitable information was available — the potential risk implications were discussed with reference to the impact/recovery attributes of the constituent habitat forming biota, similarly to previous qualitative habitat ERAs.

4 Results & Discussion

4.1 Analyses & assessments

Analyses of biological survey data, mapping of assemblages, and overlap assessments were completed for six Commonwealth trawl fisheries: SESS CTS (SET) and GAB, WDTF, NWSTF, NPF, TSPF, and the BSCZS dredge fishery (see Appendix 1).

4.1.1 South East Trawl Fishery region

In the SET region, 14 datasets contributed to the assemblage characterisation, comprising 8 fish trawl (including Fishery Independent Surveys, FIS), 4 benthic sled, 1 grab survey, and 1 aggregated video dataset. The combined information from these datasets provided functions for transforming the SET regional environment to a multi-dimensional biological space, and mapping in geographic space (Figure 2 inset). From this map of continuous compositional change, a set of assemblages were defined. While defining the appropriate number of assemblages for a region is non-exact, here a local '*optimum*' at 20 assemblages has been selected — based on the maximum F-ratio statistic for a multivariate analysis of variance method (see Methods) — and mapped (Figure 2).

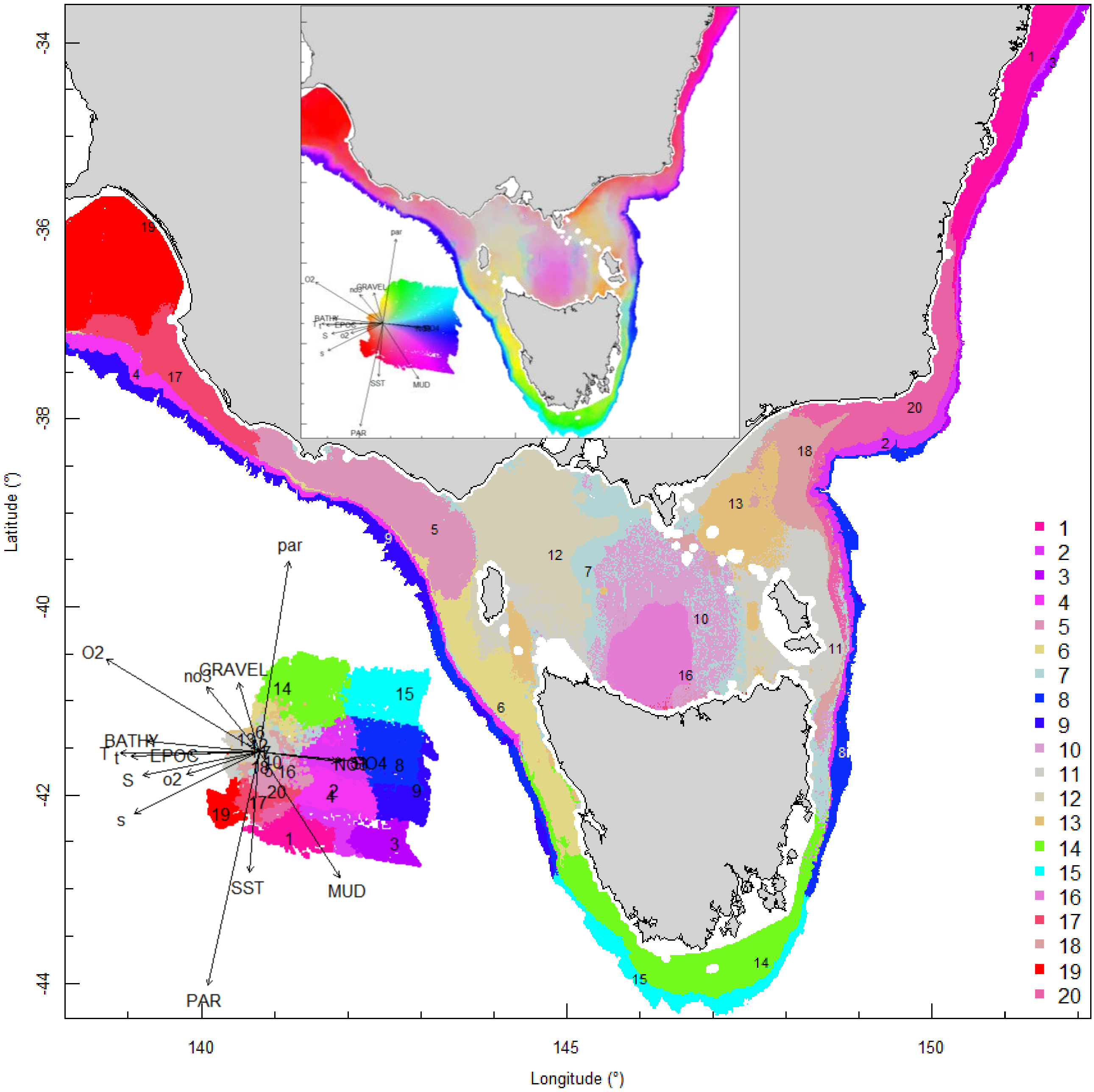


Figure 2 Map of the SET region showing patterns of species composition change predicted by relationships with multiple environmental gradients, clustered into 20 assemblages. The inset map shows continuous patterns of composition prior to clustering. The two biplots show the first 2 dimensions of the clustered multi-dimensional biological space, representing composition change in relation to vectors of the major environmental drivers.

The intersection of the mapped assemblages with CMRs & fishery closures, and with trawl effort was then estimated (Table 2). About 8.5% of the SET area (0–1500 m) is closed in CMRs, and 41.3% is trawl fishery closures — together, with overlaps, 46.7% is closed. In the case of trawl effort, trawl “Grounds” refers to the total area of 0.01° grid cells with any trawling recorded in recent years; “Uniform” refers to the trawl footprint area assuming trawling is conducted uniformly at 0.01° scale and such that overlapping effort in grid cells with swept-area ratio >1 is accounted for; “Random” is the footprint area accounting for overlapping effort *within* grid cells assuming trawling is conducted randomly at sub-0.01° scale; and “Trl swept” is the total swept area of trawling within each assemblage and is an indicator of the intensity of trawling on the trawl-exposed portion of each assemblage — typically, the exposed portions are trawled with an average intensity of about twice annually. The random area estimates the annual footprint of trawling at 7.7% across the entire region, whereas the uniform area estimates the multi-year footprint of trawling at 9.5%.

The percentage of each assemblage included in closed areas and that exposed to trawl footprint, as well as total swept area, are factors that influence the potential for habitat risk and hence the priority for future AFMA habitat ERAs. These are plotted in Figure 3. Note that area open and area of trawl footprint cannot sum to more than 100% of an assemblage, whereas total swept area could be greater than the open area of an assemblage (potentially >100%). The most exposed assemblage is Assemblage #20 on the shelf off southern NSW/eastern Victoria (Figure 2) with an annual footprint of 43.7% and total swept area of 76.3% suggesting an average intensity of ~1.75 trawls per year in exposed areas — it also has the least overlap in closed areas (0.9%). Other exposed assemblages include #4 on the slope off the Bonney Coast, followed by assemblages #1 on the NSW shelf and #2 on the outer shelf and slope beyond assemblage #20.

Table 2 Intersection of Assemblages by area, in the SET region, with CMRs and fishery closures (and both combined), and with trawl effort. Note, colours are simply to highlight relatively high & low numbers in each column, and do not imply any ‘traffic-light’ style ‘report card’ against particular benchmarks. Green indicates relatively high overlap in closed areas; Blue indicates relatively low overlap with trawling.

Assemblage	Grid count	Area(km²)	CMR_IA	CMR_II	CMR_VI	CMRs	% CMR	MPAs	Closures	%Closed	Any Clsd	Total%Clsd	Grounds	Uniform	Random	% Trawled	Trl Swept	% Swept
1	9,139	9,271			264	264	2.9	0	999	10.8	1,258	13.6	7,676	2,816	2,313	24.9	4,557	49.2
2	7,040	6,792		18	371	389	5.7	0	2,234	32.9	2,281	33.6	5,449	1,827	1,463	21.5	2,706	39.8
3	3,068	3,097			518	518	16.7	0	2,001	64.6	2,128	68.7	1,178	43	42	1.4	43	1.4
4	5,846	5,655			72	72	1.3	0	1,510	26.7	1,547	27.4	4,773	2,495	2,051	36.3	4,556	80.6
5	17,656	16,943			1,056	1,056	6.2	0	1,529	9.0	2,586	15.3	5,630	1,003	885	5.2	2,467	14.6
6	13,051	12,158		12	856	867	7.1	0	73	0.6	902	7.4	5,048	517	467	3.8	1,338	11.0
7	15,985	15,140		163	1,115	1,278	8.4	0	6,728	44.4	7,944	52.5	1,788	551	452	3.0	907	6.0
8	8,338	7,796	586	102	398	1,086	13.9	0	4,659	59.8	4,678	60.0	3,803	342	299	3.8	362	4.6
9	8,111	7,790			242	242	3.1	0	5,130	65.8	5,130	65.8	3,641	251	228	2.9	251	3.2
10	16,138	15,261		7	616	623	4.1	0	12,102	79.3	12,679	83.1	752	242	187	1.2	283	1.9
11	16,214	15,383			938	938	6.1	0	10,880	70.7	11,546	75.1	1,807	60	57	0.4	60	0.4
12	24,508	23,388			825	825	3.5	0	11,427	48.9	11,801	50.5	1,796	184	165	0.7	222	0.9
13	12,247	11,690			1,631	1,631	14.0	0	5,352	45.8	6,963	59.6	262	21	19	0.2	49	0.4
14	15,064	13,507	691	23	2,625	3,339	24.7	0	30	0.2	3,346	24.8	6,570	2,089	1,709	12.7	3,268	24.2
15	5,690	5,069	9		1,813	1,822	35.9	0	1,967	38.8	2,093	41.3	1,402	73	69	1.4	74	1.5
16	9,965	9,353				0	0.0	0	9,340	99.9	9,340	99.9	13	5	4	0.0	5	0.1
17	8,834	8,652				0	0.0	0	3,945	45.6	3,945	45.6	3,209	799	686	7.9	1,551	17.9
18	9,116	8,761			601	601	6.9	0	1,204	13.7	1,768	20.2	4,653	748	629	7.2	963	11.0
19	17,471	17,367			3,583	3,583	20.6	0	12,150	70.0	13,522	77.9	186	3	3	0.0	3	0.0
20	13,319	12,970			13	13	0.1	0	112	0.9	122	0.9	12,112	7,386	5,665	43.7	9,899	76.3
	236,800	**226,043**	**1,286**	**326**	**17,537**	**19,148**	**8.5**	**0**	**93,372**	**41.3**	**105,579**	**46.7**	**71,747**	**21,456**	**17,393**	**7.7**	**33,565**	**14.8**

Recent studies (e.g. Williams et al. 2006 & 2009) have indicated that vulnerable habitat-forming benthos types are present in these more exposed assemblages. For example, sub-cropping friable sandstone supporting gardens of large sponges are restricted within a few exposed mid-shelf assemblages; aggregations of the relict stalked crinoid *Metacrinus cyaneus* are restricted within a few exposed shelf-break assemblages; a ribbon of delicate bryozoan communities occur in a limited depth range within many shelf-edge assemblages, some of which are exposed; and tree-forming octocorals and black corals are restricted to high flow, steep banks in upper-slope assemblages, some of which are exposed. These vulnerable types occur in places potentially accessible to and removable by trawls and may be at risk (Williams et al. 2011) at least locally within assemblages, if not at regional landscape scale (Pitcher et al. 2015).

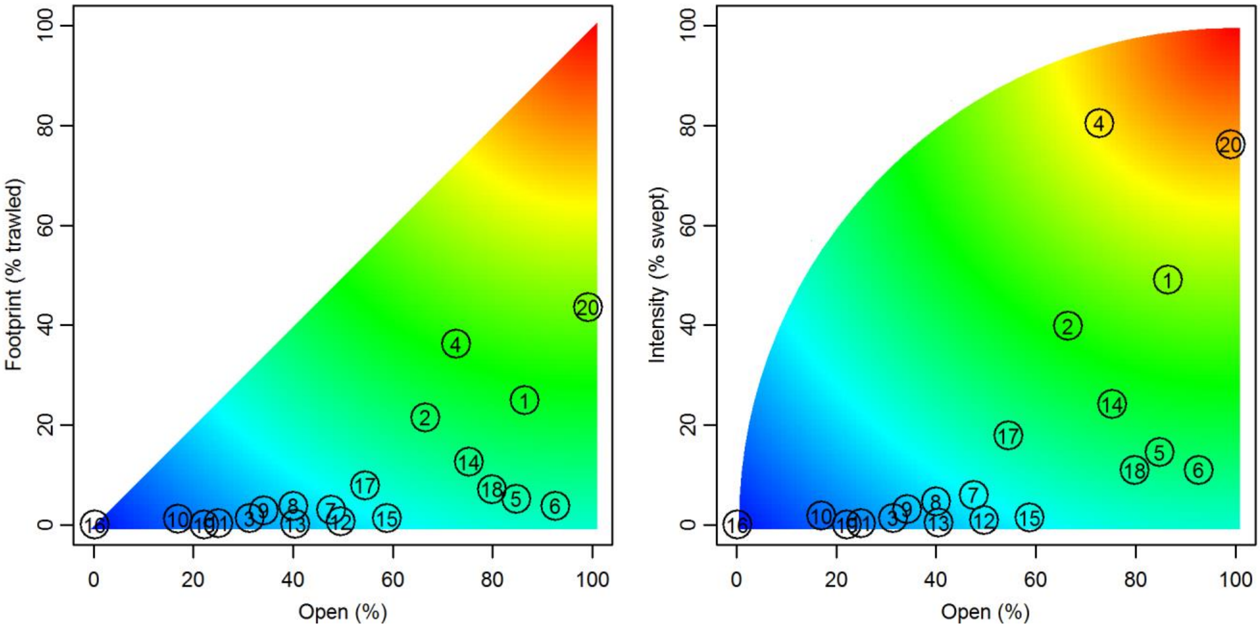


Figure 3 Plot of percentage of area of each assemblage open to potential trawling against exposure to actual effort as trawl footprint and swept intensity in the SET; diagrammatically illustrating potential for habitat risk and relative priority for habitat ERA. Note, background colours are simply to highlight relative exposure and do not imply absolute risk.

4.1.2 Great Australian Bight Trawl Fishery region

For the GAB region, 10 survey datasets contributed to the bio-physical characterisation, including 5 trawl (including FIS), 3 epibenthic sled, and 2 grab surveys. Analyses of these datasets provided transformation functions for mapping the GAB regional environment as predicted patterns of assemblages, and 13 assemblages were defined as an approximate local 'optimum' (see Figure 4).

