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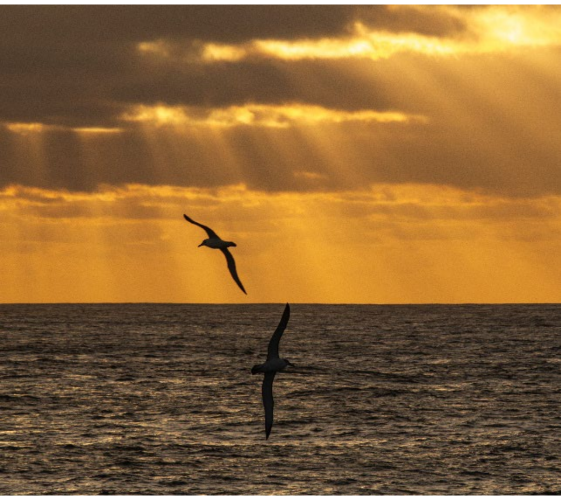
Designing a targeted monitoring program to support evidence-based management of Australian Marine Parks

National Implementation

Piers K Dunstan, Jeffery Dambacher, Skipton N.C. Woolley
Jacquomo Monk, Neville Barrett, Keith R. Hayes and Scott Foster

Parks Australia: Steffan A. Howe, David Logan, Cath R. Samson and Scott O. Francis



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UNIVERSITY of TASMANIA

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Please address inquiries to: Piers .Dunstan@csiro.au or Steffan.Howe@dcceew.gov.au

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NESP Marine and Coastal Hub partners

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Executive summary

Parks Australia, supporting the Director of National Parks, manages 60 Australian Marine Parks which are in Commonwealth waters. Commonwealth waters extend from the outer edge of State and Territory waters (approximately 5.5 km from the shore) to the outer boundary of Australia's exclusive economic zone (generally around 370 km from the shore). These parks are vast, covering 2.8 million km^2, about 31% of Australia's marine jurisdiction.

In 2016 the Director of National Parks instigated the development of a Monitoring, Effectiveness (ME) framework for the Australian Marine Park (AMP) estate. The ME framework aims to help Parks Australia move from the scoping and planning stages of the adaptive management cycle to the do, evaluate, report and improve stages. The broader ME system consists of an overarching Framework, supporting ME plan and network level Science Plans. In December 2019 Parks Australia engaged the Marine Biodiversity Hub to assist in the design of a Science Plan for the South-east marine region, which is described in detail in Hayes et al. (2021).

This report details the extension of the methods applied in Hayes et al. (2021) to the remaining AMP networks (South west, North west, North, Temperate east) and Coral Sea Marine Park. The ME system is underpinned by a common language that provides nationally consistent definitions, for: a) Natural, cultural, and heritage values; (b) Social, cultural, and economic benefits; (c) Activities and anthropogenic pressures; and, (d) Biophysical, and social and economic drivers.

An updated version of the Natural Values ecosystems map is provided in this report, with improved predictions for southern rocky reef systems and updated pressures identified in the Pressures common language. The expert-based vulnerability assessment was extended to all networks and updated with additional information based on responses from experts.

Key Natural Values (KNVs), which warrant special consideration within the networks, were identified for each network through an expert elicitation process. This information was provided for the level 2 prioritisation.

The updated ecosystem vulnerability assessment, updated ecosystem map and updated pressures were combined to provide a national relative cumulative impact index that was used to identify priorities within AMPs. The information on total impact was combined with the understanding of how management had changed with the implementation of the management plans for the South west, North west, North and Temperate east Networks and the Coral Sea MP. This allowed identification of ecosystem/zone combinations where there were (1) ongoing allowable activities responsive to management, (2) mitigation or removal of pressures and (3) pressures less responsive to management. The ecosystem/zone combinations were ranked on these three criteria and the top 10% for each criteria in each network were identified as level 1 priorities.

Level 2 prioritisation is a manual step that uses a criteria-based approach to ensure other key considerations, such as the location of Key Natural values, the ability to test the effects

of different park zoning arrangements and additional representative areas, are accommodated in, and used to refine, the monitoring priorities identified at level 1.

The Level 3 prioritisation involved assessing the availability of adequate baseline information for areas identified through the Level 2 prioritisation, to form the basis of a long-term monitoring program. Selection of ecosystems in this level of prioritisation also considers maintaining representation of Key Natural Values and ecosystems across provincial bioregions as with the Level 1 prioritisation.

This report complements the work done in Hayes et al. (2021), and taken together represents a full national priority list for monitoring inside AMPs. This work also provides a nationally accepted common language to describe natural values and pressures and a robust approach to combining this information to inform national priorities. The ME framework described here represents a significant enabling-step towards an adaptive, integrated and place-based management regime.

1. Introduction

Parks Australia has responsibility for the management of 60 Australian Marine Parks (AMPs), located in Commonwealth waters. Management plans set out the approach to managing these marine parks. There are six management plans – one for each of the five marine park networks (the North, North-west, South-west, South-east and Temperate East networks) and one for the Coral Sea. The management plans for parks in the Indian Ocean Territories are yet to be finalised.

Parks Australia has committed to adaptive management of Australian Marine Parks (AMPs). A Management Effectiveness (ME) system (previously termed a Monitoring, Evaluation, Reporting and Improvement (MERI) system) is being established to support evidence-based adaptive management and decision-making, and to assist the Director of National Parks in evaluating the effectiveness of its management of the Commonwealth parks and gardens. The first step in implementing the ME system is the identification of monitoring priorities.

To identify monitoring priorities this project also had to deliver several pre-requisites to underpin this prioritisation process. Monitoring priorities for the South-east Marine Park Network were identified through a pilot project funded by the NESP Marine Biodiversity Hub (Hayes et al. 2021). The pilot project identified ecosystems and key natural values within AMPs, combined an understanding of the pressures that impacted ecosystems, the objective of the different zones and parks, consideration of characteristic values and the practicality of monitoring different types of ecosystems to identify monitoring priorities. This project extends the approach taken in the South-east Network to the remaining four networks and the Coral Sea Marine Park and details of where these methods have been modified.

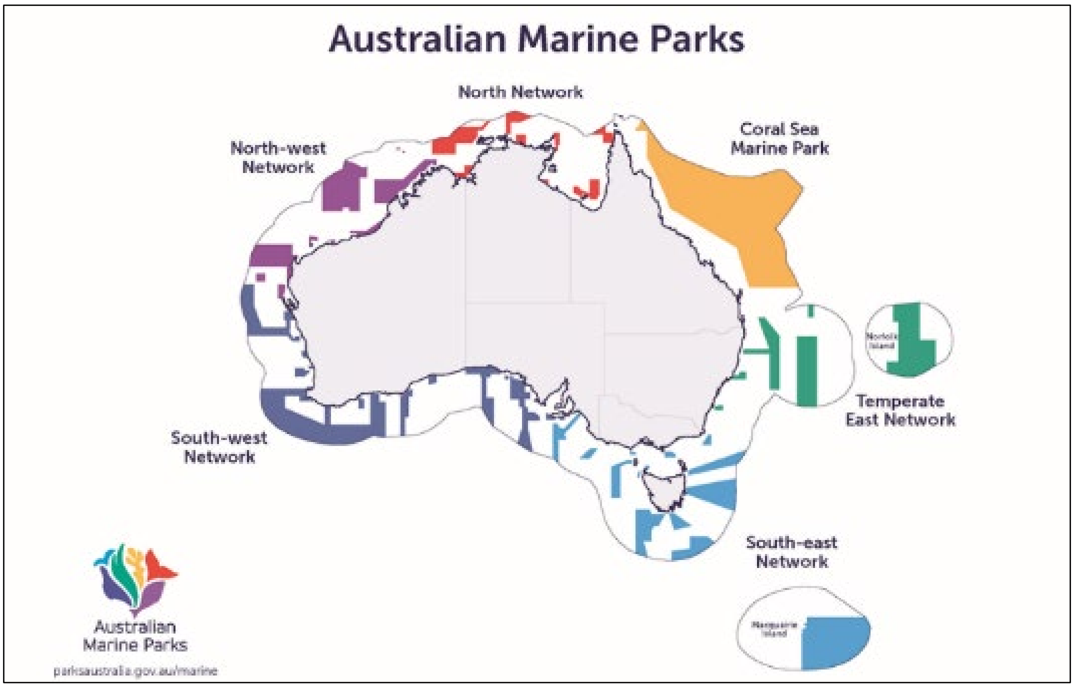

Figure 1: Application of approach outlined in Hayes et al. (2021) to the South-west, North-west, North, Temperate East networks and Coral Sea Marine Park.

Understanding the activities allowed under each management plan is key to the evaluation of the effectiveness of each zone in meeting its zone objectives.

The zone objectives include:

1) **Sanctuary Zones** (IUCN Ia) is to provide for the conservation of ecosystems, habitats and native species in as natural and undisturbed a state as possible.
2) **National Park Zones** (IUCN II) is to provide for the conservation of ecosystems, habitats and native species in as natural a state as possible.
3) **Habitat Protection Zones** (IUCN IV) is to provide for the conservation of ecosystems, habitats and native species in as natural a state as possible while allowing activities that do not harm or cause destruction to seafloor habitats.
4) **Recreational Use Zones** (IUCN IV) is to provide for the conservation of ecosystems, habitats and native species in as natural a state as possible while providing for recreational use.
5) **Multiple Use Zones** (IUCN VI) is to provide for ecologically sustainable use and the conservation of ecosystems, habitats and native species.
6) **Special Purpose Zones** (IUCN VI) is to provide for ecologically sustainable use and the conservation of ecosystems, habitats and native species, while applying special purpose management arrangements for specific activities.

The project used a comprehensive and systematic understanding of activities allowed and those which are no longer allowed under zoning to estimate the impacts on ecosystems identified within zones. The approach considers the type of activity, the known impacts of each type of activity on ecosystems, and the intensity of each activity acting on each ecosystem. This information was used to identify the natural values monitoring priorities and locations that can be used to test the effectiveness of park management in meeting the objectives of the AMP zones.

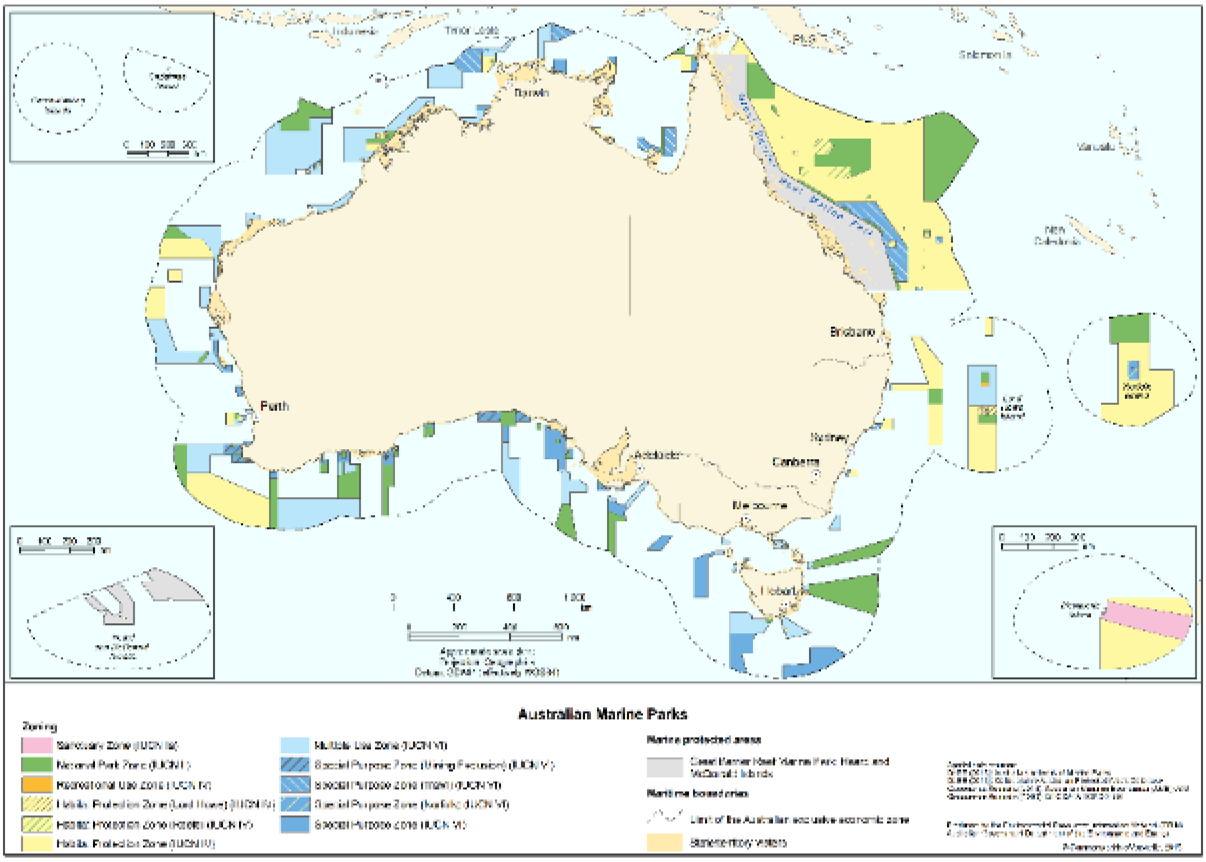

Figure 2: Australian Marine Parks – zoning

1.1 Overview of the Australian Marine Parks Management Effectiveness system

A robust ME system will provide an indication of the overall health of values in the parks, the benefits they provide to people and the effectiveness of park management. The system will include indicators that help to measure success and identify opportunities to improve management actions. Monitoring will be prioritised to address the most pressing management issues and questions. It is proposed that the AMP ME system will be guided by the following documents:

1) An overarching Parks Australia ME Framework
2) An AMP Science Strategy
3) Network-level science plans