The intersection of GAB assemblages with CMRs & fishery closures, and with trawl effort is shown in Table 3. About 12.3% of the GAB area (0–1500 m) is closed in CMRs, and 11.2% is trawl fishery closures — together, with overlaps, 21.9% is closed. The annual footprint of the GAB trawl fishery is 3.8% (random within 0.01° cells), and the multi-year footprint is ~4.9% (uniform within cells). Assemblage #8, along the shelf-edge/upper slope, is notably more exposed to trawling (~34% annually; ~59% swept ⇒ average intensity ~1.74) than all others (Figure 5). These exposure estimates are indicative of the relative potential for habitat risk within assemblages, and hence also the relative priority need for future AFMA habitat ERAs. Within assemblage #8, vulnerable habitat-forming benthos types do occur and are likely to be at risk where trawling occurs (Williams et al. 2011), but actual risk at larger scale remains to be assessed quantitatively.

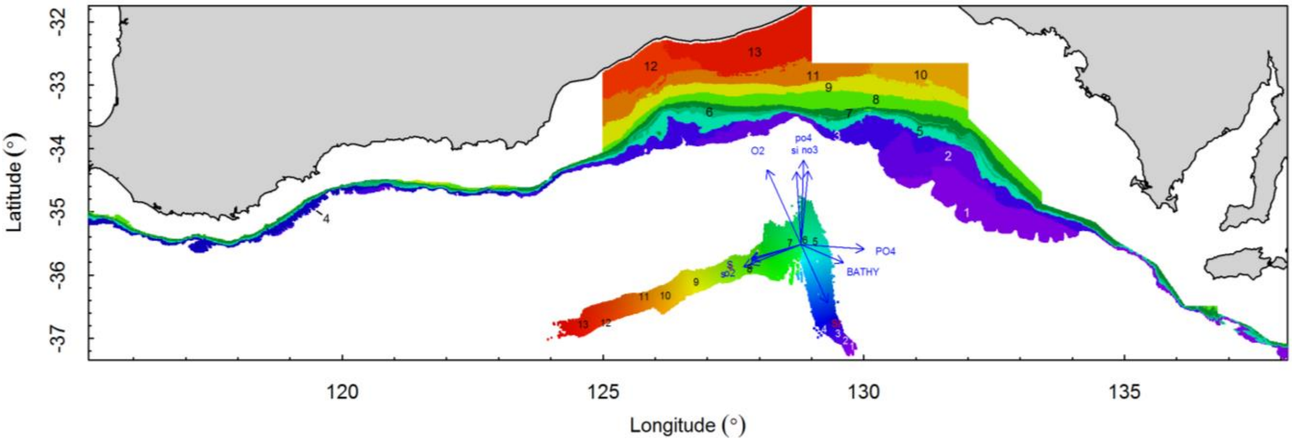


Figure 4 Map of the GAB region showing clustered patterns of species composition change predicted by relationships with multiple environmental gradients. The biplot shows the first 2 dimensions of the clustered multi-dimensional biological space, representing composition change in relation to vectors of the major environmental drivers. The clustering of the biological space suggests 13 assemblages.

Table 3 Intersection of Assemblages by area, in the GAB region with CMRs and fishery closures (and both combined), and with trawl effort.

Assemblage	Grid count	Area(km²)	CMR_?	CMR_II	CMR_VI	CMRs	% CMR	MPAs	Closures	%Closed	Any Clsd	Total%Clsd	Grounds	Uniform	Random	% Trawled	Trl Swept	% Swept
1	15,353	15,509	1,943		299	2,242	14.5	0	1,713	11.0	3,699	23.9	155	4	4	0.0	4	0.0
2	12,702	12,994	3,346		102	3,448	26.5	0	1,038	8.0	4,385	33.7	144	2	2	0.0	2	0.0
3	15,523	15,870	1,358	252	165	1,775	11.2	0	7,254	45.7	8,285	52.2	353	20	17	0.1	28	0.2
4	5,184	5,239		248	674	922	17.6	0	1,417	27.0	1,997	38.1	34	5	4	0.1	6	0.1
5	12,405	12,677	561	160	306	1,026	8.1	0	3,941	31.1	4,539	35.8	902	30	28	0.2	30	0.2
6	6,928	7,077	177	74	523	773	10.9	0	783	11.1	1,362	19.2	1,542	75	71	1.0	75	1.1
7	13,593	13,886	845	116	507	1,468	10.6	0	1,452	10.5	2,315	16.7	4,480	281	253	1.8	281	2.0
8	15,814	16,280	850	5	46	901	5.5	0	32	0.2	932	5.7	13,545	7,183	5,533	34.0	9,623	59.1
9	14,468	14,953	991	6	6	1,004	6.7	0	0	0.0	1,004	6.7	2,427	131	114	0.8	131	0.9
10	5,977	6,201	1,134			1,134	18.3	0	0	0.0	1,134	18.3	118	2	2	0.0	2	0.0
11	12,300	12,744		783		783	6.1	0	0	0.0	783	6.1	313	6	6	0.0	6	0.0
12	7,776	8,073		3,320		3,320	41.1	0	0	0.0	3,320	41.1	1	1	0	0.0	1	0.0
13	15,028	15,664		596		596	3.8	0	0	0.0	596	3.8	0	0	0	0.0	0	0.0
	153,051	**157,167**	**11,206**	**5,560**	**2,628**	**19,394**	**12.3**	**0**	**17,631**	**11.2**	**34,351**	**21.9**	**24,014**	**7,738**	**6,035**	**3.8**	**10,188**	**6.5**

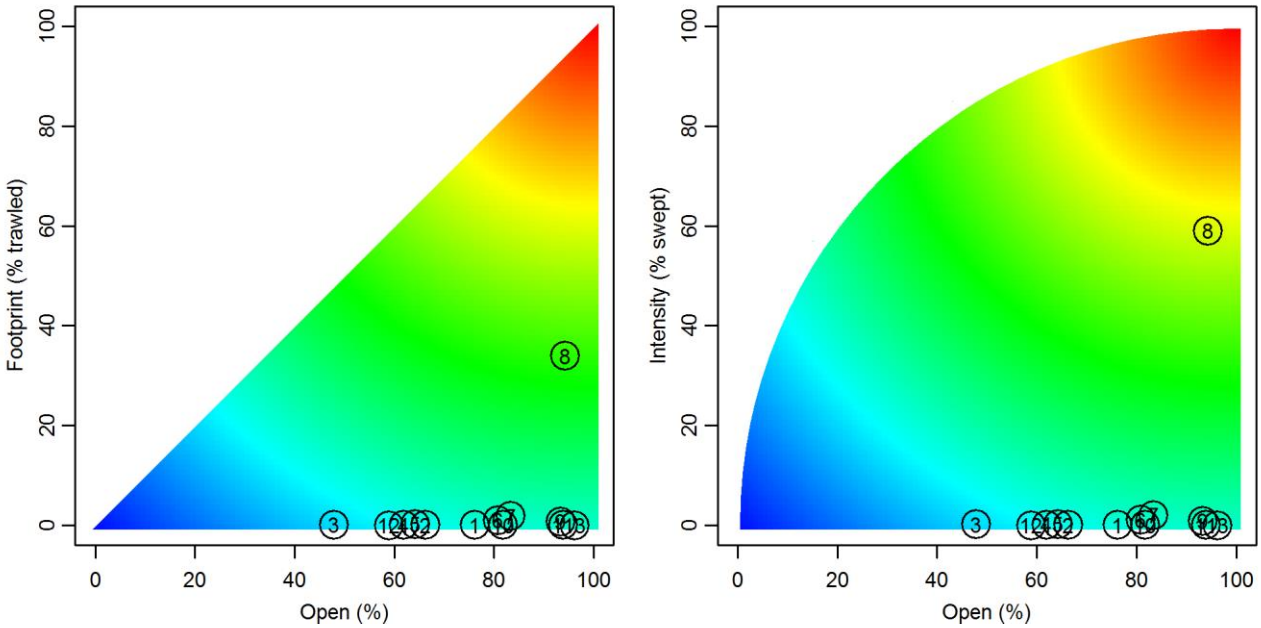
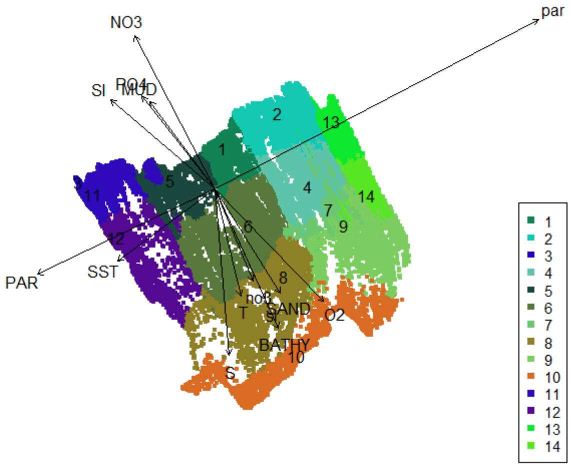


Figure 5 Plot of percentage of area of each assemblage open to potential trawling against exposure to actual effort as trawl footprint and swept intensity in the GAB. Note, background colours are simply to highlight relative exposure and do not imply absolute risk.

4.1.3 Western Deepwater Trawl Fishery region

In the WDT region, 10 survey datasets contributed to the bio-physical characterisation, including 2 fish trawl, 1 beam trawl, 1 prawn trawl, 1 epibenthic sled, and 1 grab survey. Information from these datasets provided transformation functions for mapping the WDT regional environment as predicted patterns of assemblages. Fourteen assemblages were defined as an approximate local 'optimum' (see Figure 6).



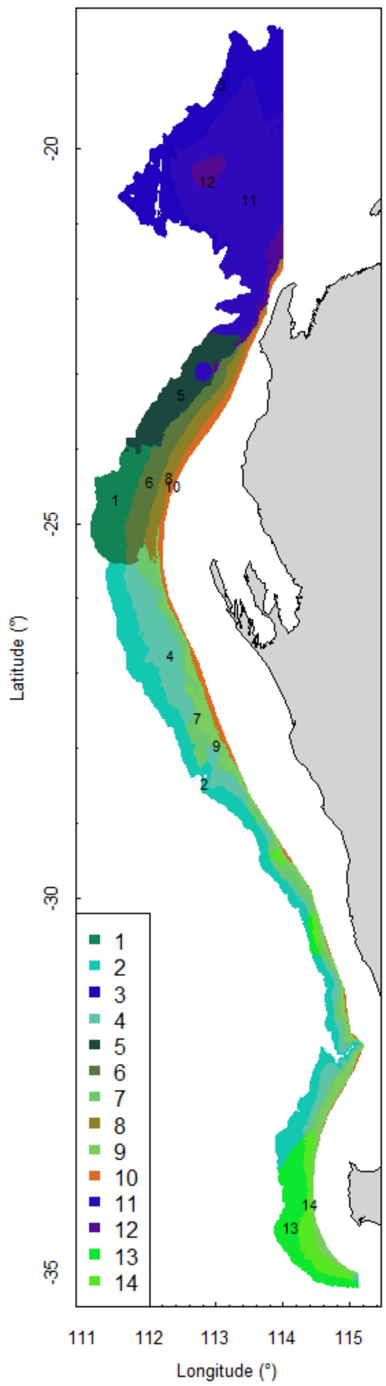


Figure 6 Map of the WDT region showing clustered patterns of species composition change predicted by relationships with multiple environmental gradients. The biplot shows the first 2 dimensions of the clustered multi-dimensional biological space, representing composition change in relation to vectors of the major environmental drivers. The clustering of the biological space suggests 14 assemblages.

The intersection of WDT assemblages with CMRs & fishery closures, and with trawl effort is shown in Table 4.

Table 4 Intersection of Assemblages by area, in the WDT region with CMRs and fishery closures (and both combined), and with trawl effort.

Assemblage	Grid count	Area(km²)	CMR_IA	CMR_II	CMR_VI	CMRs	% CMR	MPAs	Closures	%Closed	Any Clsd	Total%Clsd	Grounds	Uniform	Random	% Trawled	Trl Swept	% Swept
1	7,588	8,509				0	0.0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0
2	17,659	19,053	794	244	3,113	4,151	21.8	0	0	0.0	4,151	21.8	112	2	2	0.0	2	0.0
3	17,170	19,950			3,574	3,574	17.9	0	0	0.0	3,574	17.9	0	0	0	0.0	0	0.0
4	12,403	13,509	138	127	2,477	2,742	20.3	0	0	0.0	2,742	20.3	105	2	2	0.0	2	0.0
5	7,457	8,461			1,121	1,121	13.2	0	0	0.0	1,121	13.2	35	1	1	0.0	1	0.0
6	7,270	8,186			46	46	0.6	0	0	0.0	46	0.6	11	0	0	0.0	0	0.0
7	6,893	7,481	134		971	1,105	14.8	0	0	0.0	1,105	14.8	81	2	2	0.0	2	0.0
8	5,267	5,942	129		364	493	8.3	0	0	0.0	493	8.3	387	9	9	0.2	9	0.2
9	7,814	8,355	84		1,438	1,522	18.2	0	0	0.0	1,522	18.2	742	103	82	1.0	107	1.3
10	4,220	4,709	277		399	676	14.4	0	0	0.0	676	14.4	1,625	165	136	2.9	167	3.6
11	30,188	34,872			13,439	13,439	38.5	0	0	0.0	13,439	38.5	22	1	1	0.0	1	0.0
12	3,436	3,958	108		742	850	21.5	0	0	0.0	850	21.5	0	0	0	0.0	0	0.0
13	6,797	6,960			2,438	2,438	35.0	0	0	0.0	2,438	35.0	0	0	0	0.0	0	0.0
14	4,205	4,316	170		837	1,007	23.3	0	0	0.0	1,007	23.3	23	1	1	0.0	1	0.0
	138,367	**154,260**	**1,834**	**371**	**30,958**	**33,163**	**21.5**	**0**	**0**	**0.0**	**33,163**	**21.5**	**3,143**	**287**	**237**	**0.2**	**293**	**0.2**

About 21.5% of the WDT area (0–1500 m) is closed in CMRs, and none is closed under fishery regulation — so the total is 21.5% closed. The annual footprint of the WDT trawl fishery is 0.16% overall, and the multi-year footprint is ~0.19%, with most trawling along the shelf-edge/upper slope in assemblage ‘10’ (Figure 7). Compared with other Commonwealth fisheries, these estimates are indicative of relatively low potential for habitat risk and priority for future AFMA habitat ERAs.

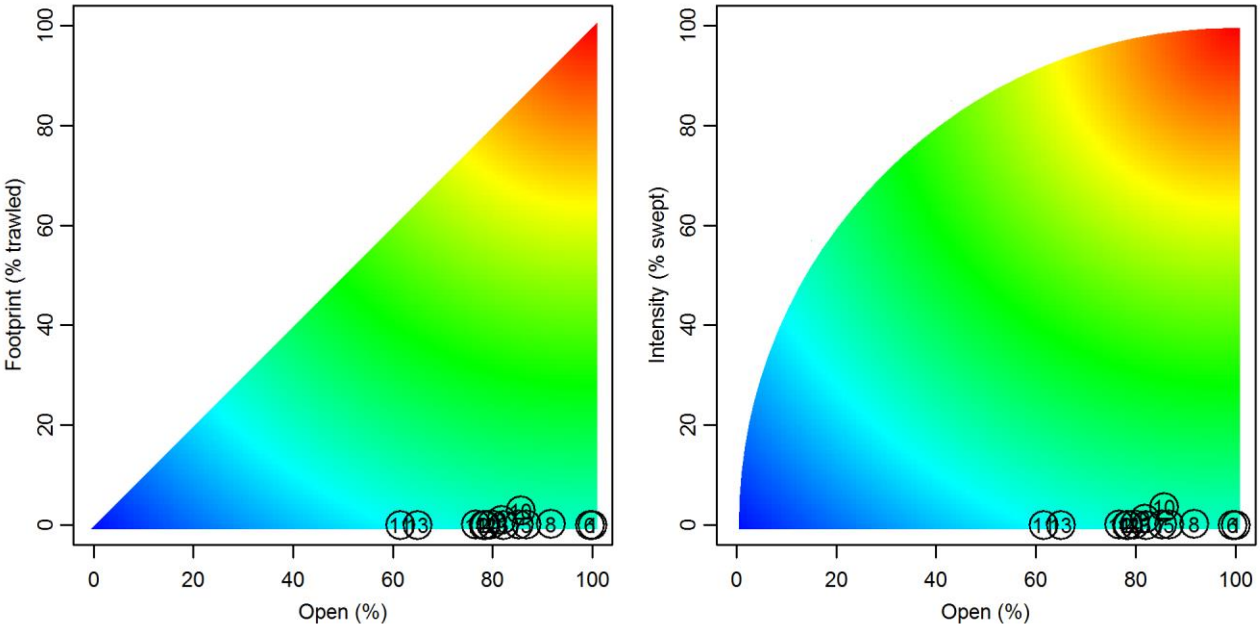


Figure 7 Plot of percentage of area of each assemblage open to potential trawling against exposure to actual effort as trawl footprint and swept intensity in the WDT.

4.1.4 Northwest Slope Trawl Fishery region

In the NWS region, 10 survey datasets contributed to the bio-physical characterisation, including 7 fish trawl, 1 beam trawl, 1 epibenthic sled, and 1 grab survey. Information from these datasets provided transformation functions for mapping the NWSF regional environment as predicted patterns of assemblages. Twenty one assemblages were defined as an approximate local ‘optimum’ (see Figure 8).

The intersection of NWS assemblages with CMRs, MPAs & fishery closures, and with trawl effort is shown in Table 5. About 12.1% of the NWS area (0–1500 m) is closed in CMRs, none in MPAs or under fishery regulation — the total closed is 12.1%. The annual footprint of the NWS trawl fishery is 0.47% overall, and the multi-year footprint is ~0.54%, with the trawling that does occur primarily located below the shelf break in assemblages ‘5’ and ‘8’ (Figure 9). These footprints are indicative of relatively low potential for habitat risk and priority for future AFMA habitat ERAs compared with other fisheries.

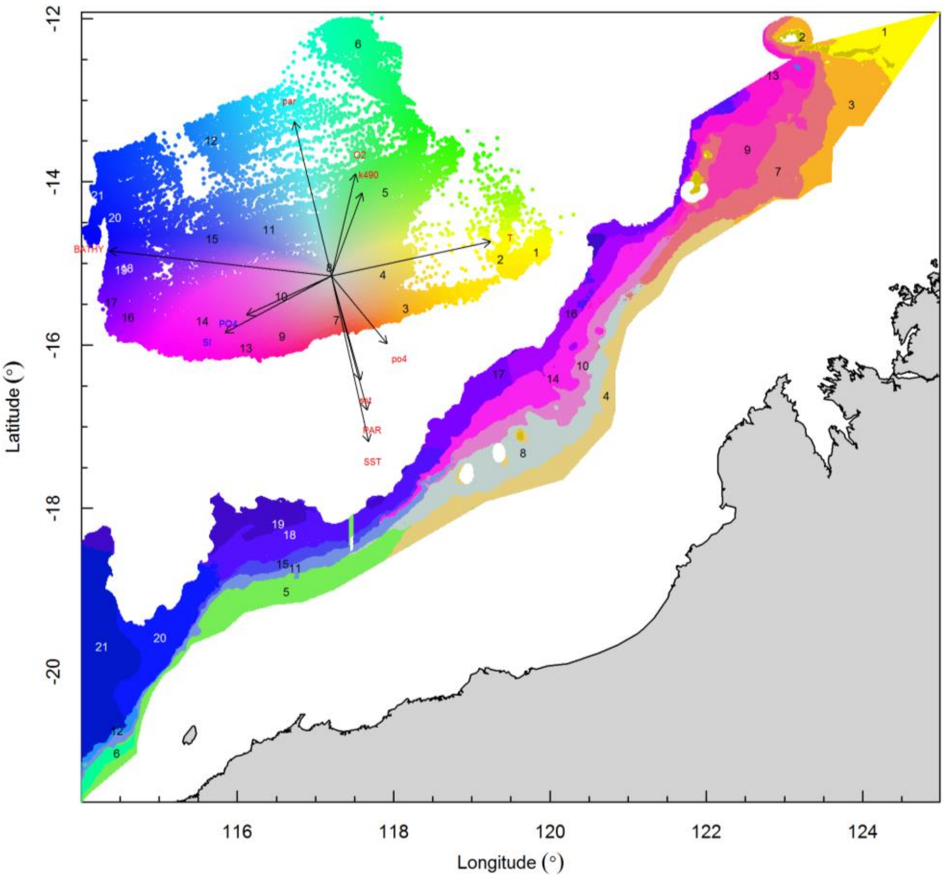


Figure 8 Map of the NWST region showing clustered patterns of species composition change predicted by relationships with multiple environmental gradients. The biplot shows the first 2 dimensions of the clustered multi-dimensional biological space, representing composition change in relation to vectors of the major environmental drivers. The clustering of the biological space suggests 21 assemblages.

Table 5 Intersection of Assemblages by area, in the NWST region with CMRs and fishery closures (and both combined), and with trawl effort.

Assemblage	Grid count	Area(km²)	CMR_IA	CMR_II	CMR_VI	CMRs	% CMR	MPAs	Closures	%Closed	Any Clsd	Total%Clsd	Grounds	Uniform	Random	% Trawled	Trl Swept	% Swept
1	4,836	5,834	19	27		46	0.8	0	0	0.0	46	0.8	538	25	24	0.4	25	0.4
2	1,225	1,474	94	261		354	24.0	0	0	0.0	354	24.0	12	0	0	0.0	0	0.0
3	8,901	10,705	197	40		236	2.2	0	0	0.0	236	2.2	25	1	1	0.0	1	0.0
4	11,725	13,857	116	1	2,540	2,657	19.2	0	0	0.0	2,657	19.2	250	21	20	0.1	21	0.2
5	10,628	12,390	2		4	6	0.0	0	0	0.0	6	0.0	1,519	316	256	2.1	342	2.8
6	1,306	1,504				0	0.0	0	0	0.0	0	0.0	40	1	1	0.1	1	0.1
7	13,039	15,637	14		594	608	3.9	0	0	0.0	608	3.9	298	22	21	0.1	22	0.1
8	11,924	14,066	253		4,064	4,316	30.7	0	0	0.0	4,316	30.7	2,839	375	328	2.3	375	2.7
9	8,627	10,354				0	0.0	0	0	0.0	0	0.0	126	3	3	0.0	3	0.0
10	7,263	8,603	35		2,788	2,824	32.8	0	0	0.0	2,824	32.8	1,449	144	126	1.5	144	1.7
11	4,920	5,744			16	16	0.3	0	0	0.0	16	0.3	881	68	62	1.1	68	1.2
12	818	947				0	0.0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0
13	5,562	6,689				0	0.0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0
14	10,743	12,740			3,697	3,697	29.0	0	0	0.0	3,697	29.0	146	3	3	0.0	3	0.0
15	2,730	3,195				0	0.0	0	0	0.0	0	0.0	40	1	1	0.0	1	0.0
16	5,534	6,587			938	938	14.2	0	0	0.0	938	14.2	0	0	0	0.0	0	0.0
17	6,803	8,080			5,251	5,251	65.0	0	0	0.0	5,251	65.0	24	0	0	0.0	0	0.0
18	9,577	11,250			850	850	7.6	0	0	0.0	850	7.6	229	5	5	0.0	5	0.0
19	6,115	7,184			60	60	0.8	0	0	0.0	60	0.8	4	1	1	0.0	1	0.0
20	7,984	9,289				0	0.0	0	0	0.0	0	0.0	2	0	0	0.0	0	0.0
21	11,988	13,929				0	0.0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0
	152,248	**180,057**	**730**	**328**	**20,803**	**21,861**	**12.1**	**0**	**0**	**0.0**	**21,861**	**12.1**	**8,423**	**987**	**851**	**0.5**	**1,013**	**0.6**

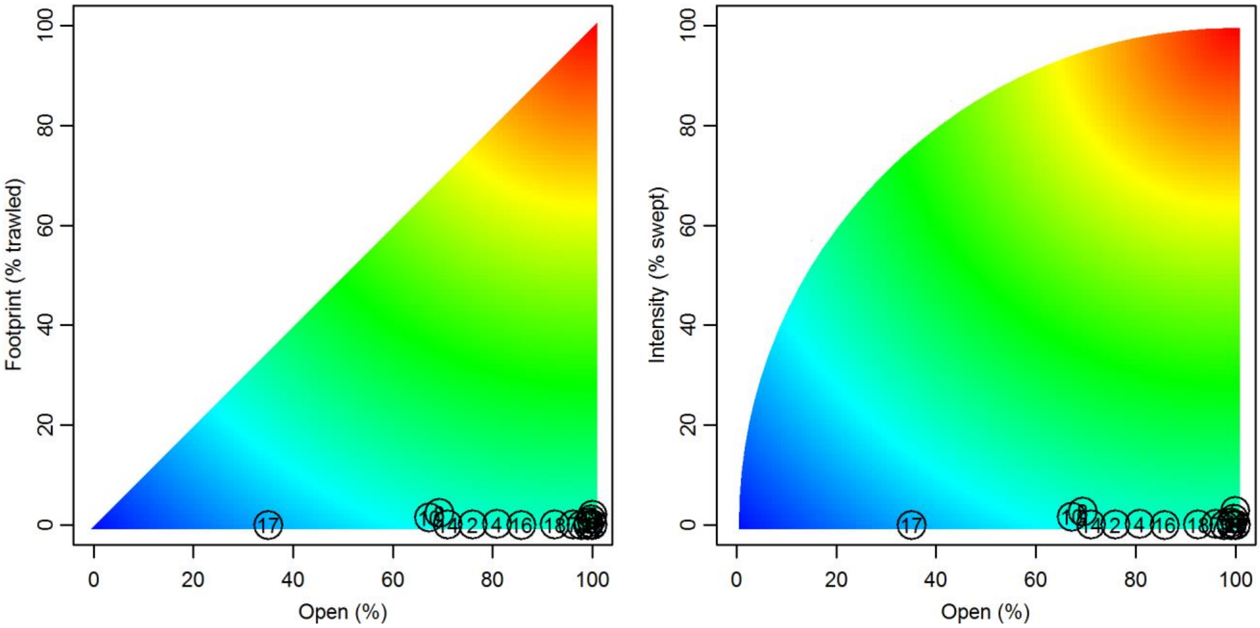


Figure 9 Plot of percentage of area of each assemblage open to potential trawling against exposure to actual effort as trawl footprint and swept intensity in the NWST.

4.1.5 Northern Prawn Fishery region

In the NPF region, 12 survey datasets contributed to the bio-physical characterisation, including 5 fish trawl, 2 prawn trawl, 4 epibenthic sled, and 1 grab survey. Information from these datasets provided transformation functions for mapping the NPF regional environment as predicted patterns of assemblages. Twenty two assemblages were defined as an approximate local 'optimum' (see Figure 10).

The intersection of NPF assemblages with CMRs, MPAs & fishery closures, and with trawl effort is shown in Table 6. About 19.6% of the NPF area (0–150 m) is closed in CMRs, ~0.2% in MPAs and ~0.7% under fishery regulation — the total closed is 20.5%. The annual footprint of the NPF trawl fishery is 1.6% overall, and the multi-year footprint is ~2%. Most trawling occurs around the perimeter of the Gulf of Carpentaria in assemblages '9' & '2' (Figure 11), with footprints of 13% & 5.7% trawled annually, total swept areas of 24.7% & 7.9%, and hence average intensities of about 1.9 & 1.4 trawls per year, respectively. Other assemblages with notable area of trawling include assemblage '14' across Arnhem Land, and parts of assemblage '10' in the western gulf (Table 6). These footprint and closures estimates, in comparison with other fisheries, are indicative of the relative potential for habitat risk and priority for future AFMA habitat ERAs.

At least two surveys have sampled benthos in parts of the Gulf of Carpentaria overlapping the more exposed assemblages and several others (e.g. SS1990-03: Long et al. 1995; and SS2005-03: Bustamante et al. 2011). These indicate that vulnerable habitat-forming benthos — including bryozoans, corals sponges, gorgonians, anemones and ascidians — are present in these more exposed assemblages. Many of these taxa have consistently higher abundances in Assemblage #2 — which has the largest area of grounds though trawled at lower intensity (Table 6) — than in other sampled assemblages. In Assemblage #9 — which has the largest swept area and highest intensity trawling, and relatively low inclusion in closed areas (Table 6) — the mean abundance of habitat-forming benthos is low compared with other sampled assemblages, although gorgonians and bryozoans are present and they and some others do occur patchily at high abundance. These vulnerable types occur in places potentially accessible to and removable by trawls and may be at risk at least locally within assemblages, if not at regional landscape scale. They have also been shown to be negatively related to trawl intensity along trawl effort gradients, suggesting that there may have been depletion impacts by repetitive trawling at local scales (Bustamante et al. 2011). Nevertheless, the actual risk and vulnerability of these habitat-forming benthos is not currently clear. At a larger landscape scale, some of these benthos may be more widely distributed in areas where prawn trawling does not occur, although corals and anemones and most bryozoans appear to be restricted to assemblage #2.

As part of MSC V2, the NPF will be required to estimate the percentage of each Vulnerable Marine Ecosystem (VME) type, including habitat-forming benthos, that has been affected by trawling compared to their un-impacted levels (i.e. the reduction in habitat due to trawling), and the time needed for recovery. The MSC requirement is that a VME habitat will not be reduced to a state below 80% of the un-impacted level. With further work, including predictive distribution modelling and estimating landscape scale status, the available data are sufficient to make a preliminary assessment of the MSC requirement. However, substantial areas of the NPF have not been sampled for habitat-forming benthos and further surveys may be necessary to cover the entire region and possibly also even in the Gulf of Carpentaria if assessment uncertainty in that area needs to be reduced.