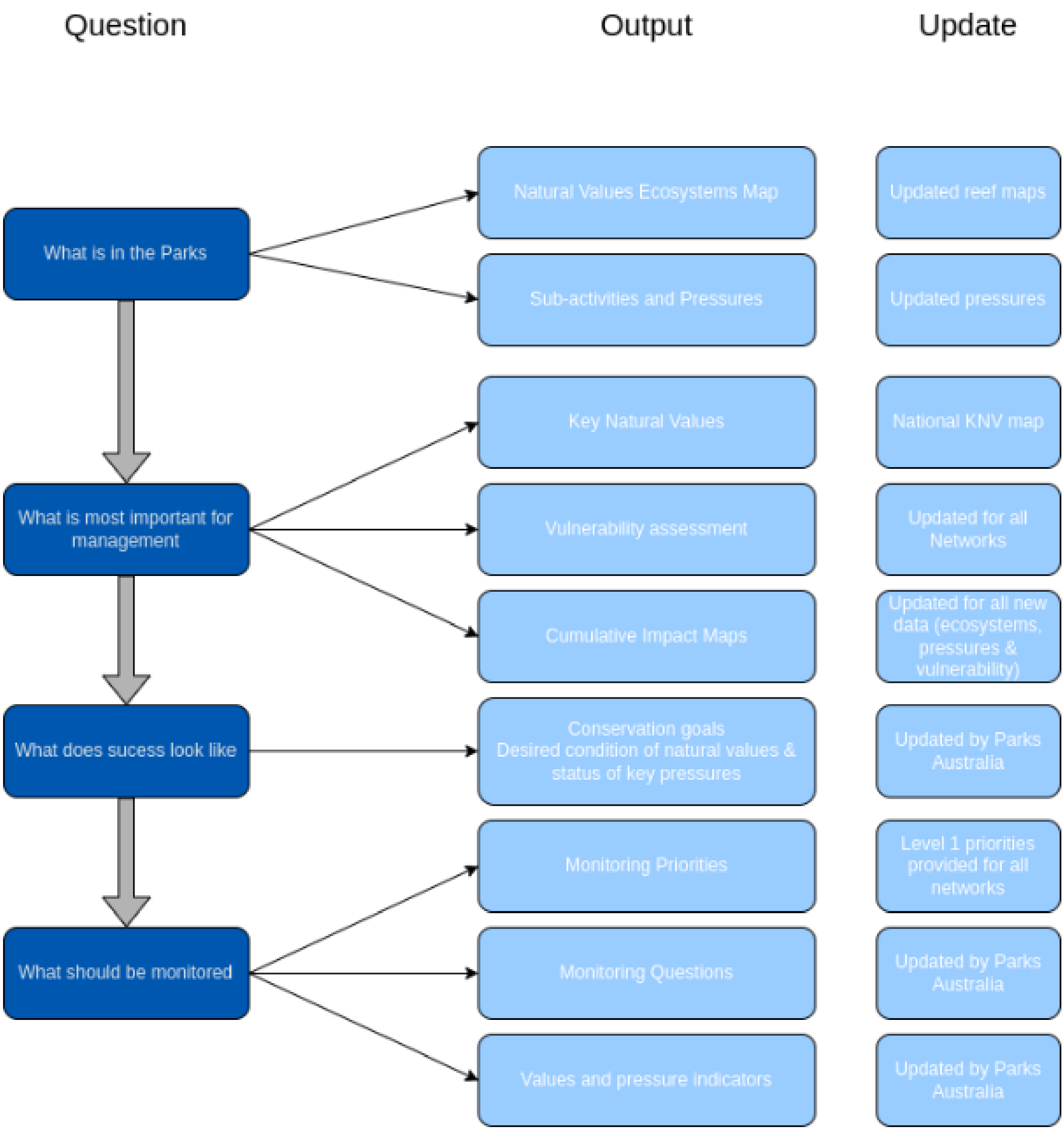

Figure 3: An overview of the key questions and elements considered in the process of identifying monitoring priorities for AMP science Plans and the updates from the SE pilot project

A detailed description of the interaction between the monitoring prioritisation, the ME system (noting the name change from MERI) and the network level science plans can be found in Hayes et al. (2021).

2. What is in the Parks?

2.1 Controlled common language

The ME system is underpinned by a controlled, common language that provides a nationally consistent, carefully defined, lexicon for: a) Natural, cultural, and heritage values; (b) Social, cultural, and economic benefits; (c) Activities and anthropogenic pressures; and (d) Biophysical, and social and economic drivers. The common language remained the same as detailed in Hayes et al. (2021). Additional values, benefits, pressures and drivers were considered in this project as it expanded to a national focus.

2.2 Map creation

2.2.1 Ecosystems

Natural values in the common language are defined at three levels from the top to the bottom of the hierarchy: 1) ecosystem complexes, 2) ecosystems, and 3) ecosystem components. The common language identifies 26 different ecosystems within AMPs - 22 benthic ecosystems and four pelagic ecosystems. A national map of ecosystem complexes is shown in Appendix E.

Ecosystems in the natural values common language are delineated by habitat and depth which ensures that their boundaries are identifiable. This enables the creation of an Australian marine ecosystem map (Figure 3). Geoscience Australia’s 2009, 250 m resolution bathymetry https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/67703 serves as the basis for the map. The process to create the ecosystem map followed the approach described in Hayes et al. (2021). Additional information was sought to update the locations of reef habitat around Australia. Coral reef mapping was improved with the additional of data from the Allen Coral Atlas (2022) and mapping of temperate reef systems was improved with an updated predictive reef layer that addressed some of the weaknesses of the modelling described in Hayes et al. (2021). The updated continental shelf reefs model is described below.

It is important to note that the common language adopts a functional, largely geo-physical perspective to define ecosystems, which assumes a combination of physical (e.g. rocky reefs) and biological (e.g. vegetated soft sediments) level surrogacy to represent Australia’s marine ecosystems. The resulting ecosystem map does not therefore, by itself, define the distribution of biodiversity in Australia’s Commonwealth marine area. However, when the map is combined with the Integrated Marine and Coastal Regionalisation of Australia (IMCRA), which delineates marine biogeographic regions on Australia’s continental shelf, a more complete picture of the distribution of species and the functions that they perform emerges.

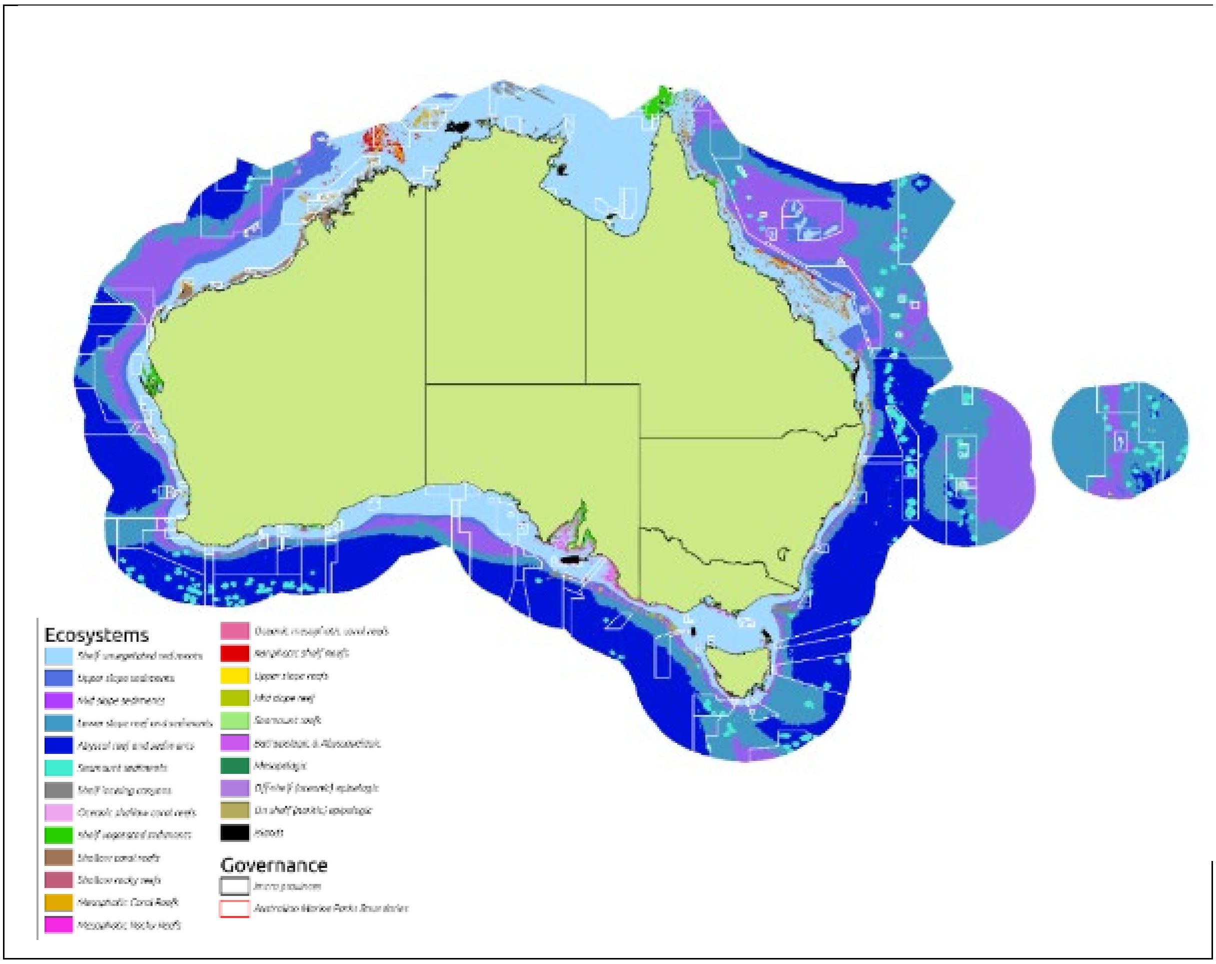

Figure 4 : Australian ecosystem map developed for the AMPs. This map is based on a large raster that identifies the depth in every 250 m grid cell across the Australian commonwealth marine area. The raster was developed from Geoscience Australia's 2009 250 m resolution bathymetry product. The map was then produced in a sequence of steps that geolocate the 19 of the 22 benthic ecosystems and all 4 of the pelagic ecosystems identified in the AMP common language, based on their characteristic habitat types and depth range. Benthic ecosystems not shown are Beaches, Intertidal coral reefs and Rocky shores. Macquarie Island is not included due to the lack of national data sets and the absence of information on the location of reefs.

2.2.2 Improved shelf reefs model

A key component of the implementation of the monitoring prioritisation process was to update the shelf reef model. Hayes et al. (2021) identified that there were significant gaps in the data used to predict reef locations – the models overpredicted in some locations, particularly in southern Australia. Additional data was sought to assist in improving the predictions of reef from researchers in NSW, VIC, SA and WA. The data was obtained from surveys from the University of WA, Deakin University, SARDI and University of Sydney. This additional data provided substantial additional information on the distribution of reef in southern Australia.

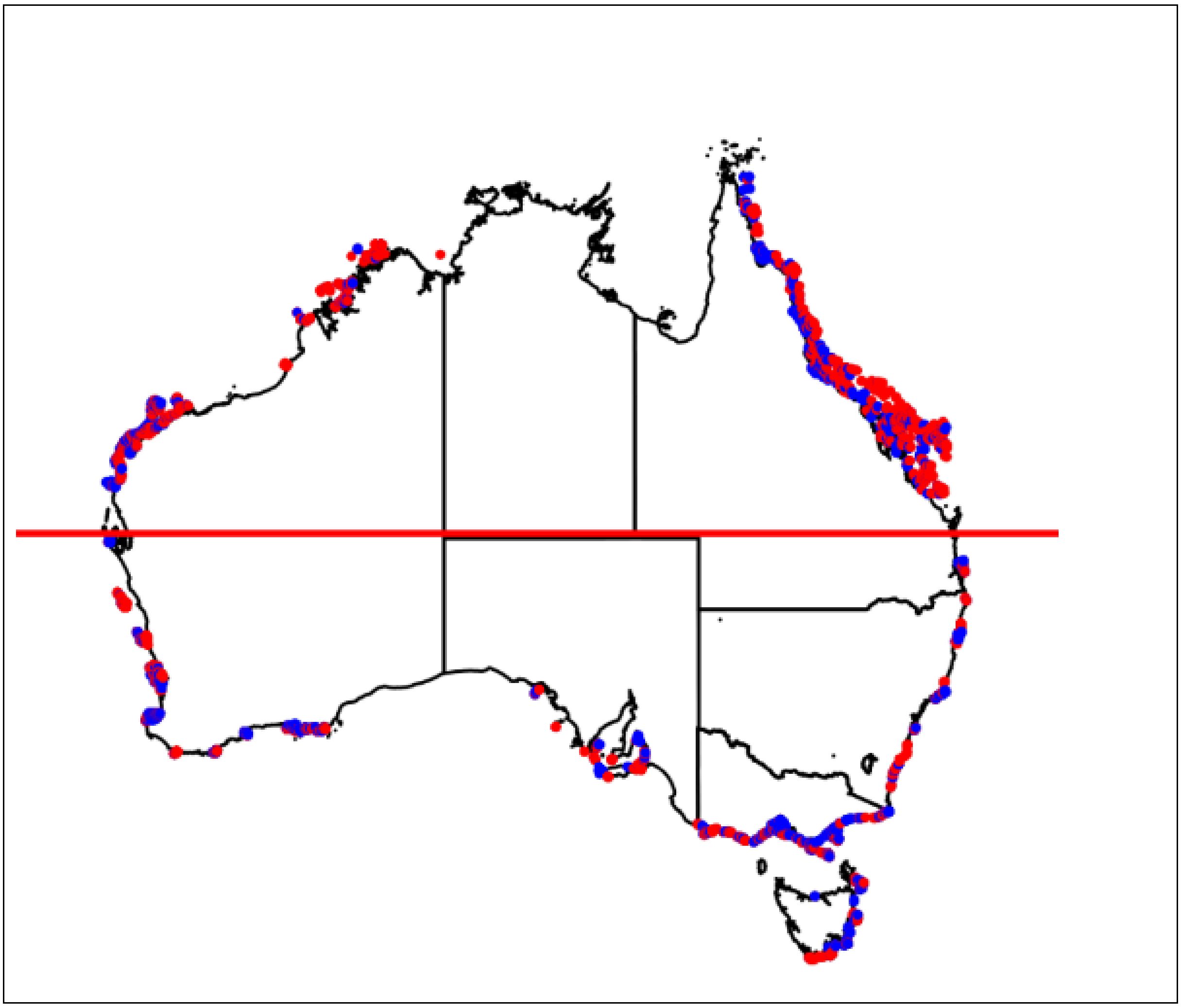

Figure 5: Locations of the images throughout the country. These are the locations where we see reef (red) / not reef (blue). Updated predictions are made only below the red line

This was added to the data used in the original modelling as described in Hayes et al. (2021). The modelling approach is described in detail in Appendix F and uses a very similar approach. The new predictions were only made for latitudes greater than 25.7834, which corresponded with the most northern latitude of the new observations. To create the updated maps the predicted reefs from Hayes et al. (2021) were used above the red line and updated predictions as described in Appendix F were used below the red line.