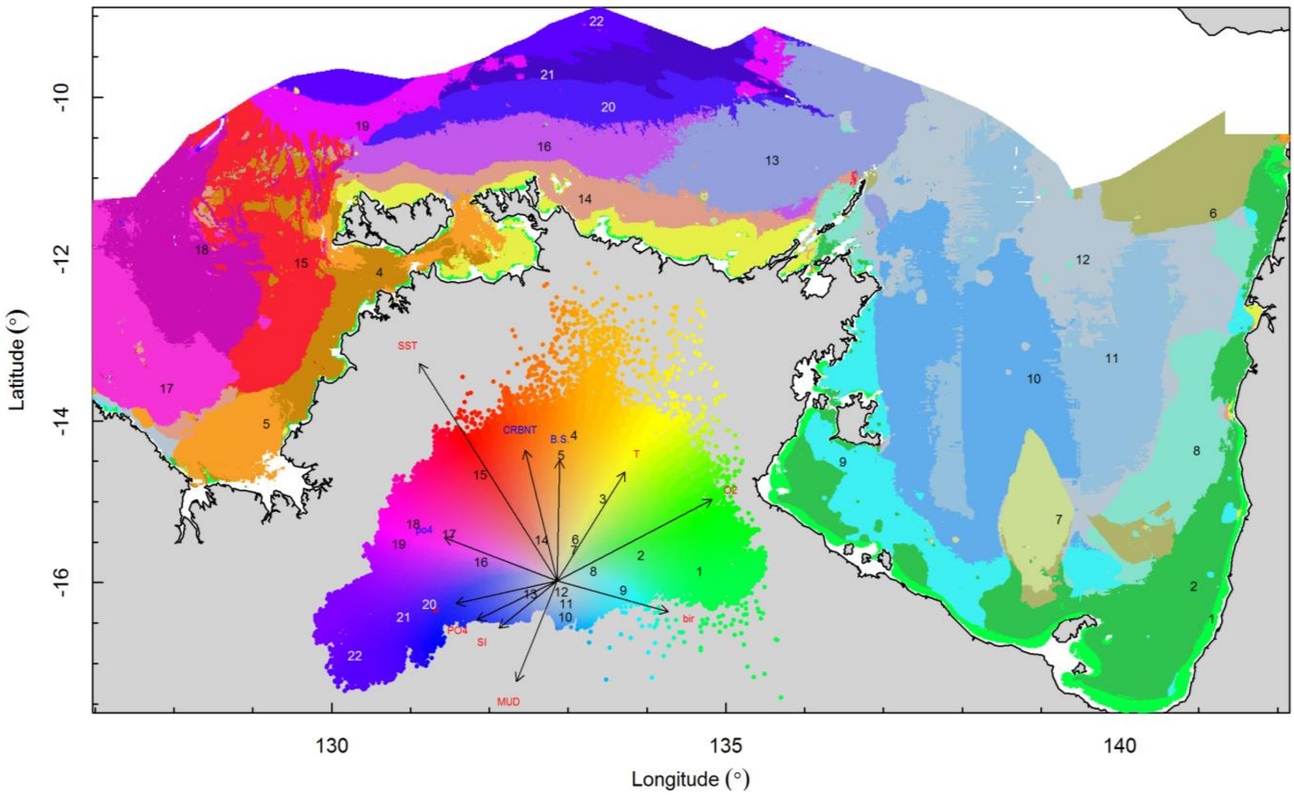


Figure 10 Map of the NPF region showing clustered patterns of species composition change predicted by relationships with multiple environmental gradients. The biplot shows the first 2 dimensions of the clustered multi-dimensional biological space, representing composition change in relation to vectors of the major environmental drivers. The clustering of the biological space suggests 22 assemblages.

Table 6 Intersection of Assemblages by area, in the NPF region with CMRs, MPAs and fishery closures (and both combined), and with trawl effort.

Assemblage	Grid count	Area(km²)	CMR_?	CMR_II	CMR_VI	CMRs	% CMR	MPAs	Closures	%Closed	Any Clsd	Total%Clsd	Grounds	Uniform	Random	% Trawled	Trl Swept	% Swept
1	13,698	16,306	107	183	423	713	4.4	604	2,464	15.1	3,687	22.6	1,870	183	156	1.0	194	1.2
2	50,011	59,520	30	7,074	8,785	15,889	26.7	73	1,525	2.6	17,396	29.2	22,374	4,109	3,375	5.7	4,715	7.9
3	17,719	21,421	2,098			2,098	9.8	725	29	0.1	2,843	13.3	4,759	777	637	3.0	881	4.1
4	16,232	19,572	4,508			4,508	23.0	0	216	1.1	4,724	24.1	2,240	405	328	1.7	551	2.8
5	16,987	20,402	7,457			7,457	36.5	45	75	0.4	7,576	37.1	1,497	126	107	0.5	138	0.7
6	25,486	30,760	854	10,453	5,782	17,090	55.6	0	12	0.0	17,102	55.6	196	26	21	0.1	31	0.1
7	11,688	13,934	5		1,977	1,982	14.2	0	0	0.0	1,982	14.2	75	6	5	0.0	9	0.1
8	27,804	33,338		1,827	3,164	4,991	15.0	0	0	0.0	4,991	15.0	3,836	630	509	1.5	681	2.0
9	28,363	33,846	2	579	819	1,400	4.1	0	1,008	3.0	2,408	7.1	17,297	5,492	4,409	13.0	8,346	24.7
10	64,800	77,804		98	1,999	2,097	2.7	0	0	0.0	2,097	2.7	2,904	928	754	1.0	1,510	1.9
11	49,485	59,536		73	21	93	0.2	0	0	0.0	93	0.2	22	0	0	0.0	0	0.0
12	54,801	66,193	44	2,206	1,249	3,499	5.3	1	0	0.0	3,500	5.3	1,675	477	384	0.6	627	0.9
13	40,914	49,670	880	31	792	1,703	3.4	0	0	0.0	1,703	3.4	19	0	0	0.0	0	0.0
14	19,786	23,942	5,919		6	5,925	24.7	65	0	0.0	5,990	25.0	5,230	1,199	951	4.0	1,347	5.6
15	31,569	38,150	17,280		1	17,281	45.3	0	1	0.0	17,283	45.3	104	8	6	0.0	13	0.0
16	23,415	28,415	2,867		11	2,878	10.1	0	0	0.0	2,878	10.1	81	1	1	0.0	1	0.0
17	22,963	27,622	641		6,459	7,100	25.7	0	0	0.0	7,100	25.7	2,751	482	395	1.4	629	2.3
18	30,612	36,978	17,198		3,926	21,124	57.1	0	0	0.0	21,124	57.1	0	0	0	0.0	0	0.0
19	14,817	18,015	5,138			5,138	28.5	0	0	0.0	5,138	28.5	0	0	0	0.0	0	0.0
20	20,801	25,289	3,367		44	3,411	13.5	0	0	0.0	3,411	13.5	0	0	0	0.0	0	0.0
21	14,904	18,144	9,608			9,608	53.0	0	0	0.0	9,608	53.0	0	0	0	0.0	0	0.0
22	11,546	14,060	7,440			7,440	52.9	0	0	0.0	7,440	52.9	0	0	0	0.0	0	0.0
	608,401	**732,919**	**85,444**	**22,525**	**35,457**	**143,426**	**19.6**	**1,513**	**5,330**	**0.7**	**150,075**	**20.5**	**66,931**	**14,849**	**12,040**	**1.6**	**19,673**	**2.7**

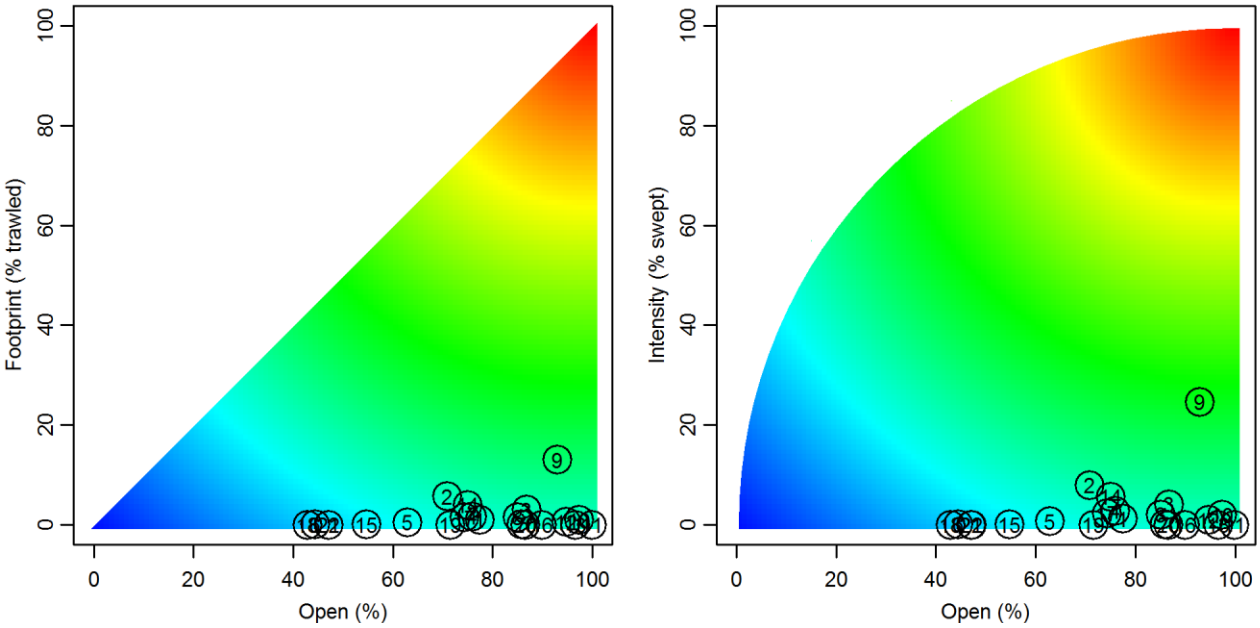


Figure 11 Plot of percentage of area of each assemblage open to potential trawling against exposure to actual effort as trawl footprint and swept intensity in the NPF.

4.1.6 Torres Strait Prawn Fishery region

The environmental sustainability of the Torres Strait Prawn Fishery has twice previously been comprehensively assessed in detail (Pitcher et al. 2007b; Pitcher 2013), including for assemblages, biogenic habitats and level-3 ERA for bycatch fish and benthic invertebrate species. For consistency, the (different) assemblage approach applied herein to the other Commonwealth trawl fisheries was also applied to the TSPF.

Four survey datasets contributed to the bio-physical characterisation of the TSPF region, including 1 prawn trawl with bycatch, 1 epibenthic sled, 3 video (1 'species' counts; 2 habitat), and several legacy habitat datasets from combined sources including diver surveys and video. As above, information from these datasets provided transformation functions for mapping the TSPF regional environment as predicted patterns of assemblages. Five assemblages were defined as an approximate local '*optimum*' (see Figure 12).

The intersection of TSPF assemblages with CMRs & fishery closures, and with prawn trawl effort is shown in Table 7. There are no CMRs in Torres Strait; nevertheless large areas (53%) of the region are closed to trawling. The overall annual footprint of the TSPF is 4.3%, and the multi-year footprint is ~5.4%. Assemblage #2 is the most exposed, having an annual footprint of 12.7%, total swept area of 24.6% (Figure 13), and average intensity of ~1.94 trawls per year.

The potential for habitat (and species) risk has twice previously been assessed in detail (Pitcher et al. 2007b; Pitcher 2013), and comprehensive information is available for the distribution of habitat-forming biota, other invertebrate species and fishes. These studies show that habitat-forming biota are primarily distributed in areas where prawn trawling does not occur (e.g. assemblages 3 & 4) and the previous level-3 ERAs showed that no types of habitat-forming species were at sustainability risk in 2005 or 2011.

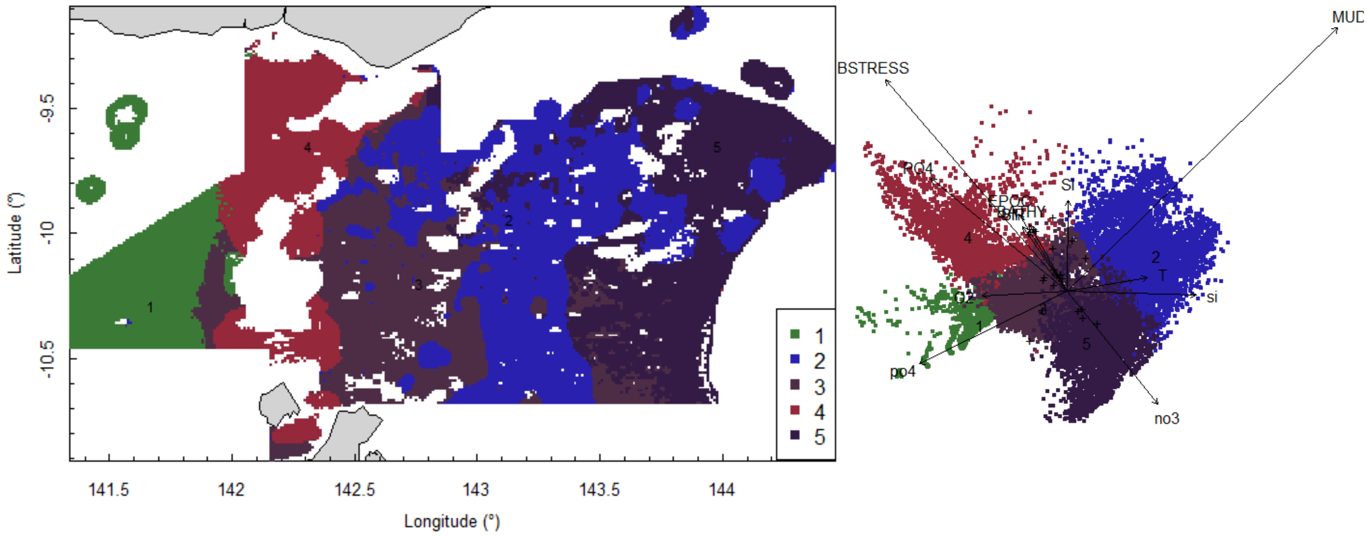


Figure 12 Map of the TSPF region showing clustered patterns of species composition change predicted by relationships with multiple environmental gradients. The biplot shows the first 2 dimensions of the clustered multi-dimensional biological space, representing composition change in relation to vectors of the major environmental drivers. The preliminary clustering of the biological space suggests 5 assemblages.

Table 7 Intersection of Assemblages by area, in the TSPF region with CMRs and fishery closures (and both combined), and with prawn trawl effort.