2.2.3 Sub-activities and pressures

The 58 activities and sub-activities common language remained the same as detailed in Hayes et al. (2021). There were a total of 200 specific pressures linked to activities & sub-activities identified in the ME common language. There were 46 specific pressures that were directly measured and 77 that were estimated using proxies, leaving a remaining 77 specific pressures without measurement. These are identified in Appendix E of Hayes et al (2021). Unidentified pressures include carbon storage, marine debris and noise from aquaculture, commercial media, commercial aviation tours and all pressures linked to General use, access & waste management. Full details can be seen in Hayes et al. (2021). Additional information was sought to update the pressures associated with the sub-activities. For many pressures, this was not possible due to time constraints and confidentiality concerns. However, five data sets were updated and details are provided in Table 1. In addition, data on ocean acidification was removed as there were concerns about the original layer and no appropriate updated layer could be sourced. The key concern for ocean acidification was that the spatial pixel size was too large and could not be smoothed across varying depths. Full details of updated layers are found in Appendix B.

Table 1: Updated Pressure Layers

Original Data Set	Updated Data Set
Commonwealth Fisheries 2011 to 2015	Commonwealth Fisheries July 2013 to June 2018
Ocean Noise	Noise prediction from Peel et al (2021)
Recreational fishing	Recreation Fishing prediction from Navarro (2021)
Sea Level Rise	CSIRO Sea Level Rise observations
Oil & Gas Wells	Extract from NOPTA database for July 2013 to June 2018

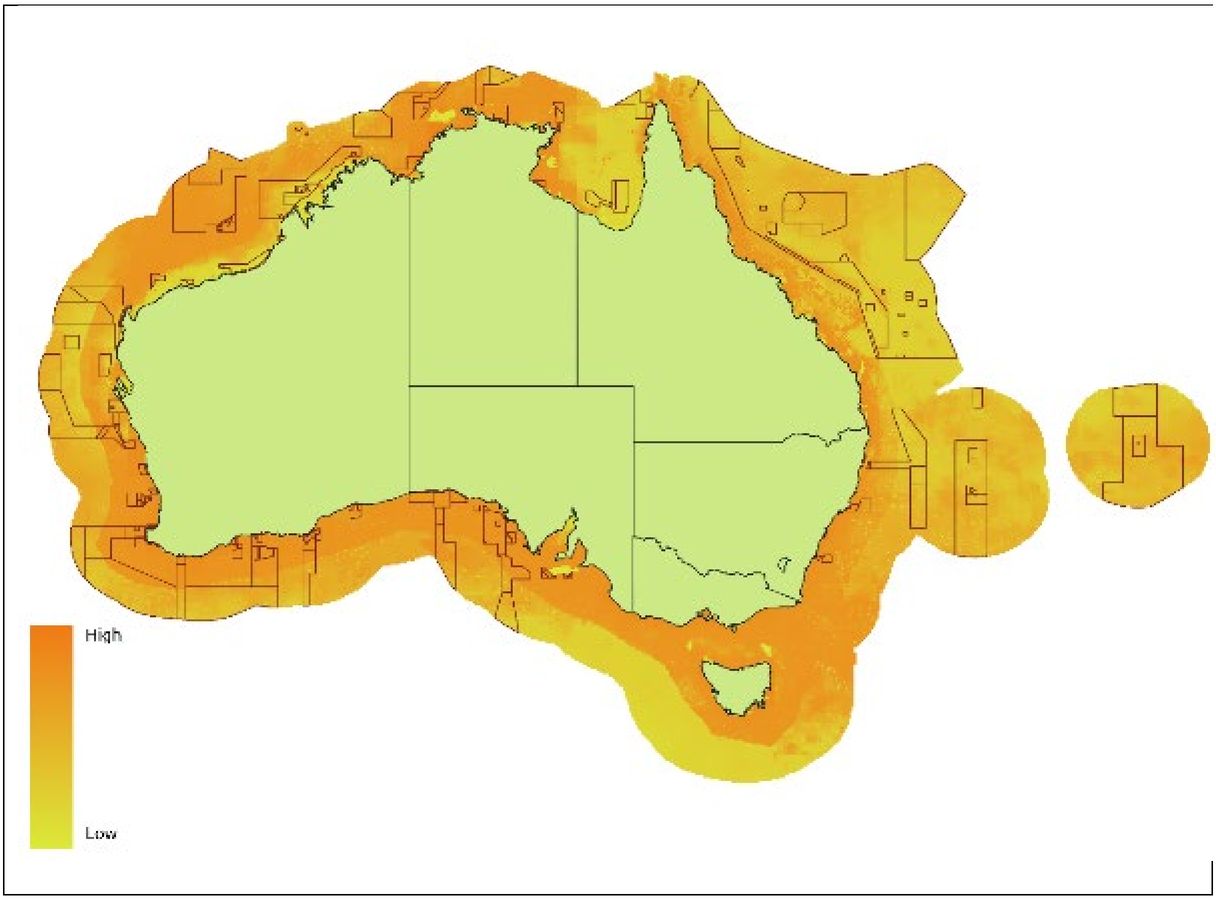

Figure 6: Sum of activities/sub-activities for all pressures

3. What is most important for management

3.1 Key natural values

The ME system recognises the existence of Key Natural Values (KNVs) that warrant special consideration. Key Natural Values are areas that contain a biological or ecological feature that is important for the functioning of ecosystems within an Australian Marine Park Network or Coral Sea Marine Park. KNVs were developed to assist with monitoring prioritisation as part of the development of the network level science plans and are generally at a finer scale than Key Ecological Features (KEF) and Biologically Important Areas (BIA) but are not intended to replace them. KNVs are described using a set of criteria and serve a different purpose.

The KNV criteria are largely based on Ecologically and Biologically Significant Area criteria (EBSA – Convention on Biological Diversity), which overlap with the Key Ecological Feature (KEF) and Biologically Important Area (BIA) criteria. In developing the KNV criteria, other international criteria for important marine areas such as Key Biodiversity Areas (KBAs - IUCN), Particularly Sensitive Sea Areas (PSSAs – International Maritime Organization), and Important Marine Mammals Areas (IMMAs - IUCN Marine Mammal Protected Areas Task Force) were also considered. Details of the criteria and the overlaps with other criteria sets can be found in Hayes et al (2021)

The KNV criteria include additional considerations beyond the EBSA criteria, such as social and economic benefits, as described in the AMP management plans and the EPBC Act[1]. As a rule, species or populations were only considered key natural values if they resided largely within the park, or if the park was important for certain aggregations, such as breeding, feeding etc. For example, migratory or transient species that are only passing through the park weren't considered key natural values unless they were especially important to the community.

Key Natural Values (KNVs) are required to fulfill the following requirements (in addition to ranking 'high' for at least one of the KNV criteria):

- The location and boundaries of the value can be defined and mapped
- The value resides within (or largely within) an AMP
- The value has a consistent presence in its defined location
- The value (including the location of the value) stands out as being especially important in comparison to other values in the network (or Coral Sea Marine Park), or the broader network of AMPs

[1] First Nations science priorities will be identified through a dedicated place-based, co-designed program that supports knowledge exchange and two-way science on Sea Country that overlaps with Australian Marine Parks.

KNV requirements ensure that KNVs are useful in identifying the most suitable locations upon which to focus monitoring activities.

Key Natural Values for the South-west, North-west, North, and Temperate East networks and the Coral Sea MP were identified through a template that was distributed to all experts who undertook the vulnerability assessment. In addition, virtual workshops for each network were held in mid-2022 to identify additional KNVs that were not captured in the template. The list of workshop participants is included in Appendix E.

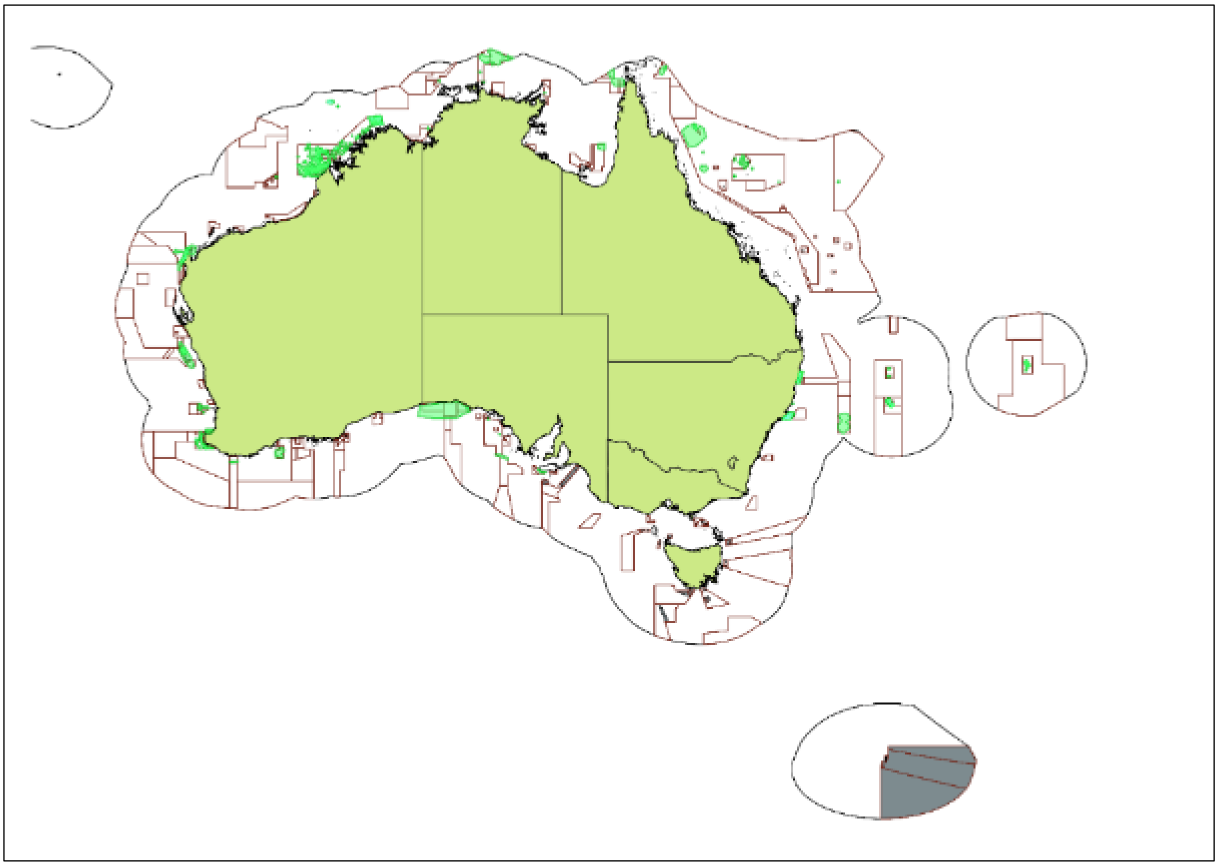

Figure 7: Key Natural Values for the South-west, North-west, North, Temperate East networks and Coral Sea MP identified through on-line submissions and workshops. KNVs identified previously in the South East Network are shown in grey

3.1.1 Process to identify KNVs within AMPs

KNVs are described using a template that lists each of the criteria, the level of importance and provides a space for a text description and references and a physical location/spatial data file. The process to describe a KNV is described below. Areas identified but that did not meet all the steps listed below were noted but not included as formal KNVs.

1) Identify the ecological or biological feature that will be described by the KNV.
    a) It should occur within at least one AMP, but may extend beyond the AMP boundary. Please identify the full extent of the KNV which may be outside the AMPs.
2) Rank each of the criteria (High, Medium, Low, NA) for that feature.

a) The KNV criteria ranks should be done relative to the rest of the ecosystems within the AMP Network its being described in.

b) A KNV should be ranked high for at least one criteria.

3) Provide a rationale for the ranking and references as appropriate.

4) Identify the Ecosystem/s (listed in the Natural Values Common Language tab), and where relevant ecosystems components.

5) Identify the boundary of the KNV, either by providing a reference/polygon or drawing the location on the KNV online map.

3.2 Risk assessment

3.2.1 Cumulative impact assessment

We followed steps outlined in Hayes et al. (2021) to undertake the cumulative impact assessment. The objective of this step is to identify and prioritise locations within the Australia's marine regions according to the magnitude of sub-activities that occur in that location, and the vulnerability of the ecosystems at that location to the pressures exerted by these sub-activities. The cumulative impact assessment aims to provide a relative measure of cumulative impacts across the Australia's marine region and Commonwealth Marine Reserves. The score generated here is not the absolute risk and it does not include estimation of the indirect effects of any activities.

One of the most popular methods for expressing cumulative impacts is by scoring a set of criteria that are combined into an impact weight, an approach exemplified and made popular by Halpern et al. (2008). In this approach, cumulative impacts are expressed as a weighted sum of pressure x ecosystem interactions across a defined regular grid:

$$I_c = \sum_{i=1}^{n} \left[\frac{1}{m} \sum_{j=1}^{m} D_i \times E_j \times \mu_{ij} \right]$$

where is the impact score I_c for raster cell c, D_i is the standardised intensity of anthropogenic pressure at the raster cell location (scaled between 0 and 1; sometimes this involves a log transformation of the data before standardisation), E_j is indicator variable scored 1 if ecosystem j is present at the raster cell location and 0 otherwise is indicator variable scored 1 if ecosystem and $\mu_{ij}$is the impact weight for anthropogenic pressure i acting on ecosystem j. Notice that this approach assumes that pressures act additively on ecosystems, so that the cumulative impact is the weighted sum of the pressures acting at a location. This means that more complex interactions, such a synergies and antagonistic behaviours between pressure cannot be accounted for.

Elicitation of the impact weights is one of the most time demanding steps in this framework, as it requires experts to identify how each ecosystem j will on average, respond to pressure i . This typically requires thousands of impact weights to be identified. Details on the interaction matrix characteristics and vulnerability assessment elicitation are provided in the following two sections.

3.2.2 Interaction matrix

The ME system controlled common language identified 26 ecosystems and 58 activities/sub-activities, leading to 1,508 possible ecosystem–activity/sub-activity combinations. The language also identifies the ecosystem components within ecosystems, and the specific pressures associated with every sub-activity (Appendix B). The cumulative impact assessment in this analysis began by considering all combinations of ecosystem components and specific pressures in a large (200 x 157) interaction matrix (identical to the matrix for the SE Network). Parks Australia scored each cell of the interaction matrix ‘1’ if any form of plausible impact between the specific pressure and ecosystem component was possible, and ‘0’ otherwise. These scores were then checked by the project leader and possible errors highlighted with Parks Australia and corrected where necessary.

The results of the interaction matrix were then “rolled-up” to the next level of the common language hierarchy in order to identify relevant ecosystem–sub-activity combinations and eliminate those combinations where no plausible impact was identified at the ecosystem component–specific pressure level. This process eliminated 468 ecosystem–activity/sub-activity combinations from the analysis, leaving 1,040 to be carried through to the vulnerability and cumulative impact assessment.

3.2.3 Vulnerability assessment

Vulnerability assessments (used to calculate μ_{ij}) were conducted through a snowball survey of experts. An initial seed population of 74 experts was identified by Parks and CSIRO staff. These experts were contacted by email and invited to contribute to vulnerability assessments and elicitations for key natural values. They were also encouraged to nominate additional experts that might be relevant to the list of habitats and regions provided. These nominees were then sent the same email invitation and request for additional names of potential experts. In this way the total number of experts contacted expanded to 137 (Table 2).

Of the invitations sent, a total of 67 experts (49%) sent return emails accepting the invitation to contribute the vulnerability assessments and KNV elicitations. Of these only 19 returned completed vulnerability assessments; a number which constitutes 28% of the invitations accepted and 14% of those sent (Table 1). A total of 55 vulnerability assessment spreadsheets were returned. These spreadsheets provided 74 separate vulnerability assessments when expanded for each region to which they were allocated. Of the 26 ecosystems in the five marine regions considered, a total of 130 ecosystem-region combination were needed to be filled, for which the returned completed assessments covered 43 or 33% (Table 2).

Table 2: Number of invitations sent in snowball survey and vulnerability assessments completed

Invitations sent to seed population of experts	74
Invitations sent to nominees	63
Total invitation sent	137
Invitations accepted & agreeing to contribute	67†
Experts returning assessments	19‡
Assessment spreadsheets returned	55
Completed assessments	74
Ecosystems to be assessed in five regions	130
Ecosystems assessed	43•
Ecosystems not assessed	87

†: 49% of total sent
‡: 28% of invitations accepted and 14% of invitations sent.
•: 33% of total to be assessed.

The greatest number of vulnerability assessments were completed for the South-west and Temperate East regions, with less than ten being returned for the North or Coral Sea regions (Table 3). Shallow coral reefs and shallow rocky reefs ecosystem received the greatest attention, but of the 26 ecosystems identified, nine had no additional vulnerability assessments completed in any region outside the South East. The value of μ_{ij} for each ecosystems was calculated by taking the average of all responses for that ecosystem across all networks. A potential extension would be networks level assessments if more responses could be obtained per network.

Table 3: Number of vulnerability assessments completed for each Ecosystem and Network.

Ecosystem	South West	North West	North	Coral Sea	Temp. East	Total
Abyssal reef and sediments	0	0	0	0	0	0
Bathypelagic and Abyssopelagic	0	0	0	0	0	0
Beaches	0	0	0	0	0	0
Intertidal coral reefs	0	0	0	1	0	1
Islands (including cays and islets)	0	0	0	0	0	0
Lower slope reef and sediments	0	0	0	0	0	0
Mesopelagic	1	0	0	0	0	1
Mesophotic coral reefs	0	2	1	2	0	5
Mesophotic rocky reefs	2	0	0	0	2	4
Mid-slope reefs	2	1	0	0	1	4
Mid-slope sediments	2	1	0	0	1	4
Oceanic shallow coral reefs	0	2	0	2	1	5
Oceanic mesophotic coral reefs	0	0	0	0	0	0
Off-shelf (oceanic) epipelagic	0	0	0	0	0	0
On-shelf (neritic) epipelagic	2	0	0	0	2	4
Rariphotic shelf reefs	1	1	0	0	1	3
Rocky shores	1	0	0	0	2	3
Seamount reefs	0	0	0	0	0	0
Seamount sediments	0	0	0	0	0	0
Shallow coral reefs	0	4	2	3	3	12
Shallow rocky reefs	5	2	0	0	6	13
Shelf-incising canyons	2	1	1	0	1	5
Shelf unvegetated sediments	1	0	0	0	1	2
Shelf vegetated sediments	2	1	0	0	1	4
Upper-slope reefs	1	1	0	0	0	2
Upper-slope sediments	1	1	0	0	0	2
Total	23	17	4	8	22	74

3.2.4 Cumulative impact scores

We followed the Hayes et al. (2021) method of generating cumulative impact scores, but did so for the entire Australian region using the updated ecosystem and pressure datasets. The cumulative impact scores for the benthic ecosystems and pelagic ecosystems are shown in Figures 4.1 and 4.2 respectively. For benthic ecosystems, each grid cell in the analysis represents a single ecosystem, hence the cumulative impact scores are the weighted sum of the standardised sub-activity pressures that operate in that cell, weighted by the vulnerability scores for the (unique) benthic ecosystem that occurs in that cell. The same is true for the on-shelf (neritic) epipelagic raster cells in the pelagic analysis.

In the pelagic ecosystems outside this region, however, each raster cell represents three depth layered ecosystems: epipelagic, mesopelagic and bathy-abyssopelagic. The cumulative impact scores in each of these raster cells have been averaged across these ecosystems as required by Equation 1. Note that this operation is designed to place the impact scores on a per ecosystem basis, but denies the reality, as emphasised by much of the expert commentary provided during the elicitation, that these ecosystems are strongly connected with changes in one propagating through to the others.

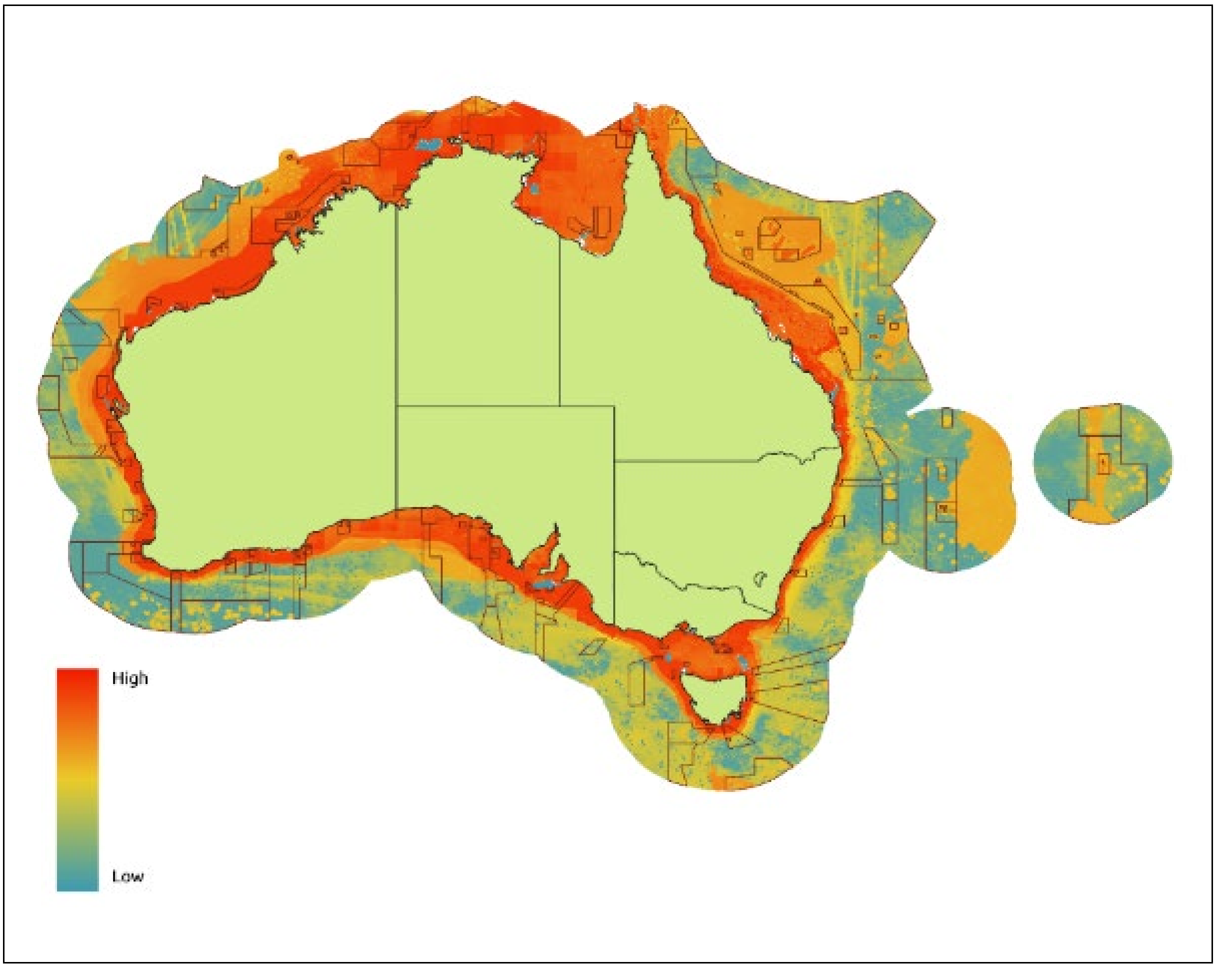

Figure 8: Cumulative impact map for benthic ecosystems for Australia’s EEZ (excluding Macquarie Island). This figure shows the cumulative impact scores across the mapped benthic ecosystems. The map should be interpreted as showing the relative intensity of cumulative impacts in Australia’s marine estate.

The cumulative impact score is calculated as a weighted sum of the (standardised) activity/sub-activities pressure layer values in each raster cell, where the weighting reflects the vulnerability of the benthic ecosystem in each cell to the activity/sub-activities that exert pressure there. The figure legend shows the 10th percentiles of the cumulative impact score, that is the values that contain 10%, 20%, 30%…,80%, 90%, 100% of all the cumulative scores across the map. The colour scale is not linear, so take care when interpreting the colours, please look at the legend to understand how the colours map to the cumulative impact score. The absolute values of the scores have no ecologically meaningful interpretation, rather, this is where the highest relative cumulative impacts are expected to occur. Macquarie Island is absent due to the lack of data on reef locations and pressure data.

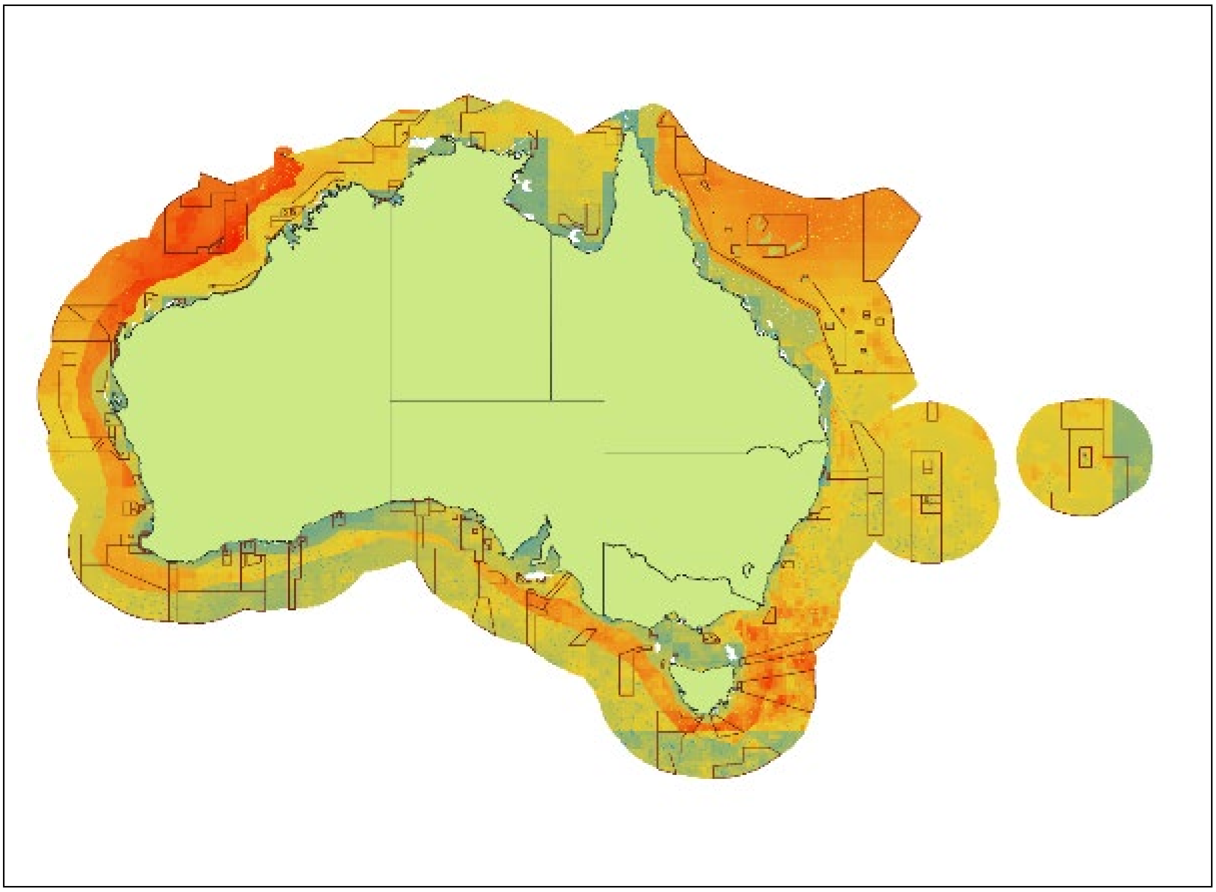

Figure 9: Cumulative impact map for pelagic ecosystems for Australia's EEZ (excluding Macquarie Island). The map should be interpreted as showing the relative intensity of cumulative impacts in the Australia's marine estate.