Assemblage	Grid count	Area(km²)	CMRs	% CMR	MPAs	Closures	%Closed	Any Clsd	Total%Clsd	Grounds	Uniform	Random	% Trawled	Trl Swept	% Swept
1	3,068	3,729	0	0.0	0	3,724	99.9	3,724	99.9	0	0	0	0.0	0	0.0
2	7,576	9,212	0	0.0	0	2,497	27.1	2,497	27.1	3,750	1,465	1,171	12.7	2,266	24.6
3	5,535	6,725	0	0.0	0	4,052	60.3	4,052	60.3	149	14	12	0.2	14	0.2
4	3,720	4,525	0	0.0	0	4,518	99.8	4,518	99.8	0	0	0	0.0	0	0.0
5	6,774	8,239	0	0.0	0	2,489	30.2	2,489	30.2	659	269	211	2.6	374	4.5
	26,673	**32,431**	**0**	**0.0**	**0**	**17,280**	**53.3**	**17,280**	**53.3**	**4,558**	**1,748**	**1,394**	**4.3**	**2,653**	**8.2**

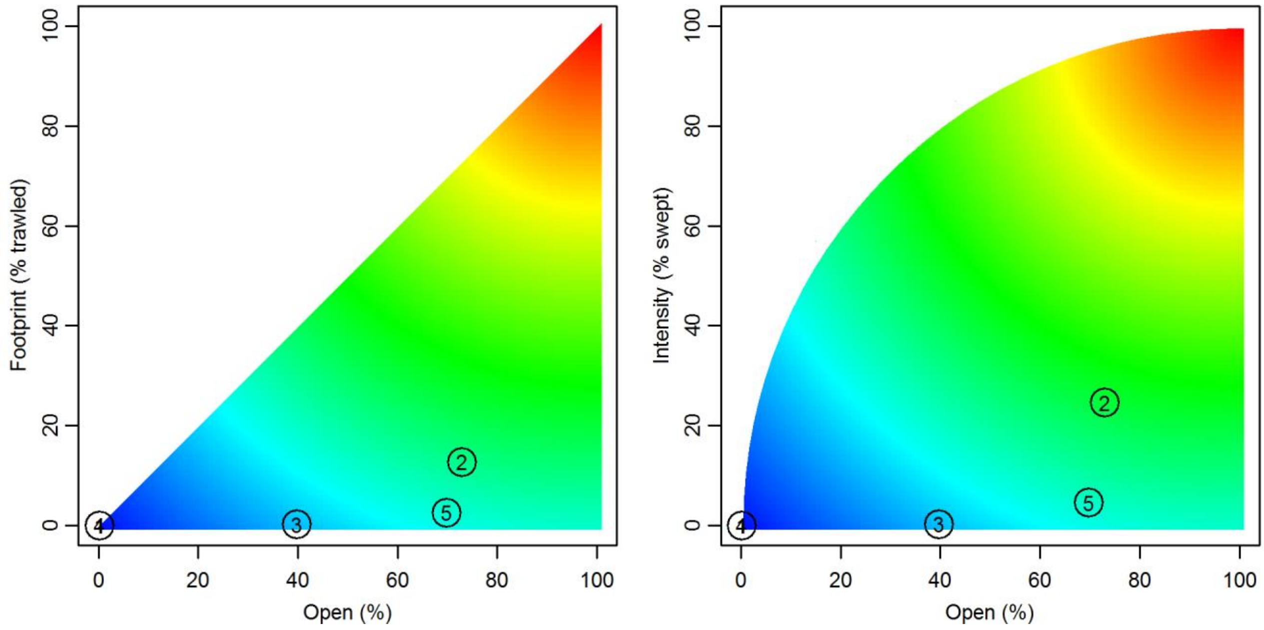


Figure 13 Plot of percentage of area of each assemblage open to potential trawling against exposure to actual effort as trawl footprint and swept intensity in the TSPF.

4.1.7 Bass Strait Central Zone Scallop Fishery region

In the case of the BSCZS fishery region, 6 datasets contributed to the bio-physical characterisation including 2 fish trawl, 3 epibenthic sled and 1 grab survey. The combined information from these datasets provided functions (essentially the same as for the SET) for transforming the BSCZS regional environment to a multi-dimensional biological space, and mapping in geographic space (Figure 14). The definition of assemblages from the continuous biological space suggested a local '*optimum*' at 11 assemblages.

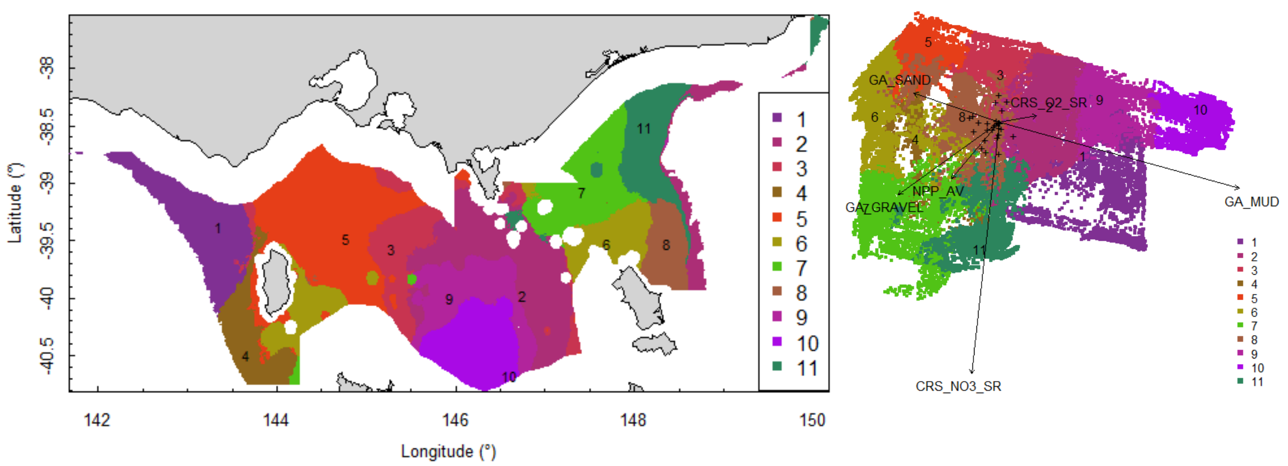


Figure 14 Map of the BSCZS area showing clustered patterns of species composition change predicted by relationships with multiple environmental gradients. The biplot shows the first 2 dimensions of the clustered multi-dimensional biological space, representing composition change in relation to vectors of the major environmental drivers. The clustering of the biological space suggests 11 assemblages.

The intersection of BSCZS assemblages with CMRs & fishery closures, and with scallop dredge effort is shown in Table 8 — 6.1% of the BSCZS area (0–150 m) was closed in CMRs but, although fishing is tightly managed by rotationally opening specified fishing grounds, there were no permanent closures in place at the time of analysis. The annual footprint of the BSCZS dredge fishery is ~22 km² (0.03%); the most exposed assemblage (#8) has a fishing footprint of <1%. These estimates, compared with the other fisheries, are indicative of among the lowest relative potential for habitat risk and priority for future AFMA habitat ERAs.

Table 8 Intersection of Assemblages by area, in the BSCZS fishery region with CMRs and fishery closures (and both combined), and with scallop dredge effort.

Assemblage	Grid count	Area(km²)	CMR_VI	% CMR	MPAs	Closures	Total%Clsd	Grounds	Uniform	Random	% Dredged	Drg Swept	% Swept
1	7112	6,788	875	12.9	0	0	12.9	0.0	0.0	0.0	0.00	0.0	0.00
2	12235	11,633	938	8.1	0	0	8.1	16.4	0.2	0.2	0.00	0.2	0.00
3	6057	5,764	308	5.3	0	0	5.3	0.0	0.0	0.0	0.00	0.0	0.00
4	4126	3,885	113	2.9	0	0	2.9	0.0	0.0	0.0	0.00	0.0	0.00
5	14834	14,156	376	2.7	0	0	2.7	3.8	0.0	0.0	0.00	0.0	0.00
6	6332	6,011	280	4.7	0	0	4.7	74.6	0.8	0.8	0.01	0.8	0.01
7	6849	6,567	1,419	21.6	0	0	21.6	42.1	0.4	0.4	0.01	0.4	0.01
8	3246	3,090	1	0.0	0	0	0.0	413.5	20.7	19.4	0.63	20.7	0.67
9	5965	5,642		0.0	0	0	0.0	0.0	0.0	0.0	0.00	0.0	0.00
10	6205	5,834		0.0	0	0	0.0	0.0	0.0	0.0	0.00	0.0	0.00
11	5926	5,715	240	4.2	0	0	4.2	88.6	1.2	1.1	0.02	1.2	0.02
	78887	**75,084**	**4,550**	**6.1**	**0**	**0**	**6.1**	**639.0**	**23.2**	**21.9**	**0.03**	**23.2**	**0.03**

4.2 Conclusions

Across all Commonwealth trawl fisheries, there were relatively few assemblages that had both high exposure to trawling and low inclusion in closed areas (Figure 15, Table 9). A number of more trawl-exposed assemblages had notable levels of inclusion in closed areas. Most assemblages had little or no exposure to trawling, including a large number with little or no protection in closures as well as those with high levels of protection in closures. Those assemblages towards the top of Table 9 may be considered higher priority for future AFMA habitat ERAs (e.g. coloured orange & yellow in Figure 15), those somewhat lower in the table may be medium priority (e.g. coloured bright green in Figure 15), whereas those even lower in the table may be low priority (e.g. coloured aqua or blue in Figure 15). However, the ordered list represents only relative potential for risk, and does not necessarily imply actual risk to habitats. Sensitive habitats may or may not occur in trawl exposed areas. Assessment of the actual level of risk in priority assemblages requires information on the occurrence and landscape distribution of habitats susceptible to trawl impacts, their resilience and recovery, and quantitative estimation of their status.

4.2.1 Uncertainty

It is important to emphasise that the unit of assessment used in this project, assemblages, are surrogates for habitats at meso-scales. Assemblages, were used in order to make progress in the absence of suitable spatial data for habitats in most fisheries. However, like all research, these assessments of assemblage exposure and protection are subject to uncertainties. The assemblage mapping has uncertainties beyond determining the appropriate number of assemblages for a region (see Methods). For example, not all variation in demersal species composition is explained by relationships with environmental variables. Typically more than half the species present in a biological survey dataset are too rare for analysis, and of those having adequate occurrence perhaps a third show no statistical relationship with the environment — and further, of those that have a relationship, on average 10–40% of their variation in abundance could be successfully predicted by environmental variables (see also e.g. Pitcher et al. 2012). In addition, representation of multi-species compositional patterns by means of environmental variables also has uncertainty, for which there is no established method of quantification. Initial approaches (Ellis and Pitcher 2011) indicate that uncertainty in mapping composition is spatially variable and (like other analyses) related to data density and quality; uncertainty is higher where data are sparse and poor. The magnitude of uncertainty in composition in ‘biological space’ (as represented by the

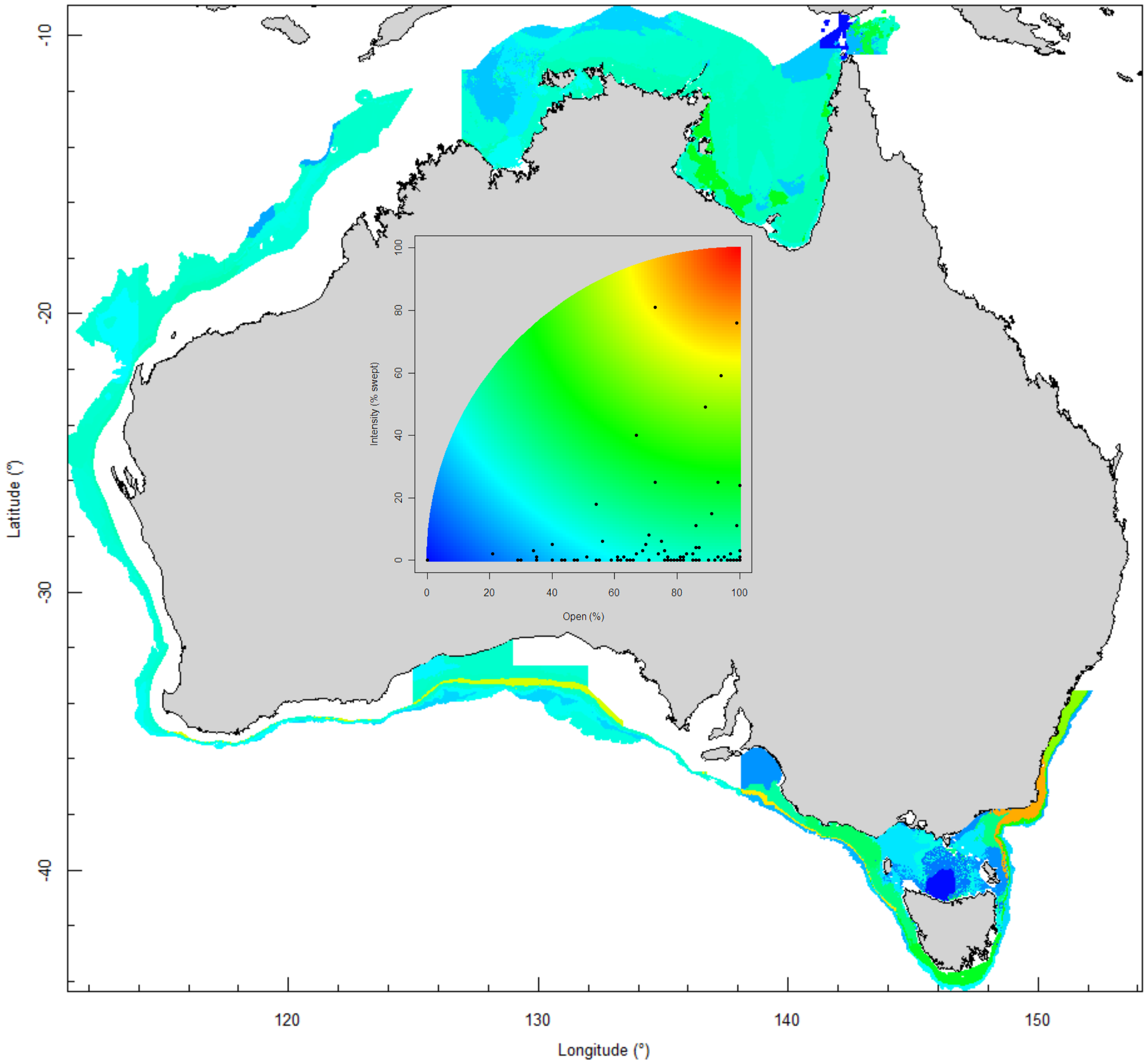


Figure 15 Map of all Commonwealth trawl fisheries jurisdictions (<1500 or <150 as appropriate), excluding BSCZS, showing overall relative exposure of mapped demersal assemblages to trawl swept intensity. Inset: colour scale indicating swept intensity, as used in previous figues.

Table 9 List of Assemblages for all fisheries, ordered by both trawl footprint exposure & swept intensity and (inverse) closure, to represent a relative priority for future habitat ERAs

Fishery	Assemblage	Grid count	Area(km²)	CMRs	% CMR	MPAs	Closures	%Closed	Any Clsd	Total%Clsd	Grounds	Uniform	Random	% Trawled	Trl Swept	% Swept
SET	20	13,319	12,970	13	0.1	0	112	0.9	122	0.9	12,112	7,386	5,665	43.7	9,899	76.3
SET	4	5,846	5,655	72	1.3	0	1,510	26.7	1,547	27.4	4,773	2,495	2,051	36.3	4,556	80.6
GAB	8	15,814	16,280	901	5.5	0	32	0.2	932	5.7	13,545	7,183	5,533	34.0	9,623	59.1
SET	1	9,139	9,271	264	2.9	0	999	10.8	1,258	13.6	7,676	2,816	2,313	24.9	4,557	49.2
SET	2	7,040	6,792	389	5.7	0	2,234	32.9	2,281	33.6	5,449	1,827	1,463	21.5	2,706	39.8
NPF	9	28,363	33,846	1,400	4.1	0	1,008	3.0	2,408	7.1	17,297	5,492	4,409	13.0	8,346	24.7
SET	14	15,064	13,507	3,339	24.7	0	30	0.2	3,346	24.8	6,570	2,089	1,709	12.7	3,268	24.2
TSP	2	7,576	9,212	0	0.0	0	2,497	27.1	2,497	27.1	3,750	1,465	1,171	12.7	2,266	24.6
SET	5	17,656	16,943	1,056	6.2	0	1,529	9.0	2,586	15.3	5,630	1,003	885	5.2	2,467	14.6
SET	6	13,051	12,158	867	7.1	0	73	0.6	902	7.4	5,048	517	467	3.8	1,338	11.0
SET	18	9,116	8,761	601	6.9	0	1,204	13.7	1,768	20.2	4,653	748	629	7.2	963	11.0
SET	17	8,834	8,652	0	0.0	0	3,945	45.6	3,945	45.6	3,209	799	686	7.9	1,551	17.9
NPF	2	50,011	59,520	15,889	26.7	73	1,525	2.6	17,396	29.2	22,374	4,109	3,375	5.7	4,715	7.9
NPF	3	17,719	21,421	2,098	9.8	725	29	0.1	2,843	13.3	4,759	777	637	3.0	881	4.1
NPF	14	19,786	23,942	5,925	24.7	65	0	0.0	5,990	25.0	5,230	1,199	951	4.0	1,347	5.6
WDT	10	4,220	4,709	676	14.4	0	0	0.0	676	14.4	1,625	165	136	2.9	167	3.6
NWS	5	10,628	12,390	6	0.0	0	0	0.0	6	0.0	1,519	316	256	2.1	342	2.8
NPF	10	64,800	77,804	2,097	2.7	0	0	0.0	2,097	2.7	2,904	928	754	1.0	1,510	1.9
NWS	11	4,920	5,744	16	0.3	0	0	0.0	16	0.3	881	68	62	1.1	68	1.2
NPF	8	27,804	33,338	4,991	15.0	0	0	0.0	4,991	15.0	3,836	630	509	1.5	681	2.0
GAB	7	13,593	13,886	1,468	10.6	0	1,452	10.5	2,315	16.7	4,480	281	253	1.8	281	2.0
NPF	12	54,801	66,193	3,499	5.3	1	0	0.0	3,500	5.3	1,675	477	384	0.6	627	0.9
GAB	9	14,468	14,953	1,004	6.7	0	0	0.0	1,004	6.7	2,427	131	114	0.8	131	0.9
BSCZ	8	3,246	3,090	1	0.0	0	0	0.0	1	0.0	413.5	20.7	19.4	0.6	20.7	0.7
NWS	1	4,836	5,834	46	0.8	0	0	0.0	46	0.8	538	25	24	0.4	25	0.4
TSP	5	6,774	8,239	0	0.0	0	2,489	30.2	2,489	30.2	659	269	211	2.6	374	4.5
NPF	4	16,232	19,572	4,508	23.0	0	216	1.1	4,724	24.1	2,240	405	328	1.7	551	2.8
NWS	7	13,039	15,637	608	3.9	0	0	0.0	608	3.9	298	22	21	0.1	22	0.1
NWS	6	1,306	1,504	0	0.0	0	0	0.0	0	0.0	40	1	1	0.1	1	0.1
NWS	15	2,730	3,195	0	0.0	0	0	0.0	0	0.0	40	1	1	0.0	1	0.0
NWS	9	8,627	10,354	0	0.0	0	0	0.0	0	0.0	126	3	3	0.0	3	0.0
NWS	19	6,115	7,184	60	0.8	0	0	0.0	60	0.8	4	1	1	0.0	1	0.0
WDT	6	7,270	8,186	46	0.6	0	0	0.0	46	0.6	11	0	0	0.0	0	0.0
NWS	20	7,984	9,289	0	0.0	0	0	0.0	0	0.0	2	0	0	0.0	0	0.0
NPF	11	49,485	59,536	93	0.2	0	0	0.0	93	0.2	22	0	0	0.0	0	0.0
WDT	1	7,588	8,509	0	0.0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0
NWS	12	818	947	0	0.0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0
NWS	13	5,562	6,689	0	0.0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0
NWS	21	11,988	13,929	0	0.0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0
BSCZ	9	5,965	5,642		0.0	0	0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BSCZ	10	6,205	5,834		0.0	0	0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NWS	3	8,901	10,705	236	2.2	0	0	0.0	236	2.2	25	1	1	0.0	1	0.0
BSCZ	5	14,834	14,156	376	2.7	0	0	0.0	376	2.7	3.8	0.0	0.0	0.0	0.0	0.0
BSCZ	4	4,126	3,885	113	2.9	0	0	0.0	113	2.9	0.0	0.0	0.0	0.0	0.0	0.0
WDT	9	7,814	8,355	1,522	18.2	0	0	0.0	1,522	18.2	742	103	82	1.0	107	1.3
NPF	13	40,914	49,670	1,703	3.4	0	0	0.0	1,703	3.4	19	0	0	0.0	0	0.0
BSCZ	11	5,926	5,715	240	4.2	0	0	0.0	240	4.2	88.6	1.2	1.1	0.0	1.2	0.0
GAB	13	15,028	15,664	596	3.8	0	0	0.0	596	3.8	0	0	0	0.0	0	0.0
BSCZ	6	6,332	6,011	280	4.7	0	0	0.0	280	4.7	74.6	0.8	0.8	0.0	0.8	0.0
GAB	11	12,300	12,744	783	6.1	0	0	0.0	783	6.1	313	6	6	0.0	6	0.0
WDT	8	5,267	5,942	493	8.3	0	0	0.0	493	8.3	387	9	9	0.2	9	0.2
BSCZ	3	6,057	5,764	308	5.3	0	0	0.0	308	5.3	0.0	0.0	0.0	0.0	0.0	0.0
NWS	18	9,577	11,250	850	7.6	0	0	0.0	850	7.6	229	5	5	0.0	5	0.0
BSCZ	2	12,235	11,633	938	8.1	0	0	0.0	938	8.1	16.4	0.2	0.2	0.0	0.2	0.0
GAB	6	6,928	7,077	773	10.9	0	783	11.1	1,362	19.2	1,542	75	71	1.0	75	1.1
NPF	16	23,415	28,415	2,878	10.1	0	0	0.0	2,878	10.1	81	1	1	0.0	1	0.0
NPF	17	22,963	27,622	7,100	25.7	0	0	0.0	7,100	25.7	2,751	482	395	1.4	629	2.3
BSCZ	1	7,112	6,788	875	12.9	0	0	0.0	875	12.9	0.0	0.0	0.0	0.0	0.0	0.0
WDT	5	7,457	8,461	1,121	13.2	0	0	0.0	1,121	13.2	35	1	1	0.0	1	0.0
NPF	20	20,801	25,289	3,411	13.5	0	0	0.0	3,411	13.5	0	0	0	0.0	0	0.0
NPF	7	11,688	13,934	1,982	14.2	0	0	0.0	1,982	14.2	75	6	5	0.0	9	0.1
NWS	16	5,534	6,587	938	14.2	0	0	0.0	938	14.2	0	0	0	0.0	0	0.0
NPF	1	13,698	16,306	713	4.4	604	2,464	15.1	3,687	22.6	1,870	183	156	1.0	194	1.2
WDT	7	6,893	7,481	1,105	14.8	0	0	0.0	1,105	14.8	81	2	2	0.0	2	0.0
NWS	8	11,924	14,066	4,316	30.7	0	0	0.0	4,316	30.7	2,839	375	328	2.3	375	2.7
WDT	3	17,170	19,950	3,574	17.9	0	0	0.0	3,574	17.9	0	0	0	0.0	0	0.0

NWS	4	11,725	13,857	2,657	19.2	0	0	0.0	2,657	19.2	250	21	20	0.1	21	0.2
GAB	10	5,977	6,201	1,134	18.3	0	0	0.0	1,134	18.3	118	2	2	0.0	2	0.0
WDT	4	12,403	13,509	2,742	20.3	0	0	0.0	2,742	20.3	105	2	2	0.0	2	0.0
WDT	12	3,436	3,958	850	21.5	0	0	0.0	850	21.5	0	0	0	0.0	0	0.0
BSCZ	7	6,849	6,567	1,419	21.6	0	0	0.0	1,419	21.6	42.1	0.4	0.4	0.0	0.4	0.0
WDT	2	17,659	19,053	4,151	21.8	0	0	0.0	4,151	21.8	112	2	2	0.0	2	0.0
WDT	14	4,205	4,316	1,007	23.3	0	0	0.0	1,007	23.3	23	1	1	0.0	1	0.0
GAB	1	15,353	15,509	2,242	14.5	0	1,713	11.0	3,699	23.9	155	4	4	0.0	4	0.0
NWS	2	1,225	1,474	354	24.0	0	0	0.0	354	24.0	12	0	0	0.0	0	0.0
NWS	10	7,263	8,603	2,824	32.8	0	0	0.0	2,824	32.8	1,449	144	126	1.5	144	1.7
NPF	19	14,817	18,015	5,138	28.5	0	0	0.0	5,138	28.5	0	0	0	0.0	0	0.0
NWS	14	10,743	12,740	3,697	29.0	0	0	0.0	3,697	29.0	146	3	3	0.0	3	0.0
GAB	2	12,702	12,994	3,448	26.5	0	1,038	8.0	4,385	33.7	144	2	2	0.0	2	0.0
NPF	5	16,987	20,402	7,457	36.5	45	75	0.4	7,576	37.1	1,497	126	107	0.5	138	0.7
GAB	5	12,405	12,677	1,026	8.1	0	3,941	31.1	4,539	35.8	902	30	28	0.2	30	0.2
WDT	13	6,797	6,960	2,438	35.0	0	0	0.0	2,438	35.0	0	0	0	0.0	0	0.0
SET	15	5,690	5,069	1,822	35.9	0	1,967	38.8	2,093	41.3	1,402	73	69	1.4	74	1.5
GAB	4	5,184	5,239	922	17.6	0	1,417	27.0	1,997	38.1	34	5	4	0.1	6	0.1
SET	7	15,985	15,140	1,278	8.4	0	6,728	44.4	7,944	52.5	1,788	551	452	3.0	907	6.0
WDT	11	30,188	34,872	13,439	38.5	0	0	0.0	13,439	38.5	22	1	1	0.0	1	0.0
GAB	12	7,776	8,073	3,320	41.1	0	0	0.0	3,320	41.1	1	1	0	0.0	1	0.0
NPF	15	31,569	38,150	17,281	45.3	0	1	0.0	17,283	45.3	104	8	6	0.0	13	0.0
SET	12	24,508	23,388	825	3.5	0	11,427	48.9	11,801	50.5	1,796	184	165	0.7	222	0.9
SET	8	8,338	7,796	1,086	13.9	0	4,659	59.8	4,678	60.0	3,803	342	299	3.8	362	4.6
GAB	3	15,523	15,870	1,775	11.2	0	7,254	45.7	8,285	52.2	353	20	17	0.1	28	0.2
NPF	22	11,546	14,060	7,440	52.9	0	0	0.0	7,440	52.9	0	0	0	0.0	0	0.0
NPF	21	14,904	18,144	9,608	53.0	0	0	0.0	9,608	53.0	0	0	0	0.0	0	0.0
NPF	6	25,486	30,760	17,090	55.6	0	12	0.0	17,102	55.6	196	26	21	0.1	31	0.1
NPF	18	30,612	36,978	21,124	57.1	0	0	0.0	21,124	57.1	0	0	0	0.0	0	0.0
SET	13	12,247	11,690	1,631	14.0	0	5,352	45.8	6,963	59.6	262	21	19	0.2	49	0.4
SET	9	8,111	7,790	242	3.1	0	5,130	65.8	5,130	65.8	3,641	251	228	2.9	251	3.2
TSP	3	5,535	6,725	0	0.0	0	4,052	60.3	4,052	60.3	149	14	12	0.2	14	0.2
NWS	17	6,803	8,080	5,251	65.0	0	0	0.0	5,251	65.0	24	0	0	0.0	0	0.0
SET	3	3,068	3,097	518	16.7	0	2,001	64.6	2,128	68.7	1,178	43	42	1.4	43	1.4
SET	11	16,214	15,383	938	6.1	0	10,880	70.7	11,546	75.1	1,807	60	57	0.4	60	0.4
SET	19	17,471	17,367	3,583	20.6	0	12,150	70.0	13,522	77.9	186	3	3	0.0	3	0.0
SET	10	16,138	15,261	623	4.1	0	12,102	79.3	12,679	83.1	752	242	187	1.2	283	1.9
SET	16	9,965	9,353	0	0.0	0	9,340	99.9	9,340	99.9	13	5	4	0.0	5	0.1
TSP	4	3,720	4,525	0	0.0	0	4,518	99.8	4,518	99.8	0	0	0	0.0	0	0.0
TSP	1	3,068	3,729	0	0.0	0	3,724	99.9	3,724	99.9	0	0	0	0.0	0	0.0

biplots in figures) was also a relevant consideration influencing the selection of the appropriate number of assemblages. Too many assemblages would mean that the clusters in biological space would be smaller than the uncertainty and could not be justified; hence, the guide used to indicate the number of assemblages (see Methods) was as robust as possible given the partial coverage of regions by the multiple datasets used. Given also that in reality demersal species composition patterns change in a continuous manner — although not uniformly — along environmental gradients (e.g. see Figure 2, inset map), the imposition of assemblage boundaries is artificial. That is, their boundaries also have uncertainty and are non-exact.

While the strength of the predicted assemblage approach taken in this project is that a spatial mapping approach can be taken when habitat data per se are not available, the weakness is that only potential risk can be assessed not actual habitat risk — due to the lack of information on susceptible habitat components within assemblages and their finer scale distribution relative to trawling. The project could not directly consider habitat impacts *per se*, and did not address past trawl footprints. Thus, the outputs are an interim step that helps focus future priorities, and these will need to take into account the uncertainties above when assessing habitat risk in more exposed/less protected assemblages by acquiring robust data regarding the distribution of habitats, and biological components of habitat, that are susceptible to trawl impacts.