This figure shows the cumulative impact scores across the 4 mapped pelagic ecosystems identified in the common language, together with the boundaries of AMPs. The cumulative impact score is calculated as a weighted sum of the (standardised) activity/sub-activities pressure layer values in each raster cell, where the weighting reflects the vulnerability of the ecosystem in each cell to the activity/sub-activities that exert pressure there. The figure legend shows the 10th percentiles of the cumulative impact score, that is the values that contain 10%, 20%, 30%…,80%, 90%, 100% of all the cumulative scores across the map. The absolute values of the scores have no ecologically meaningful interpretation. Please note the benthic and pelagic maps are on different colour scales.

4. What does success look like?

Well informed conservation goals and science priorities are intended to be used by marine park managers, scientists, stakeholders and Traditional Owners to inform management interventions, science projects, science collaborations and allocation of resources. The outputs of this project will help guide science action in Australian Marine Parks and increase the impact of science.

4.1 Conservation goals

Conservation goals were developed for natural values identified as monitoring priorities for the AMPs, specifically for an ecosystem associated with a particular park zone (as outlined for the SE network in Hayes et al. (2021). Conservation goals provide greater clarity about what management is seeking to achieve for natural values within marine parks. They are specific, measurable and should be set at ecologically meaningful timeframes where relevant, but otherwise they align with Management Plan timeframes. For example, improvement in the condition of deep-sea coral communities following high impact demersal trawl is likely to take decades. Therefore, conservation goal timeframes are set accordingly.

Conservation goals seek to maintain natural values (consistent with zone objectives) where there is an ongoing allowable activity[2] or pressure likely to be affecting those natural values and improve values where there was a mitigation and removal of pressures pressure that has been mitigated by management. Similarly, they seek to improve resilience of values facing pressures such as climate change and biophysical drivers such as weather or hydrodynamics that are less responsive to marine parks management.

[2] Allowable activities that are no longer ecologically sustainable become pressures.

5. What should be monitored?

5.1 Prioritising locations for monitoring

5.1.1 Prioritisation process overview

The monitoring prioritisation process is driven by the management objectives listed in the management plans for each park, the values and pressures acting within each AMP and the feasibility of monitoring different ecosystems and KNVs. The process for the identification of priorities is derived from Hayes et al. (2021).

Three considerations were taken into account in designing the monitoring prioritisation:

1) The particular ecosystems in specific marine parks and zones where the highest pressures are currently occurring (termed ongoing impacts), or where the largest changes due to management are expected to be seen (termed mitigation and removal of pressures).
2) Pressures or biophysical drivers that are less responsive to management (e.g. climate change) that are expected to influence or mask the change achieved by effective management.
3) Areas that are most suitable for evaluating management effectiveness, including testing the effectiveness of zoning and possible reference sites (depending on the conservation goals and monitoring questions).[3]

These questions were taken into account in developing prioritisation levels to help inform the selection of locations and monitoring questions (Figure 5.1). Each level of prioritisation further refined the list of monitoring locations until a very targeted list was achieved. These levels are identical to those identified in Hayes et al. (2021).

4) Levels 1 and 3 were very structured and data-driven, with additional checks and balances to allow for further analysis if required, in the absence of data or if data resolution was problematic.
5) Level 2 was focused on ensuring there was adequate representation of key features or areas in the priority list of monitoring sites. This was an opportunity to manually add in any features or places that were not picked up through the data driven process of Level 1.
6) Level 4 allowed for final refinement of the priorities if the list of locations resulting from the Level 3 analysis were not feasible to monitor over the life of the management plan. For example, if the Level 3 process identified only a few priority locations with adequate baselines for establishing a monitoring program, those locations would be the highest priority for monitoring and no further refinement would be required.

[3] Monitoring design will be determined separately as part of the AMP Science Program and will depend on conservation goals and monitoring questions.

Priority locations that have inadequate baselines will feed into the separate research prioritisation process.

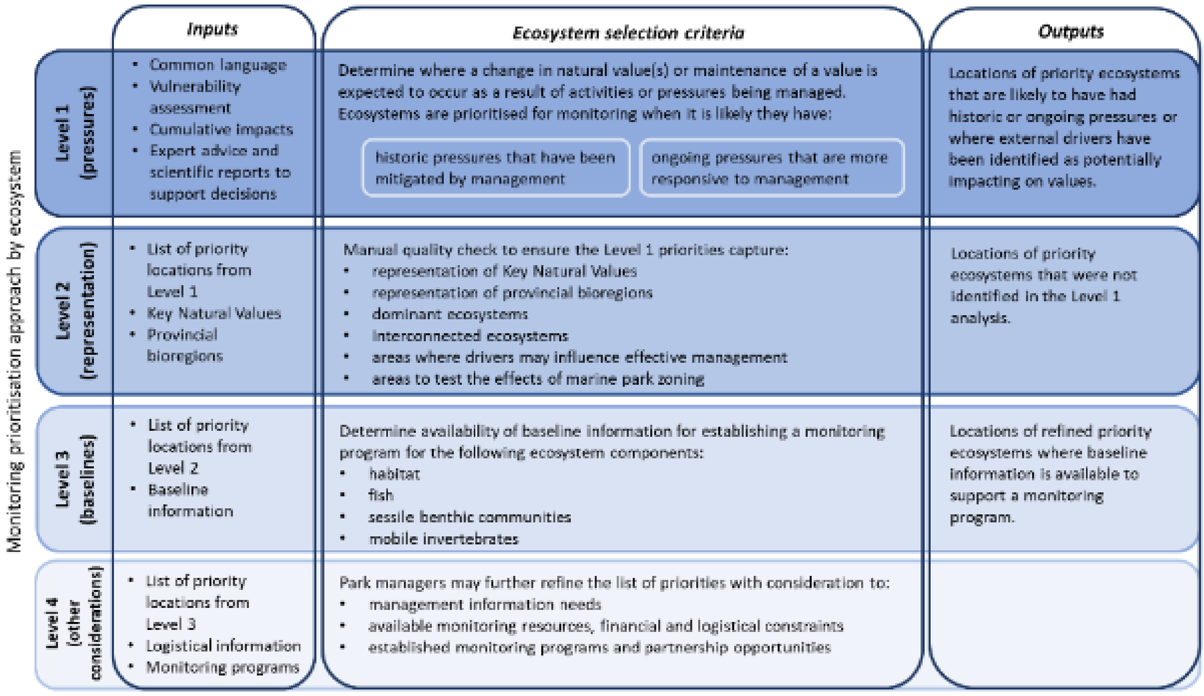

Figure 10: Monitoring prioritisation process for natural values and pressures. This figure shows the inputs, selection criteria and resulting outputs from running each level of the process.

5.1.2 Level 1 Results

The first step in the prioritisation focused on identifying where there were mitigation and removal of pressures or ongoing allowable activities for individual ecosystems. This involved collating a list of all individual ecosystems present in each network by marine park and zone (e.g. multiple use, habitat protection, recreational use zones etc.), a total of 954 combinations across the 4 networks and Coral Sea AMP.

Table 4: Combinations of Zone and Ecosystem across each network

Network	Ecosystem/Zone Combinations
South-west	343
North-west	145
North	89
Temperate East	154
Coral Sea AMP	223

The cumulative impact assessment allows the identification of the **relative** contribution of total impact for each activity/pressure on each ecosystem for the time period before the implementation of the 2018 AMP Management Plans (i.e. all data is prior to July 2018). The total cumulative impact score is calculated as the average impact for that pressure/ecosystem combination in each zone (thus accounting for different sized zones and ecosystems). Proclamation of Parks prior to July 2018 (i.e. Solitary Islands, Lord Howe, Cod Grounds, Ningaloo, Ashmore, Mermaid Reef, Cartier Island, Great Australia Bight and Coral Sea reserves) were noted in the assessment outputs so that it was clear where changes in management had not occurred. The cumulative impact scores are a relative measure of impact and individual scores should be interpreted relative to the other scores in Australian waters – they do not give the absolute impact.

When the Management Plans came into force it was expected that the activities that occur within each zone would change – depending on the activities allowed in the zone. Activities (from the Pressure Common Language) that are allowed or not allowed were documented for each zone. This allows the identification of activities that will continue under the Management Plan and those that will no longer occur in the zone.

Level 1 prioritisation considers two key questions:

1. Are there continued high pressures on an ecosystem in a zone based on the activities that occurred there and are allowed under the Management Plans – ongoing allowable activities responsive to management

For example, Commercial fishing – Net Demersal occurred in Bremer Special Purpose Zone (SPZ) II prior to the management plan coming into force. As the activity was allowed to continue in the SPZ post July 2018, it is assumed that the activity continued to occur, and that the ecosystems in the SPZ remain under pressure from those activities.

2. Is there an expected reduction in pressure on an ecosystem in a zone based on the activities that occurred there no longer being allowed under the Management Plans - mitigation or removal of pressures.

For example, Commercial Fishing – Net Demersal occurred in Bremer National Park zone prior to the management plan coming into force. As this activity was no longer allowed in the NPZ once the management plan came into force, it is assumed that post July 2018 this will no longer occur and the ecosystems in the NPZ will have a reduced level of pressure.

The level 1 prioritisation also identified ecosystems where there are continued allowable activities that are permitted through the management plans – drivers that cannot be managed using spatial zoning such as weather and hydrodynamics, and pressures like climate change that are less responsive to management.

For each of these categories (Ongoing pressures responsive to management, Mitigation or removal of pressures, Pressures less responsive to management) the cumulative impact scores for the pressures in the categories for each zone/ecosystem was calculated.

For example, the total cumulative impact score for shelf sediment ecosystems in Bremer NPZ is 2.044. The Ongoing pressures responsive to management score from all allowed activities for shelf sediment ecosystems is 0.001, the Mitigation or removal of pressures score from all not allowed activities is 1.03 and the Pressures less responsive to management score for unmanageable pressures is 1.012, summing together to the total cumulative impact score.

Ranking Cumulative Impact Scores

Level one priorities for each network (and the Coral Sea MP) were identified using the ongoing pressure, mitigation or removal of pressures, and pressures less responsive to management cumulative impact scores. Each combination of zone and ecosystem within a network was given a rank of 1, 2 and 3 for each of the three cumulative impact scores. This means that each ecosystem/zone combination is given 3 ranks, corresponding to the 3 different cumulative impact scores (Ongoing pressures responsive to management, Mitigation or removal of pressures, and Pressures less responsive to management).).

A rank of 1 (insignificant) was given for ecosystem/zone combinations that were in the bottom 80% of CI scores for a network, a rank of 2 (possible impacts) was given for ecosystem/zone combinations between 80% and 90% of scores for a network and a rank of 3 was given for CI scores in the top 10% (likely impacts). The cumulative impact cut of values for each rank are shown in Table 5. The higher the cumulative impact score for a category of impact, the higher the priority for monitoring the impact.

For example, for shelf sediment ecosystems in Bremer NPZ, Ongoing pressures responsive to management (CI score of 0.001) is given rank 1, the Mitigation or removal of pressures score (CI score of 1.03) is given rank 3 and Pressures less responsive to management (CI score of 1.012) is given rank 1. This ecosystem/zone combination is a high priority for monitoring reductions in pressures, but a low priority for continued pressure.

Table 5: Cut off points for prioritisation ranks for each network

Network		**Temperate East**	**North-west**	**North**	**South-west**	**Coral Sea**
Mitigation or removal of pressures	Insignificant	< 0.005	< 0.013	< 0.1346	< 0.053	
	Possible	0.005 to 0.011	0.013 to 0.045	0.1346 to 0.2204	0.053 to 0.121	0 to 1.00E-05
	Likely	> 0.011	> 0.045	> 0.2204	> 0.121	> 1.00E-05
Ongoing pressures responsive to management	Insignificant	< 0.0682	< 0.0252	< 0.325	< 0.157	
	Possible	0.0682 to 0.1899	0.0252 to 0.0562	0.325 to 0.4464	0.157 to 0.334	0 to 1.00E-05
	Likely	> 0.1899	> 0.0562	> 0.4464	> 0.3344	> 1.00E-05
Pressures less responsive to management	Insignificant	< 0.7006	< 1.2726	< 1.1286	< 1.3428	< 1.007
	Possible	0.7006 to 0.8172	1.2726 to 1.5096	1.1286 to 1.389	1.1976 to 1.3428	1.007 to 1.1924
	Likely	> 0.8172	> 1.5096	> 1.389	> 1.3428	> 1.1924

This process is repeated for every combination of zone and ecosystem (as in Table 4) within each network. It identifies the level 1 monitoring priorities specific to each network. The cuts-off for the Coral Sea MP are significantly lower than other networks, due to the small amount of activity with the marine park. National Maps, including the results from the South East Pilot Project are shown in Appendix E.

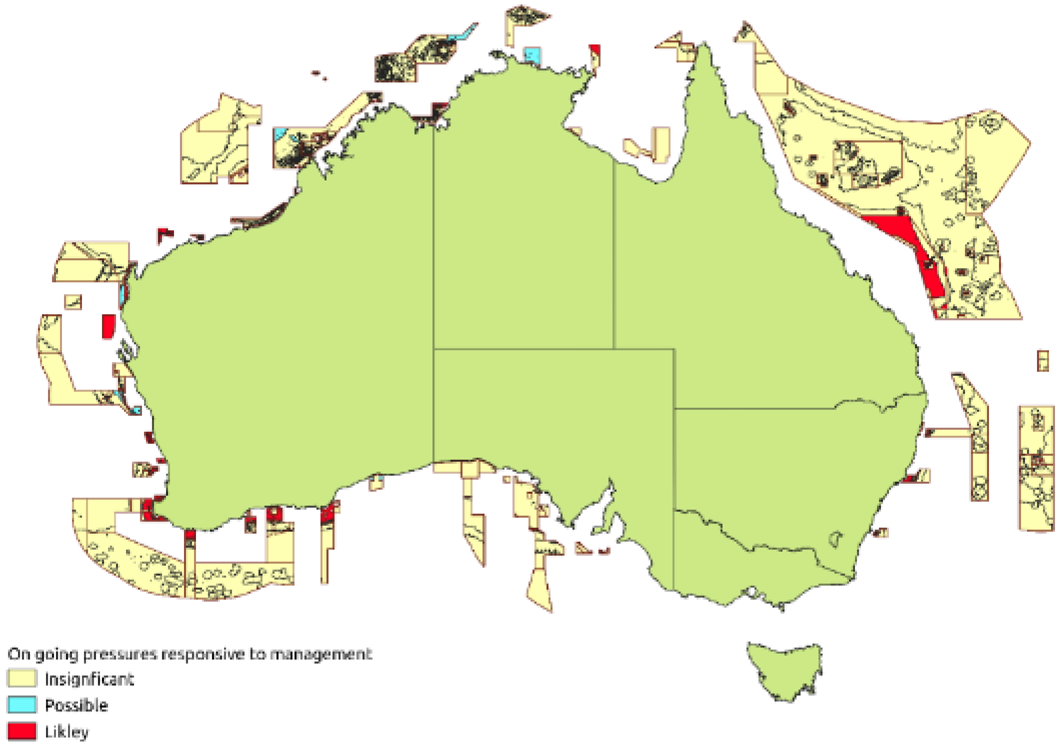

Figure 11: Level 1 priority ecosystems for Ongoing pressures responsive to management for the South-west, North-west, North and Temperate East networks and the Coral Sea MP

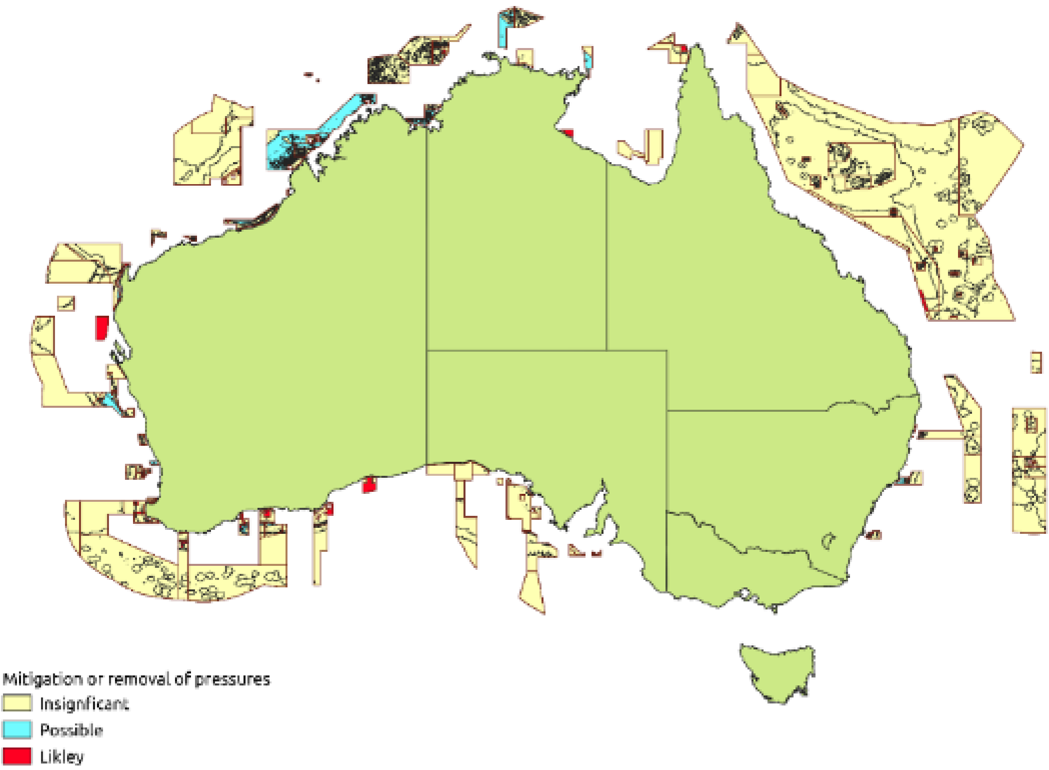

Figure 12: Level 1 priority ecosystems for Mitigation or removal of pressures for the South-west, North-west, North and Temperate East networks and the Coral Sea MP

5.1.3 Issues with the data

There remain challenges with the data that underpin this prioritisation. These are related to both data availability and data robustness. These issues include:

- Some sub-activities appeared as pressures on some ecosystems in the CI assessment although they are “not allowed” under the management regime. This was attributable to grid cell overlap and data resolution not conforming to the bounds of the marine park zones, and therefore these pressures were ignored for the purposes of the analysis.
- Pressure data sets are absent for some components of the pressure common language. These include carbon storage, marine debris and noise from aquaculture, commercial media, commercial aviation tours and all pressures linked to General use, access & waste management. It will require dedicated work to identify if data may exist but be difficult to obtain or can be provided through modelling.
- Some pressure data sets require modelling to obtain national (or even AMP) coverage (e.g. estimates of recreational fishing). The appropriateness of these data sets and their robustness needs to be evaluated.
- All pressure data will need to be updated to inform pressure monitoring for indicators in the ME framework.

5.1.4 Level 2 Prioritisation

This step was a manual check to determine whether the Level 1 priorities adequately represent KNVs; provincial bioregions; dominant ecosystems; areas where drivers influence or mask the change achieved by effective management and areas that can be used to test the effects of marine park zones. Key Natural Values helped to prioritise a sub-set of ecosystems or locations under similar pressure. However, KNVs were not necessarily included if the pressure on them was insignificant.

For some networks, soft sediment ecosystems make up a large proportion of the parks but are not areas of high vulnerability to pressures. Some additional areas were included as priority monitoring locations to ensure these dominant ecosystems were properly represented. Areas were also added or prioritised to maximise representation across bioregions within the same ecosystem and across different ecosystems. For example, if five of the same ecosystems were identified during level 1 prioritisation and occur in one bioregion, a smaller subset was selected to adequately represent the diversity of habitats and communities in the network. Ecosystems adjacent to high priority ecosystems were also added to better understand the change in interconnected ecosystems over time. This was particularly important in the Coral Sea, where islets / cays, shallow and deeper reefs interact.

5.1.5 Level 3 Prioritisation

Priorities were refined in this step based on assessment of available baseline information that could support a monitoring program. Baseline information was assessed for the following ecosystem components: habitat (i.e. available mapping data); fish; sessile benthic communities; and mobile invertebrates. The baseline information for each ecosystem component was assessed as being adequate; partly adequate; or inadequate (see Table 6). Baseline data were considered adequate where there was sufficient habitat mapping and inventory surveys to characterise the specific ecosystem component. Inadequate baselines reflect insufficient habitat mapping or inventory surveys to characterise the specific ecosystem component.

Table 6 : Example of a Level 3 analysis for mesophotic rocky reefs in Huon and Flinders Marine Parks, including the type of pressure, ecosystem component being impacted and availability of baseline information to inform a monitoring program. From Hayes et al. (2021)

Ecosystem	**Park**	**Zone**	**Pressure**	**Ecosystem component impacted**	**Baseline**			
					H	**F**	**BC**	**MI**
Mesophotic rocky reefs	Flinders	Multiple Use Zone	mitigation and removal of pressures& ongoing	F, BC, MI	A	A	A	IA
	Huon	Multiple Use Zone	Ongoing	MI	A	IA	A	IA

Key: H = habitat, F = demersal fish, BC = sessile benthic communities, MI = mobile invertebrates; A = adequate, IA= inadequate.

The assessment of baselines included the following criteria:

- Was the data collected in a systematic repeatable way, that aligns with national standards (e.g. NESP field manuals) or best practice.
- Are there enough sites to be informative?

An overall adequacy rating was then applied to each area to determine which of the priorities would form the basis for monitoring, and which should be identified as research priorities due to a need for more baseline information. Those with adequate baselines for all components where we expect to see a change were ranked as 'adequate' for monitoring priorities. Those with inadequate baselines for most components were ranked as 'inadequate'.

For those with partial baseline information, or baselines for only some components of the ecosystem, they were still assigned as 'adequate' where the information was sufficient to begin monitoring that component of the ecosystem expecting to change overtime. For these areas, an additional research priority was identified to complete the baselines on the other components. For example, there are areas with a baseline of seagrass extent and condition that were possibly impacted by previous commercial fishing but without a characterisation of the fish communities associated with that area. Monitoring can commence on the recovery of the habitat forming seagrass from previous impact and a research project be undertaken to establish a baseline of fish abundance, diversity and population dynamics.

The following information categories describe the type of baseline information corresponding to components of the environment and ecosystems needed to inform monitoring of natural values. Each category requires different sampling methods and responds differently to pressures.

1. Habitat – multibeam seafloor mapping provides the potential extent of different habitats and available substrate for habitat forming species (coral, seagrass) to grow in a park. The amount of high-resolution mapping provides an understanding of the different habitats in the park and their extent. This habitat is then further sampled through methods such as diver visual census, AUV, ROV and Towed video.
2. Sessile benthic invertebrate communities – characterising benthic invertebrate communities, including habitat forming species is undertaken by methods such as towed video, AUV, ROV and diver visual census. These can be impacted by activities such as demersal trawl, anchoring and other activities interacting with the seafloor.
3. Fish – characterising demersal fish communities through methods such as diver visual census and BRUVs primarily. Other sampling includes ROV, hand line, long line or trawl. Commercial and recreation fishing are examples of pressure that act directly on this component of the ecosystem.
4. Mobile invertebrates – includes target species such as lobster and sea cucumber. Target species are impacted by activities such as hand, pot and trap style fishing. Baseline information in this category can also provide a measure of invasive species such as mussels, urchins and seastars which may be introduced through ballast water and other vectors.
5. Megafauna and pelagic species of interest – species often inhabiting the surface waters of parks, and occasionally nesting on islands. These include turtles, dugong,

cetaceans, whale sharks, seabirds and others. These are impacted by pressures such as vessel transits, marine pollution or entanglement with fishing gear.

Assessment of baselines occurred in this way for aquatic ecosystems. At the time of analysis baseline information had not been compiled for island and beach ecosystems. These will be considered using a similar process involving different categories of information, including satellite / areal mapping, characterisation of vegetation and beach habitat as well as turtle and seabird communities and nesting sites.

5.1.6 Level 4 Prioritisation

This step assesses which monitoring priorities are feasible in terms of the logistics, costs and opportunities for partnerships, and also considers opportunities to test the effectiveness of marine park zoning. This step is a subjective process and is undertaken through workshops and discussions with park managers. Each of the monitoring priorities that were derived from three steps above were discussed with regional teams through a workshop and considered for final monitoring prioritisation as shown in Table 5.1 and considering the following aspects:

a. Logistical and financial aspects
Logistics were assessed as simple; moderate; or hard based on the distance from the nearest port, the accessibility of vessels and the prevailing weather conditions. The cost was categorised as high; medium; or low based on assessment of number of crew and type of vessel required.

b. Opportunities for partnerships
Leveraging opportunities to partner with other organisations or groups working in an area can reduce costs for monitoring and research. These opportunities are often built on existing partnerships, though new partnership opportunities are also explored.

c. Testing effectiveness of marine park zoning
In areas where there is a need to test zone effectiveness/ mitigation and removal of pressures, was the data collected prior to, or soon after, the declaration of the park or zoning coming into effect?

d. National-scale representativeness

After prioritising at the network level, a final assessment looking at representativeness across all marine parks was considered. It looked at the national coverage and identified any major gaps, focussed on where an effect of management is expected and on maintaining representative examples of biodiversity in Australian Marine Parks.

Details of science priorities will be provided in the Australian Marine Park Science plans aiming to be published in 2023.

Table 7: Example of final prioritisation for the Cod Grounds and Central Eastern Marine Parks within the Temperate East Network. The Cod Grounds are highlighted in light green in the Level 4 prioritisation (right hand column) indicating a high priority for monitoring based on the adequacy of baselines and feasibility. The Central Eastern is highlighted in red indicating the inadequacy of the baseline information and low feasibility and high cost for monitoring. This area may be listed as a research priority.

Ecosystem	Park	Zone	Pressure	Baseline H	Baseline F	Baseline BC	Baseline MI	Baseline adequacy summary	Level 4 prioritisation justification
Mesophotic rocky reefs	Cod Grounds	National Park Zone	Ongoing	A	A	A	PA	**Adequate -** BRUV monitoring program; Towed video surveys; Reef Life Surveys; Grey Nurse Shark monitoring program.	Potential opportunity to test effectiveness of NPZ, given BRUVs in comparable habitats outside the park. Note no pre-park data, and only limited data soon after park came into effect. Logistics - simple (BRUVs); hard (diving) Cost - low
Mid slope reef	Central Eastern	Multiple Use Zone	mitigation and removal of pressures & ongoing	A	IA	IA	IA	**Inadequate**	Baselines - Inadequate Logistics - Hard (likely require MNF application); depth of mid-slope ecosystems makes them logistically more challenging. Cost - Medium providing there is support from MNF; depth of mid-slope ecosystems requires more time to sample so they are relatively more expensive to sample.
Key: H = habitat, F = demersal fish, BC = sessile benthic communities, MI = mobile invertebrates; A = adequate, IA= inadequate.									