4.3 Implications

This study has provided — for all continental Commonwealth demersal trawl fisheries — a consistent spatial approach for mapping seabed assemblages and assessing exposure & protection of the demersal environment, *in lieu* of habitat data lacking for most fisheries. The results demonstrate that the great majority of assemblages within these Commonwealth demersal fishery jurisdictions have little or no exposure to trawling, independent of whether they have high or no protection. It is highly probable that this majority is subject to no substantive risk from Commonwealth demersal trawling. The results also demonstrate that relatively few seabed assemblages within Commonwealth fishery jurisdictions have high exposure to trawling and therefore potential for risk to sensitive habitats if they occur in these areas. The implications are that limited resources for future habitat ERAs can be focussed on the small number of more highly exposed assemblages, particularly those with lower levels of protection, to assess whether sensitive habitats are present and whether they are at substantive risk from trawling. This focus will assist with more efficient application of industry resources regarding management expenditure on environmental risk assessments for habitats, and ultimately lead to reduction in environmental risks due to trawling, enhanced environmental sustainability and social licence, and AFMA meeting its obligations regarding environmental legislation. The beneficiaries of these outcomes include the Commonwealth demersal trawl fisheries and AFMA; other stakeholders with responsibilities for sustainable use of the marine environment such as the Department of the Environment; and the Australian community.

4.4 Recommendations

Further discussions of the project's outputs, with AFMA and industry associations and industry members of relevant fisheries, AFMA's consultative management and scientific committees, are recommended to decide the final priority of assemblages for future habitat risk assessments, while taking into account the uncertainties in the current outputs. Discussions should include consideration of the potential methods that may be suitable for assessing whether sensitive habitats and biological components are present in the priority assemblages and whether or not they are at substantive risk from trawling. The initial qualitative habitat ERA outputs are anticipated to be able to assist this process.

4.5 Further development

This project focussed on Commonwealth trawl & dredge fishery jurisdictions only — it did not map assemblages outside of these jurisdictions, or address the footprints of State bottom-trawl fisheries, or other non-trawl bottom-contact fisheries. This may be significant because some assemblages extend outside of Commonwealth jurisdictions and could be exposed to State trawl fisheries; in addition, some state fisheries trawl within the spatial jurisdictional boundaries of some Commonwealth trawl fisheries. There are also other types of fishing, such as bottom long-lining, that interact with seabed habitats. These additional exposures may substantively change the relative risk of assemblages determined by this project. It is now feasible to extend the approach used in this project to apply a single consistent national approach to assessment of trawl exposure of assemblages, with the ultimate outcome of leading to achievement and demonstration of habitat sustainability for all demersal trawl fisheries in Australia. In this context, future research is planned that will map demersal assemblages nationally — for all areas of shelf and slope in both State and Commonwealth waters — and include assessment of trawl footprints and closures for all other bottom trawl fisheries such as those managed by States.

5 Extension and Adoption

A steering committee for the project was established by October 2014, with membership including AFMA staff from the research & environment section, other AFMA staff and managers as AFMA deemed appropriate, and CFA members from SET & GAB. Additional CFA members, where appropriate, were contacted as the project progressed to other fisheries. For cost effective travel and time for all agencies involved, steering committee meetings were held in association with scheduled AFMA consultative meetings. The first steering committee meeting was held on 19 May 2015, when the first mutually suitable conjunction of other meetings occurred. At this first meeting, held at AFMA in Canberra, progress with the project was presented as outlined in the June 2015 milestone report, as were details of the steps in the analysis. In addition, a detailed presentation was made of the results of the NERP Marine Hub Project "2.3.2 *Landscape approaches to supporting management of benthic biodiversity*" (Pitcher et al. 2015), which had focussed on the Southeast Marine Region and was highly relevant to the SET. In particular, part of NERP Project 2.3.2 developed and applied the methods utilised in the current project, hence its results were indicative of the likely outputs. Further, progress with the international "Trawling Best Practices" Project was also presented, including a preliminary status assessment for sedimentary habitats in the Southeast Region, as well as the extension to assessment of benthos invertebrate communities being conducted by a CSIRO OCE Postdoctoral Fellow. SEMAC was held on the following day, 20 May, where more concise presentations were made on these projects.

The co-PI's participated in a Forum of the Expert Scientific Panel for the Commonwealth Marine Reserve Review in Melbourne on Thursday 11 June 2015. On 10 June, the PI met with the co-chairs of the CMRs review and a number of Parks Australia staff to present preliminary results of Project 2014–204, as well as those of several related projects.

The second steering committee meeting was held on 11 August 2015, again at AFMA in Canberra, to coincide with the timing of other meetings that members attended. At this meeting, preliminary results for SET, BSCZS, TSPF and GAB were presented and discussed.

In the intervening periods, contact was maintained with steering committee members by email and phone call discussions regarding progress and preliminary results for each fishery as they became available, formats of outputs, and planning of meetings. Discussions also included the possibility of using these and related assessments to evaluate proposed changes to closures in the CTS.

Further extension included presentations at SESS Shelf and Slope RAGs in Hobart on 28 October 2015; NPF RAG in Brisbane on 12 November 2015; and GAB RAG/MAC in Adelaide on 23 November 2105. Future meetings with AFMA in Canberra are anticipated, to discuss uptake of the results.

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7 Appendices

7.1 Appendix 1: Scope of project

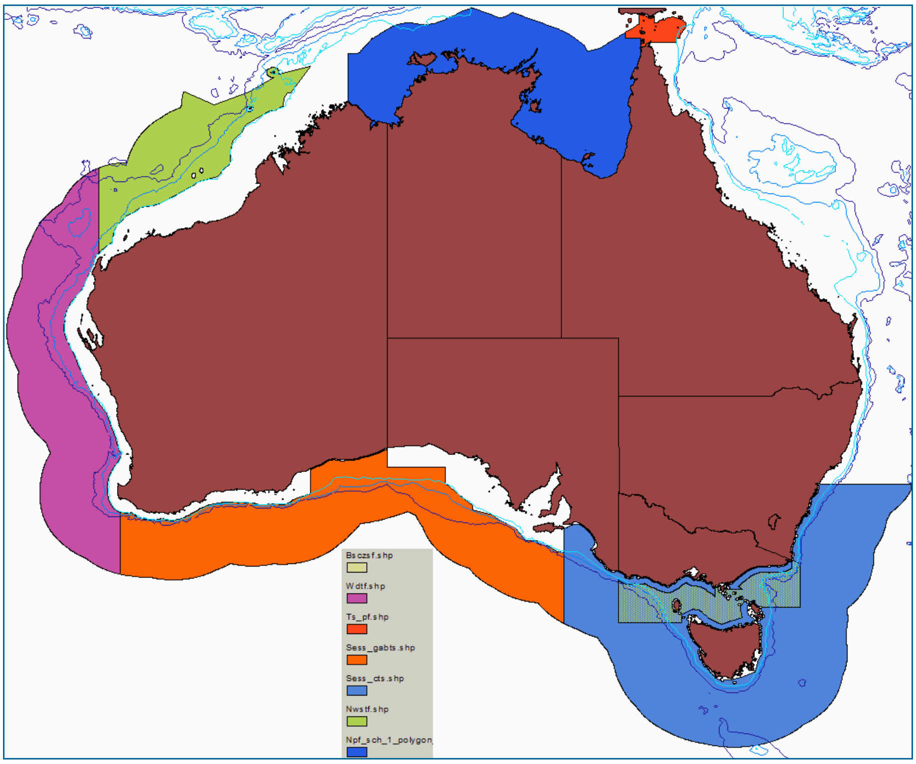

Figure 16 Boundaries of Commonwealth demersal trawl fisheries, with bathymetry contours (— 1500m), indicating scope of the project.

7.2 Appendix 2: Existing biological survey datasets

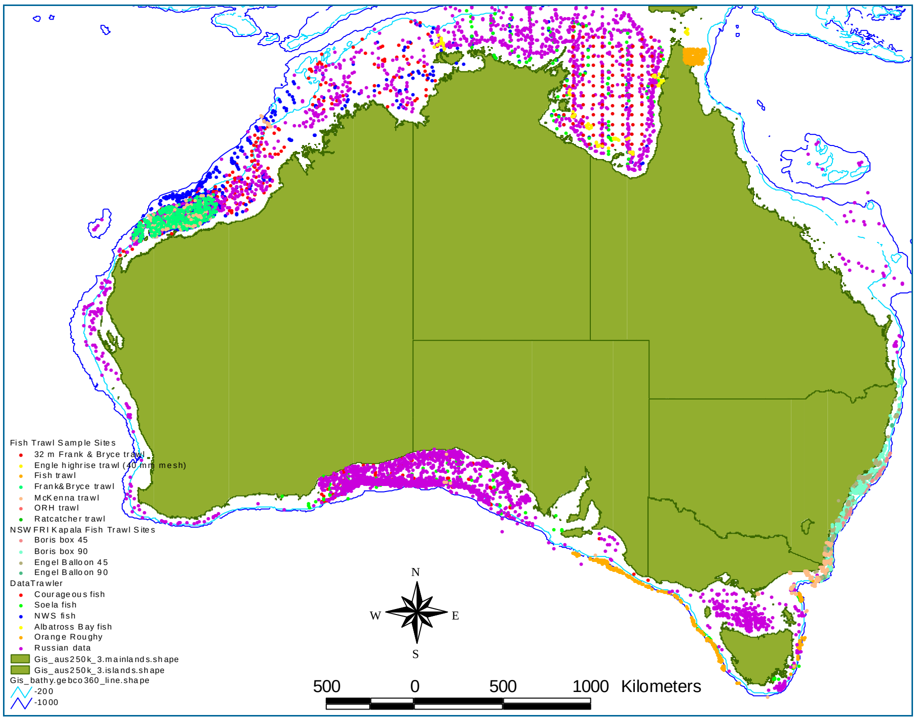

Figure 17 Existing available fish trawl datasets comprising primarily larger species of fishes.

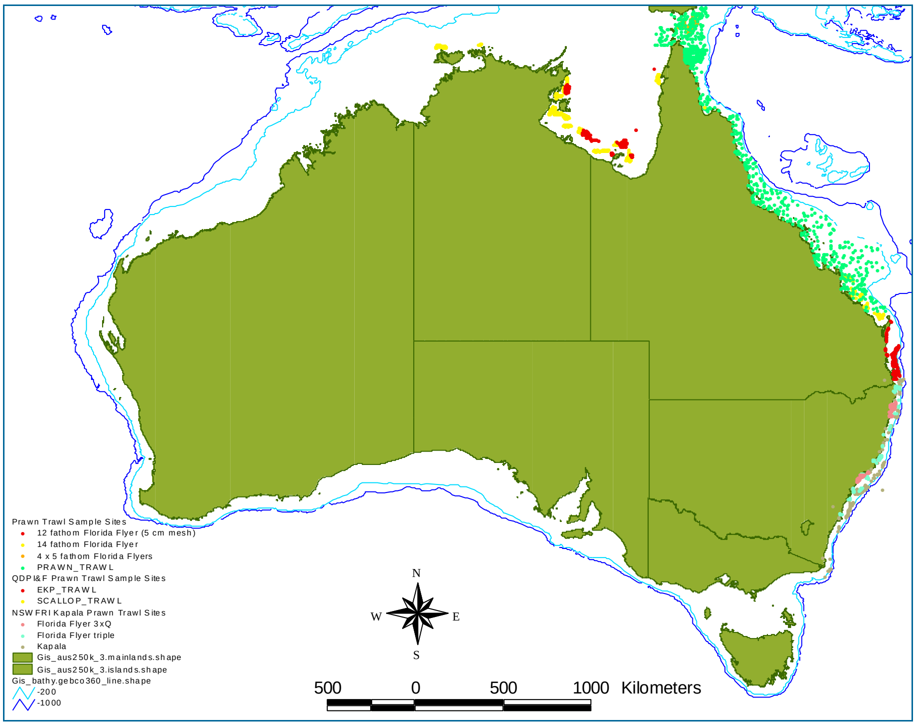

Figure 18 Existing available prawn trawl datasets comprising smaller species of fishes and mobile invertebrates.

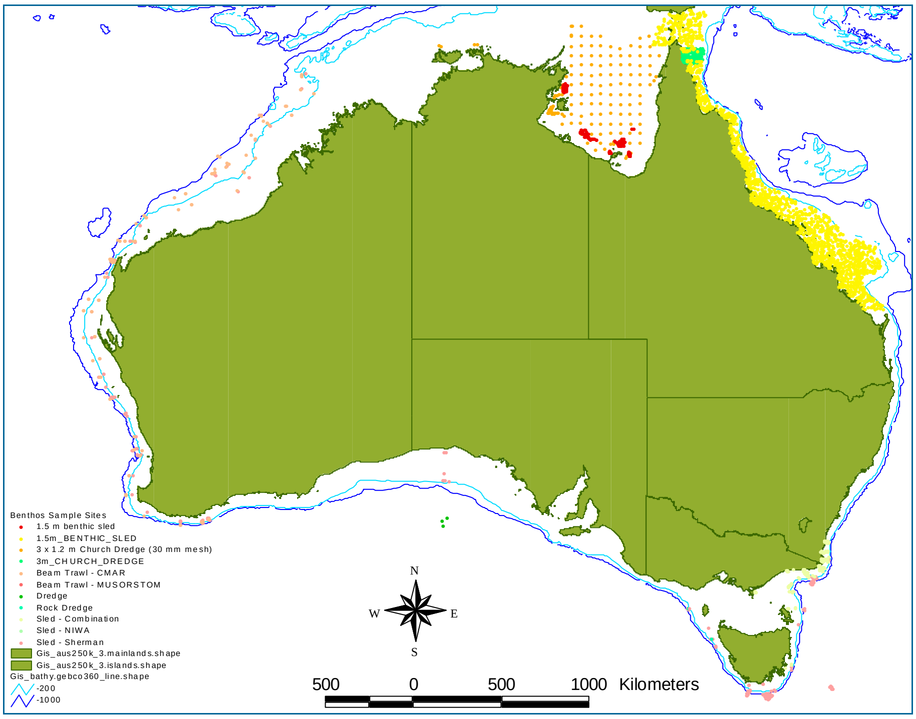

Figure 19 Existing available epibenthic sled datasets comprising mobile and sessile invertebrates.

7.3 Appendix 3: List of biological survey data sources

<u>CSIRO Surveys:</u>

Benthic habitat surveys: Southern Surveyor Voyage SS 01/2000 Biological Data Overview. MarLIN # 5746 : http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=5746

Benthic Habitats Video Image compilation for SE Australia. MarLIN # 14436 : http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=14436

Biodiversity Survey for SE MPA's including the Tasmanian Sea Mounts Marine Reserve, Southern Surveyor Voyage SS 02/2007 (Williams et al. 2008) MarLIN # 6939 http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=6939

Biological Data from CMR Research Vessels from the Australian North West Shelf, Part I (1982-1997 "North West Shelf Study" database). A compilation of biological data from voyages SO 5/82, SO 6/82, SO 1/83, SO 2/83, SO 3/83, SO 4/83, SO 5/83, SO 6/86, SO 7/87, SO 5/88, PoE 4/89, SS 02/90, SS 04/91, SS 08/95, and SS 07/97 (Brodie et al. 2006; see individual MarLIN records for these voyages).