6. Conclusion

This report provides the methods and approaches to conclude a national process to identify monitoring priorities for AMP networks and the Coral Sea MP. It provides a science-based decision-making process for Parks Australia to use in prioritisation and a significant amount of scientific information that can be used to inform other decisions not directly referenced here. It is the first national process of this type globally. The ME framework represents a significant enabling-step towards a system of adaptive, integrated and place based management. The remaining steps will be completed as data are collected in a systematic, prioritised fashion, and environmental outcomes are compared to management objectives. These steps can then be re-iterated, in a process that aims for continual improvement in management actions and environmental outcomes, as the evidence base to support adaptive management grows, and our understanding of how ecosystems respond to multi-sectoral activities improves.

Significant recommendations were identified in Hayes et al. (2021). The most significant gap identified was the limited understanding of the distribution of mesophotic and rariphotic reefs in Australia. This is currently being addressed through a project within the NESP Marine and Coastal Hub. This project needs to ensure a national map is developed and that other key ecosystems (ie seagrass) are included in that mapping. The distribution of recreational fishing was improved from the SE pilot project, but there remain significant uncertainties and the overall impacts of recreational fishing within AMPs remains unquantified.

The following recommendations from Hayes et al. (2021) remain. Of particular priority are:

1. Development of a formal KNV process and implementation of that process. This should be done to ensure that KNV descriptions contain the most robust information and are kept up to date. Formalising the process will allow KNVs to the published and updated so that park users and managers are aware of and prioritising protecting these special places.

2. Mapping of intertidal areas remains challenging. There is no description of where these features occur within AMPs, and the identification of islands was based on areas where depth was great than 0m in the GA 250m layer. This will ensure that the AMP ecosystem model is accurately depicting all ecosystems managed by Parks Australia.

3. Continued improvement of habitat models and data to inform and characterise the ecosystems within AMPs. This will improve the confidence that the AMP ecosystems model is accurate and useful as a basis for decisions.

4. Development of an understanding of how migratory and threatened species use AMPs and where the most important areas for this are. A greater understanding will allow park managers to direct resources towards those species that can best benefit from spatial management.

5. Updating the pressure data sets to ensure that they are relevant for use as ME indicators. This may also require developing continued sources of data from various

data holders, and a process to ensure that it is integrated into the ME system. An up to date understanding of pressures over time is critical to interpret trends in condition of park values and effectiveness of park management.

6. The future of the vulnerability assessment should be a considered and a determination of how or if it is used in the future. If the vulnerability assessment is used then consideration should be given to updating it to a full cumulative impact assessment that includes ecosystem effects. This would provide park managers with an improved understanding of how pressures are impacting park values and improved ability to assess the risks of new activities within AMPs.

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Appendix A Ecosystems

Creation of the Australian ecosystem map

Table A1: Steps used to develop Ecosystem Map for benthic ecosystems. This describes the process used to create the ecosystem map from the base GA Bathy data set and the sequence the decision rules are applied.

Step	Ecosystem	Decision rules	Class No.
1	Shelf unvegetated sediments	GA Bathy < 0m AND >= -200m	1
2	Upper slope sediments	GA Bathy < -200m AND >= -700m	2
3	Mid-slope sediments	GA Bathy < -700m AND >= -2000m	3
4	Lower slope reef & sediments	GA Bathy < -2000m AND >= -4000m	4
5	Abyss reefs & sediments	GA Bathy < -4000m	5
6	Seamount sediments	Yesson-Seamounts = TRUE	6
7	Seamount sediments	GA 2006 Geomorphology feature = (“pinnacle” or “seamount/guyot”) AND IS NOT Continental Shelf	6
8	Seamount reefs	CSIRO Seamount Reefs = TRUE	18
9	Shelf incising canyons	Select features by GA Canyons depth > -200m	7
10	Shelf vegetated sediments	Seagrass = TRUE OR National Benthic Habitat Layer = “seagrass”	9
11	Oceanic coral reefs	WCMC Reefs = TRUE AND IS NOT Continental Shelf	8
12	Oceanic corals reefs	National Reefs = TRUE AND GA Bathy >= -30m AND IS Coral (Latitude >= -32. 69) AND IS NOT Continental Shelf	8
13	Oceanic shallow coral reefs	National Reefs = TRUE AND GA Bathy >= -30m & IS Coral (Latitude >= -32. 69) AND Continental Shelf = TRUE	10
14	Shallow rocky reefs	National Reefs =TRUE AND GA Bath >= -30m AND IS NOT Coral (Latitude < 32.69)	11
15	Mesophotic coral reefs	National Reefs =TRUE AND GA Bath < -30m AND GA Bathy >= -70m AND IS Coral (Latitude >= -32.69) AND Continental Shelf = TRUE	12
16	Mesophotic rocky reefs	National Reefs =TRUE AND GA Bath < -30m AND GA Bathy >= -70m AND IS NOT Coral (Latitude < -32.69) AND Continental Shelf = TRUE	13
17	Oceanic mesophotic coral reefs	National Reefs =TRUE AND GA Bath < -30m AND GA Bathy >= -70m AND IS NOT Coral (Latitude < -32.69) AND Continental Shelf = FALSE	14

18	Rariphotic shelf reefs	National Reefs =TRUE AND GA Bath < -70m AND GA Bathy >= -200m	15
19	Upper slope reefs	GA Canyons <= -200m AND GA Bathy < -200m AND GA Bathy -700m	16
20	Upper slope reefs	National Reefs =TRUE AND GA Bathy < -200m AND GA Bathy -700m	16
21	Mid-slope reefs	GA Canyons <= -200m AND GA Bathy < -700m AND GA Bathy -2000m	17

Table A2: Steps used to develop Ecosystem Map for pelagic ecosystems

Step	Ecosystem	Processing	Class No.
1	On shelf (neritic) epipelagic	GA Bathy < 50m AND GA Bathy >= -200m	23
2	Off-shelf (oceanic) epipelagic	GA Bathy < -200m	22
3	Mesopelagic	GA Bathy < -200m AND GA Bathy >= -1000m	21
4	Bathypelagic & Abyssopelagic	GA Bathy < -1000m	20

Table A3: Steps used to develop National Reefs Layer

Step	Process	Comment
1	NESP Predicted Reefs = TRUE	
2	CSIRO Deep Reefs = TRUE	
3	(National Benthic Habitat Layer SC_Level1 IS NOT “Hard Substrata”) IS NOT Reef	Clears NESP Predicted Reefs over prediction where reef is known not to occur
4	National Benthic Habitat Layer SC_Level1 = “Hard Substrata”	Identified where reef is known to occur
5	GA 2006 Geomorphology Feature = “Banks/Shoals”	Identified Banks and shoals contain hard substrate
6	GA 2006 Geomorphology feature = (“pinnacle” or “seamount/guyot”) AND Continental Shelf = TRUE	Identified Pinnacles on the continental shelf
7	NESP Surveyed Reefs = TRUE	
8	(Australian Marine Parks RESNAME = “Boags”) IS NOT Reef	Boags AMP has been identified not containing reef

Table A4: Data Sources used to develop Ecosystem Maps

Identifier	Source
GA Bathy	Geoscience Australia Bathymetry 2009, https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/67703
Yesson-Seamounts	Yesson, C., et al., The global distribution of seamounts based on 30 arc seconds bathymetry data. Deep-Sea Research I (2011), doi:10.1016/j.dsr.2011.02.004, http://doi.pangaea.de/10.1594/PANGAEA.757564
CSIRO Seamounts	Seamount Reef was estimated using the estimate of potential live Solenosmilia habitat mapped as vulnerable marine ecosystems as identified in Williams et al (2020). https://www.frontiersin.org/articles/10.3389/fmars.2020.00187/full
GA Geomorphology	https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/69797
GA Canyons	National Marine Canyons of Australia. https://data.gov.au/data/dataset/national-submarine-canyons-of-australia
Seagrass	CAMRIS Seagrass, https://doi.org/10.4225/08/5514852027A1E
Australia National Benthic Habitat Layer	Lucieer V, Walsh P, Flukes E, Butler C, Proctor R, Johnson C (2017). Seamap Australia - a national seafloor habitat classification scheme. Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS). https://metadata.imas.utas.edu.au/geonetwork/srv/eng/metadata.show?uuid=4739e4b0-4dba-4ec5-b658-02c09f27ab9a
WCMC Reefs	https://data.unep-wcmc.org/pdfs/1/WCMC008_CoralReefs2010_v4.pdf?1544544636
Cables Active and Cables Decommissioned	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=4uaa2q6y6oqge0if416dss61#/metadata/b8824a13-8e0b-4172-9678-dabccdedeeb7
Pipelines	https://data.gov.au/data/dataset/5ff102cb-5d48-4a0e-9af9-3d2dda90b67d
CSIRO Deep Reefs	Kloser RJ and Keith G (2010) Key Ecological Features of the East and South-east Marine Regions: “deep reefs” within 150-700 m depths. Draft report to the Department of the Environment, Water, Heritage and the Arts
CSIRO Deep Reefs	Kloser RJ, Keith G and Althaus F (2010) Key Ecological Features of the East and South-east Marine Regions: Shelf Incising Canyons. Draft Report to the Department of the Environment, Water, Heritage and the Arts.
NESP Surveyed Reefs	Heaney, B Davey C 2019. Hydrographic Survey of the Freycinet, Huon and Tasman Fracture Australian Marine Parks. BF2019_v01. CSIRO Report to IMAS and PA
NESP Surveyed Reefs	https://www.nespmarine.edu.au/document/seafloor-biota-rock-lobster-and-demersal-fishes-assemblages-tasman-fracture-commonwealth
NESP Surveyed Reefs	https://www.nespmarine.edu.au/document/biological-and-habitat-feature-descriptions-continental-shelves-australia's-temperate-water
NESP Surveyed Reefs	Ierodiaconou, D Young, Y O’Brien S 2020 Hydrographic Survey of Apollo Marine Park. Report to PA

NESP Surveyed Reefs	Lucieer, VL Porter-Smith, R Nichol, SL Monk, J Barrett, NS 2016 Collation of existing shelf reef mapping data and gap identification - Phase 1 Final Report Shelf reef key ecological features. Report to NESP
NESP Surveyed Reefs	Vandenbossche, P Davey, C 2018 Hydrographic Survey of the Boags Commonwealth Marine Reserve in Southwestern Bass Strait. BF2018_v01. Report to PA
NESP Surveyed Reefs	Additional locations were identified through conversations with local fishers. Neville Barret pers comm.

Appendix B - Updated pressure datasets

In this appendix we plot the updated pressure layers used in the Australian wide cumulative impact assessment (as opposed to the cumulative impact assessment for the South-east pilot in Hayes et al. 2021). Maps of the pressures at the sub-activity scale are presented and the associate layers and meta-data used to generate these data is reported below.

Climate change

Altered ocean currents

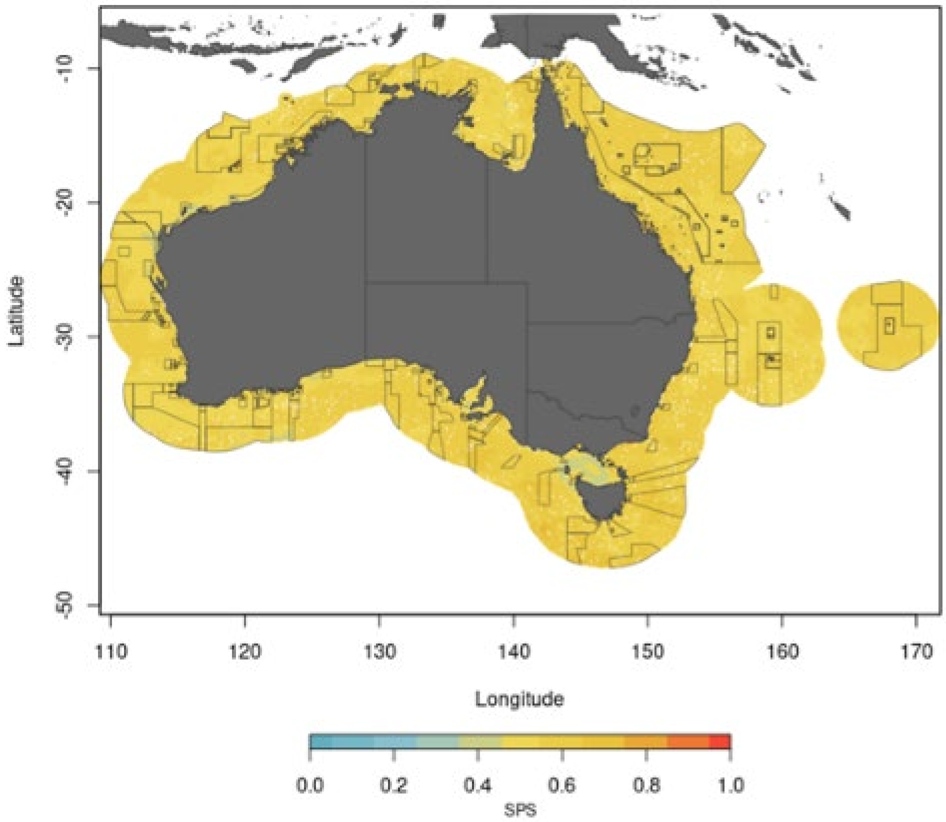

Figure B.1: Pressure map for the altered ocean currents sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B.1: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
Average.linear.trend.for.CHLOR_A.on.log.scale_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/c685a21e-8770-4b3b-ac3c-2c4f815f7176	unmanageable