Demersal fauna of the continental slope off Western Australia - Voyage SS 01/91 (Williams et al. 1996). MarLIN # 4951 : http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=4951

FRV 'Courageous' Fish Trawl surveys, 1978–1979, CSIRO
includes FRV Courageous voyages: COUR197831, COUR197832, COUR197833, COUR197834, COUR197835, COUR197945, COUR197946, COUR197947, COUR197949, COUR197950, COUR197951, COUR197952 (see individual MarLIN records for these voyages, http://www.marine.csiro.au/marq/ search).

FRV 'Soela' regional exploratory fishery surveys, 1980–1984, CSIRO.
includes Soela voyages: SO198001, SO198003, SO198004, SO198005, SO198006, SO198007, SO198102, SO198102, SO198105, SO198202, SO198204, SO198401, SO198402, SO198403, SO198404, SO198405, SO198406 (see individual MarLIN records for these voyages, http://www.marine.csiro.au/marq/ search).

Gulf of Carpentaria Fish Data, 1990-1993,CSIRO (Blaber et al. 1993); includes Southern Surveyor voyages: SS199003, SS199105, SS199301. MarLIN # : 3202
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=3202

Gulf of Carpentaria survey, Southern Surveyor 1990-03, CSIRO.
beam trawl megabenthos samples (Long et al. 1995), MarLIN # : 4682
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=4682
grab infauna samples (Long et al. 1995), MarLIN # : 4679
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=4679

Mapping & Characterisation of Biotic & Physical Attributes of the Torres Strait (Pitcher et al. 2007b).
Epibenthic Sled, MarLIN # 7044 :
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=7044
Prawn Trawl, MarLIN # 7045 :
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=7044
Towed Video, MarLIN # 7046 :
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=7046

NPF bycatch sustainability surveys, 1997-1998, CSIRO (Stobutski et al. 2000),
Southern Surveyor voyages: SS199702, SS199708, SS199803. MarLIN # : 4941, 4939, 4971
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=4941
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=4939
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=4971

Orange Roughy Surveys, 1988-1989, CSIRO (Bulman et al. 1994),
includes Soela voyages: SO198801, SO198802, SO198803, SO198901, SO198902, SO198903.

South East Fishery (SEF) Ecosystem Study 1993-1996 (Bax & Williams 2000):
Benthic Faunal Survey Data. MarLIN # 5248 :
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=5248
Fish Surveys. MarLIN # 5245 :
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=5245

Soviet trawl surveys 1969–1977, data compilation, CSIRO (Koslow et al, 1999)
includes voyages: ALBA196909, ALBA197009, ALBA197103, ALBA197310, BACA197506, BERG196503, BERG196601, BERG196705, EQUA197109, KAME197607, KORI196802, LIRA196702, LIRA196806, LIRA197304, MY-TIC197803, P-DER197210, P-DER197405, P-DER197512, P-DER197701, POSE197107, POSE197704, PROM196811, PROM197002, RADU196608, RADU197206, RADU197503, SESK196601, SHAN197405, SRTM196903, SUTC196807, TICH197703, TICH197710.

Tasmanian Seamounts Study 1997: Benthic Faunal Survey Data (Koslow & Gowlett-Holmes 1998). MarLIN # 5256 : http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=5256

Torres Strait Seabed & Water-Column Data Collation, Modeling & Characterisation (Pitcher et al. 2004).
'Low-Level' Bio-survey data compilation, Neptune # 1028 :
http://www.marine.csiro.au/nddq/ndd_search.Browse_Citation?txtSession=1028
'Medium-Level' Bio-survey data compilation, Neptune # 1025 :
http://www.marine.csiro.au/nddq/ndd_search.Browse_Citation?txtSession=1025

Voyage of discovery - benthic biodiversity of the deep continental shelf & slope in Western Australia
South West Region, SS10/2005, (Williams et al. 2010a), MarLIN # 6937 :
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=6937
North West Region, SS05/2007, (Williams et al. 2010b),MarLIN # 6938 :
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=6938

Surveys by other research agencies:

'Kapala' trawl surveys dataset, 1975–2006, NSW Fisheries Research Institute (Ken Graham, pers comm.).

Bass Strait Survey 1979-1983 collections data – Museum of Victoria (Wilson & Poore 1987; O'Hara 2002)

Eastern Great Australian Bight benthic sled and grab infauna survey dataset, 2002, SARDI (Ward et al. 2003)

Eastern Great Australian Bight benthic sled epifauna survey dataset, 2006, SARDI (Currie et al. 2008).

Eastern Great Australian Bight grab infauna survey dataset, 2006, SARDI (Currie et al. 2007).

Northern Australian Groundfish Stock survey, 1990 & 1992, NT Fisheries (Ramm 1997).

SESSF CTS Fishery Independent Surveys (FIS) dataset, Fishwell Consulting/AFMA.

SESSF GAB Fishery Independent Surveys (FIS) dataset, Fishwell Consulting/AFMA.

Shark Bay and Exmouth Gulf Biodiversity survey, Western Australia Fisheries (Kangas et al. 2007).

7.4 Appendix 4: List of mapped environmental variables & sources

Table 10 Environmental variables mapped to the Australian EEZ, available to the project

#	VARIABLE	DESCRIPTION	SOURCE
1	BATHY	Depth from bathymetry DEM – metres	1
2	SLOPE	Slope derived from bathymetry DEM – degrees	1
3	ASPECT	Aspect of slope derived from bathymetry DEM – degrees T	1
4	MUD	Sediment % mud grainsize fraction, (Ø < 63 µm)	2
5	SAND	Sediment % sand grainsize fraction, (63 µm < Ø < 2 mm)	2
6	GRAVEL	Sediment % gravel grainsize fraction, (Ø > 2 mm)	2
7	CRBNT	Sediment % carbonate ($CaCO_3$) composition, percent	2
8	BSTRESS	Seabed tidal current stress, RMS mean – Nm^{-2}	5
9	NO3	Nitrate bottom water annual average NO_3 – µM	3
10	no3	Nitrate Seasonal Range	3
11	PO4	Phosphate bottom water annual average PO_4 – µM	3
12	po4	Phosphate Seasonal Range	3
13	O2	Oxygen bottom water annual average O_2 – mL L^{-1}	3
14	o2	Oxygen Seasonal Range	3
15	S	Salinity bottom water annual average S – ‰ (ppt)	3
16	s	Salinity Seasonal Range	3
17	T	Temperature bottom water annual average T – °C	3
18	t	Temperature Seasonal Range	3
19	SI	Silicate bottom water annual average Si – µM	3
20	si	Silicate Seasonal Range	3
21	CHLA	Chlorophyll annual average from SeaWiFS – mg m^{-3}	4
22	chla	Chlorophyll Seasonal Range	4
23	K490	Attenuation coefficient at wavelength 490nm annual average from SeaWiFS – m^{-1}	4
24	k490	Attenuation coefficient Seasonal Range	4
25	SST	Sea Surface Temperature annual average from Modis – °C	4
26	sst	Sea Surface Temperature Seasonal Range	4
27	NPP	Net Primary Production annual average from SeaWiFS – mg C m^{-2} d^{-1}	4
28	npp	Net Primary Production seasonal range	4
29	PAR	Photosynthetically Active Radiation (PAR) from MODIS – Einsteins $m^{-2}day^{-1}$	4
30	par	Photosynthetically Active Radiation seasonal range	4
31	EPOC	Export Particulate Organic Carbon flux annual average from SeaWiFS – mg C m^{-2} d^{-1}	4
32	epoc	Export Particulate Organic Carbon seasonal range	4
33	BIR	Benthic Irradiance annual average, BIR = PAR × exp(-K490 * Depth)	4
34	bir	Benthic Irradiance Seasonal Range	4
35	CHAN	Terrain channel, probability of membership of topographic shape "channel"	6
36	PASS	Terrain pass, probability of membership of topographic shape "pass"	6
37	PEAK	Terrain peak, probability of membership of topographic shape "peak"	6
38	PIT	Terrain pit, probability of membership of topographic shape "pit"	6
39	PLAN	Terrain plane, probability of membership of topographic shape "plane"	6
40	RIDG	Terrain ridge, probability of membership of topographic shape "ridge"	6

1. Australian Bathymetry and Topography Grid, Geoscience Australia (Webster & Petkovic 2005):
   https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=67703
2. Australian MARine Sediments Database (MARS), Geoscience Australia (Passlow et al. 2005):
   http://www.ga.gov.au/oracle/mars/ and http://dbforms.ga.gov.au/pls/www/npm.mars.search
3. Australian bottom water attributes (Ridgway et al. 2002; Dunn & Ridgway 2002):
   CSIRO Atlas of Regional Seas (CARS) http://www.marine.csiro.au/~dunn/cars2009/
4. NASA SeaWiFS and MODIS satellite derived ocean color data (http://oceancolor.gsfc.nasa.gov/cms/):
   Source: Integrated Marine Observing System (IMOS) - National Collaborative Research Infrastructure Strategy, an Australian Government Initiative. https://imos.aodn.org.au
5. Seabed current stress:
   Source: CSIRO Ribbon Model, CSIRO Oceans & Atmosphere, Hobart
   http://www.emg.cmar.csiro.au/www/en/emg/projects/-Ribbon--Model.html
6. Terrain morphometry (Lucieer 2007):
   Source: Vanessa Lucieer, Institute for Marine and Antarctic Studies, University of Tasmania,
   http://www.imas.utas.edu.au/people/profiles/current-staff/l/Vanessa-Lucieer

7.5 Appendix 5: Trawl effort and spatial management datasets

Commonwealth trawl fishing effort:

Source: Commonwealth trawl fishery logbooks and VMS data. Australian Fisheries Management Authority (AFMA) [Confidential].

Commonwealth trawl fishery closures:

Source: Australian Fisheries Management Authority (AFMA), and CSIRO: Fisheries Spatial Management through time. MarLIN # 14472.
http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=14472

Commonwealth Marine Reserves:

Commonwealth of Australia (2014) Australia's network of Commonwealth Marine Reserves.
http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B2E8DD19C-1B93-4D90-BD1C-128DDC4A2998%7D Source: Environment Australia

Marine Protected Areas:

Collaborative Australian Protected Areas Database (CAPAD) 2012 – Marine.
http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B9F45DF80-CB86-440C-98DD-0B206B86D712%7D Source: Environment Australia

7.6 Appendix 6: Maps of updated ocean colour variables

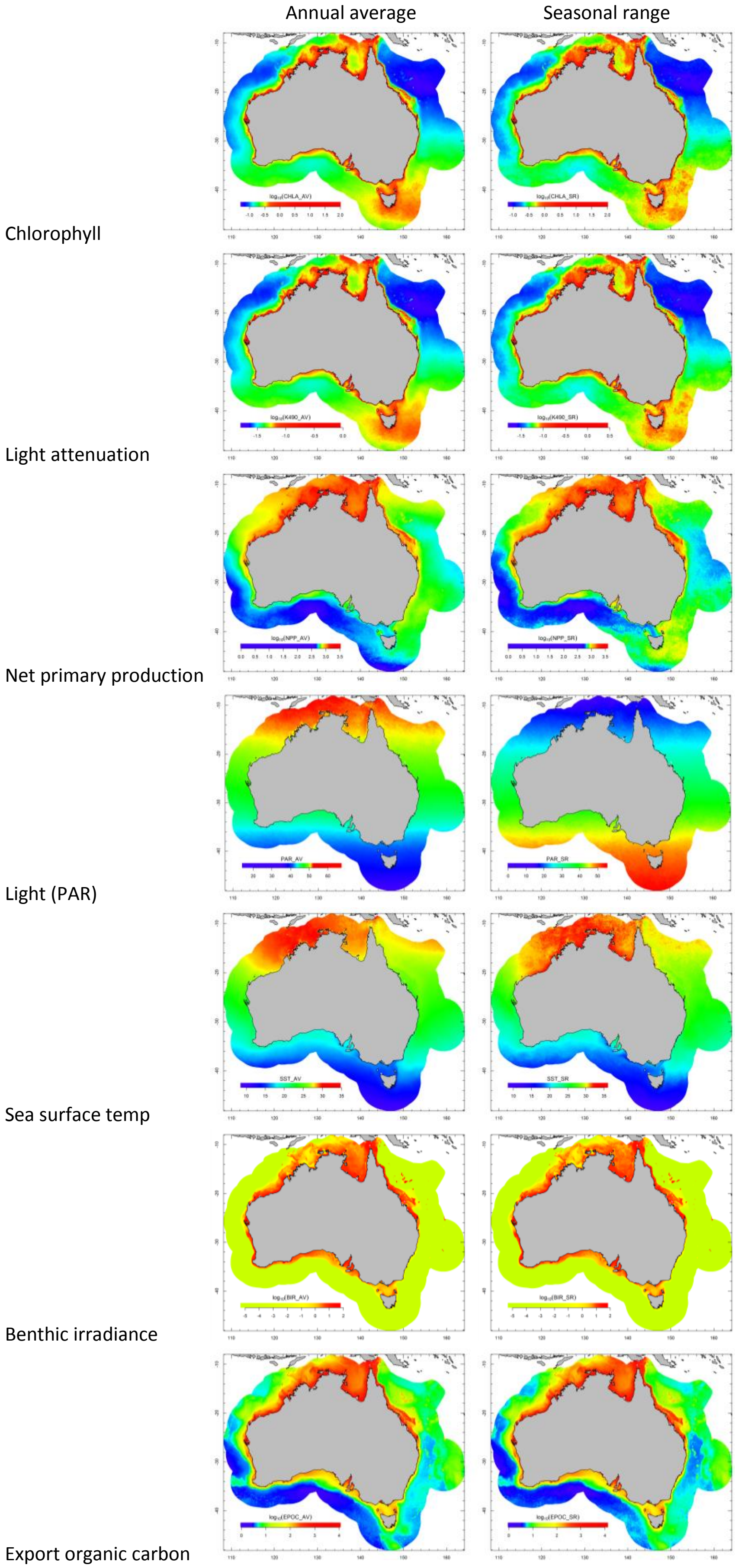

Figure 20 Maps of updated the Ocean Colour derived variables, at 0.01° resolution.

7.7 Appendix 7: List of researchers and project staff

Roland Pitcher, CSIRO

Alan Williams, CSIRO

Nick Ellis, CSIRO

Franzis Althaus, CSIRO

Ian McLeod, CSIRO

Rodrigo Bustamante, CSIRO

Robert Kenyon, CSIRO

Michael Fuller, CSIRO

7.8 Appendix 8: Intellectual Property

Published, widely disseminated and promoted, and/or training and extension provided. Related products and/or services developed. Relates mainly to outputs that will largely be available in the public domain, but components may be commercialised or intellectual property protected.

Data collated by the project are existing IP and most have associated data agreements that do not permit provision of data to third parties. In particular, fishing effort data are confidential and maps of fishing effort cannot be made publicly available at the fine scale and detail used in this project.

All derived products produce by the project are expected to be unrestricted and thus made available in the public domain.

FOR FURTHER INFORMATION

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