Increased frequency and intensity of weather events

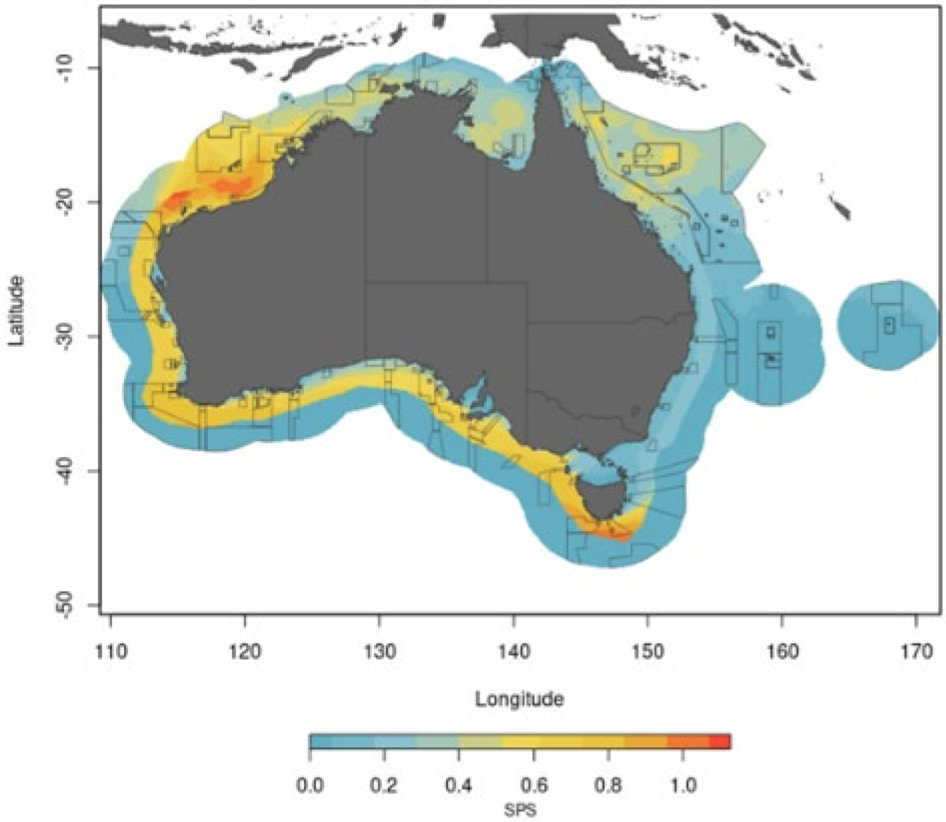

Figure B2: Pressure map for the increased frequency and intensity of severe weather events sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B2: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
cyclones_windspeed_radius_rasterised_masked_linearStd	https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C01552	Unmanageable
wave_p504m_linearStd	https://nationalmap.gov.au/renewables/#share=s-gGd5ztFcxe2ysy9f	Unmanageable

Increased sea surface temperature

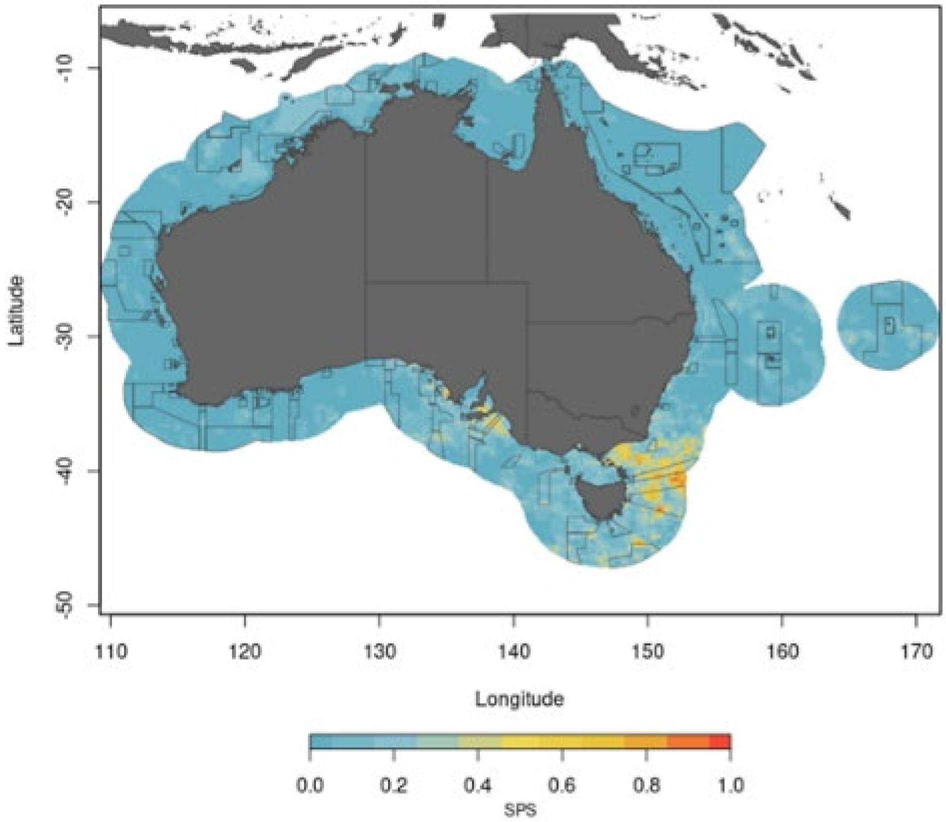

Figure B3: Pressure map for the increased sea surface temperature sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B3: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
cyclones_windspeed_radius_rasterised_masked_linearStd	https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C01552	Unmanageable
wave_p504m_linearStd	https://nationalmap.gov.au/renewables/#share=s-gGd5ztFcxe2ysy9f	Unmanageable

Sea level rise

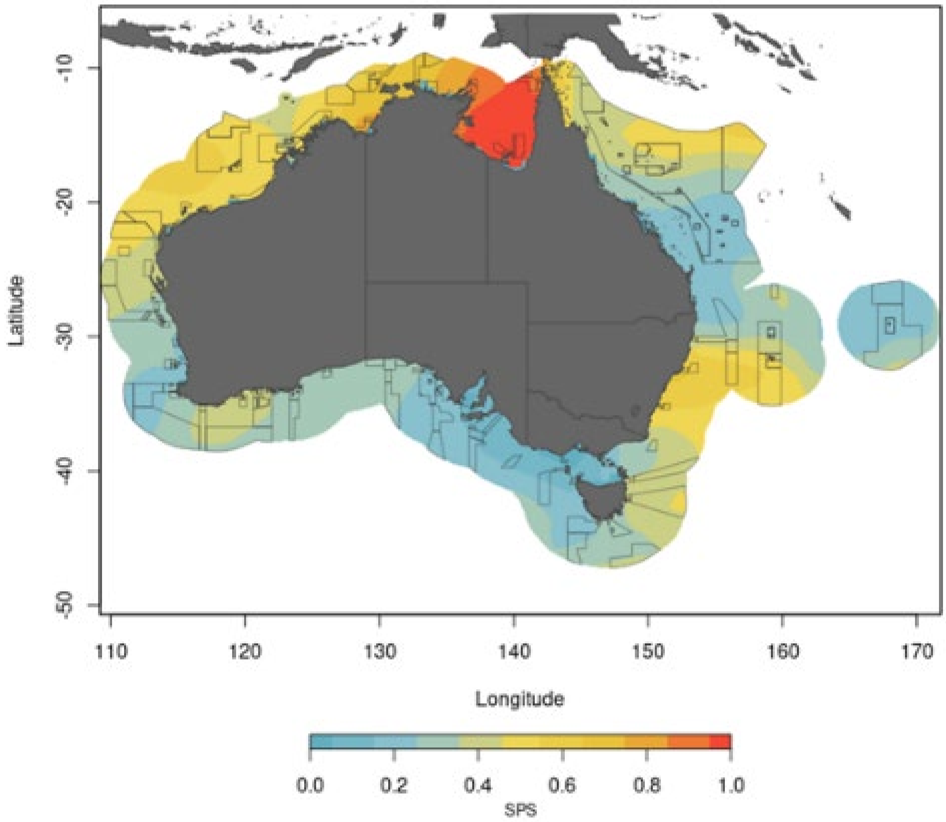

Figure B4: Pressure map for the sea level rise sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B4: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
height_diff_1993_2018_res01_linearStd	https://catalogue-imos.aodn.org.au/geonetwork/srv/eng/catalog.search#/metadata/7709f541-fc0c-4318-b5b9-9053aa474e0e	Unmanageable

Commercial aquaculture

Aquaculture including commercial pearling

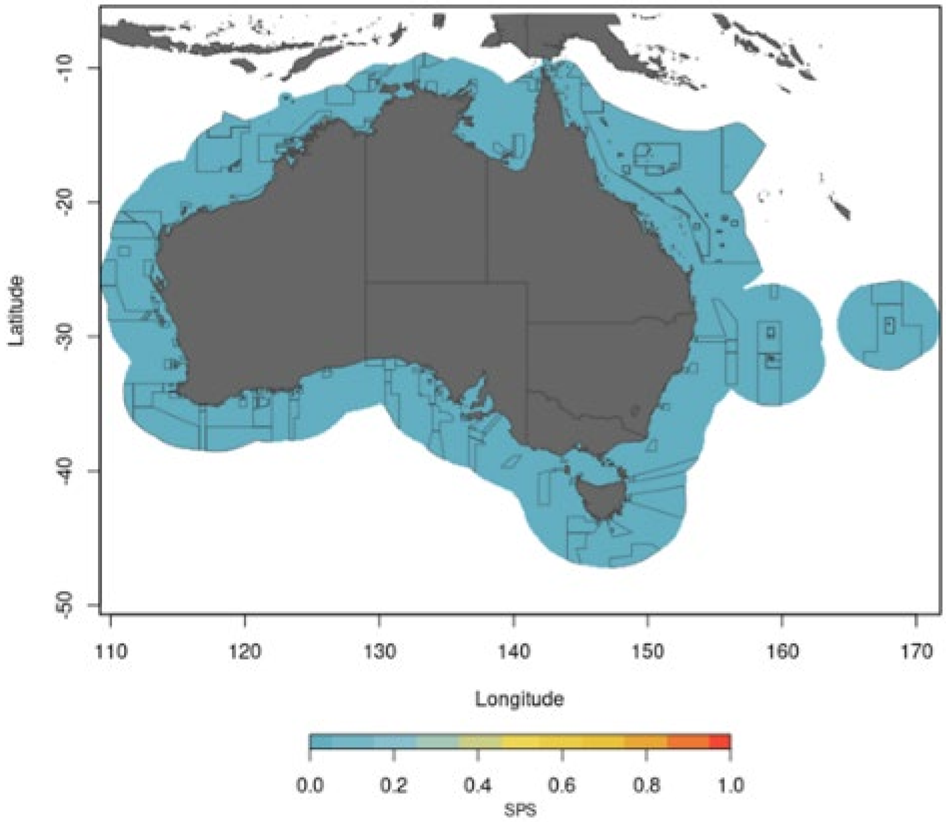

Figure B5 Pressure map for the aquaculture including commercial pearling sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B5: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
national_aquaculture_map_fieldID_area_SpatiallyProcessed_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/100d2c8b-0a0c-4a58-9217-de913a7866ee	manageable

Vessel transiting

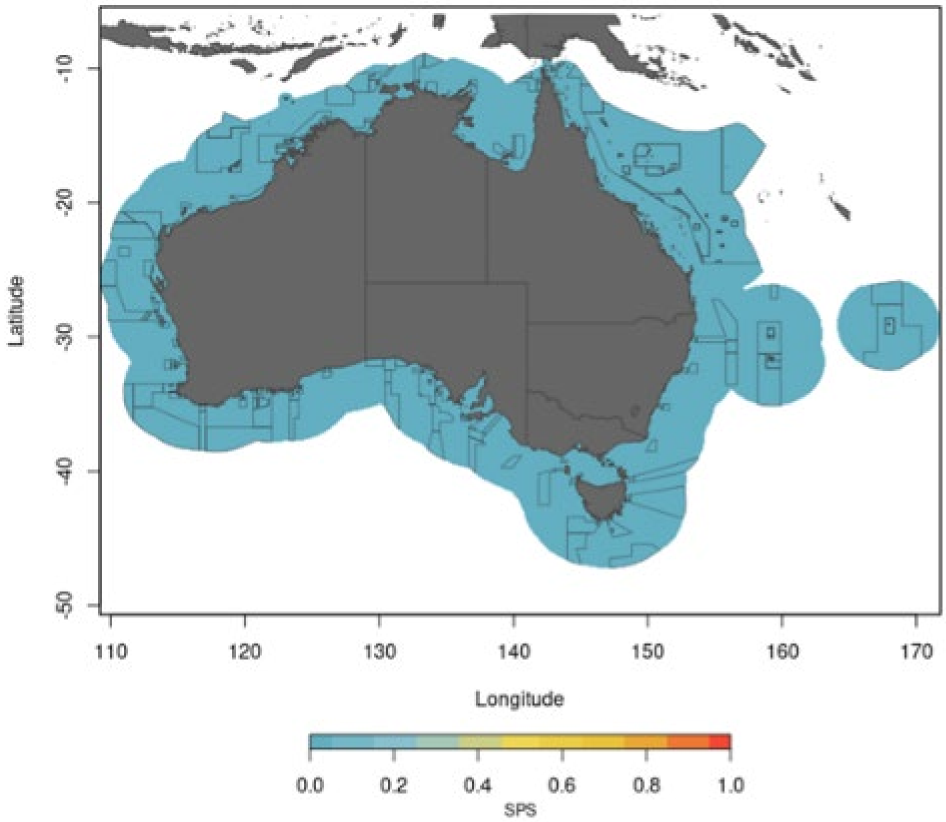

Figure B6 Pressure map for the commercial aquaculture activity-vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B6 Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
transiting_distance_general_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search	manageable

Commercial fishing

Danish Seine

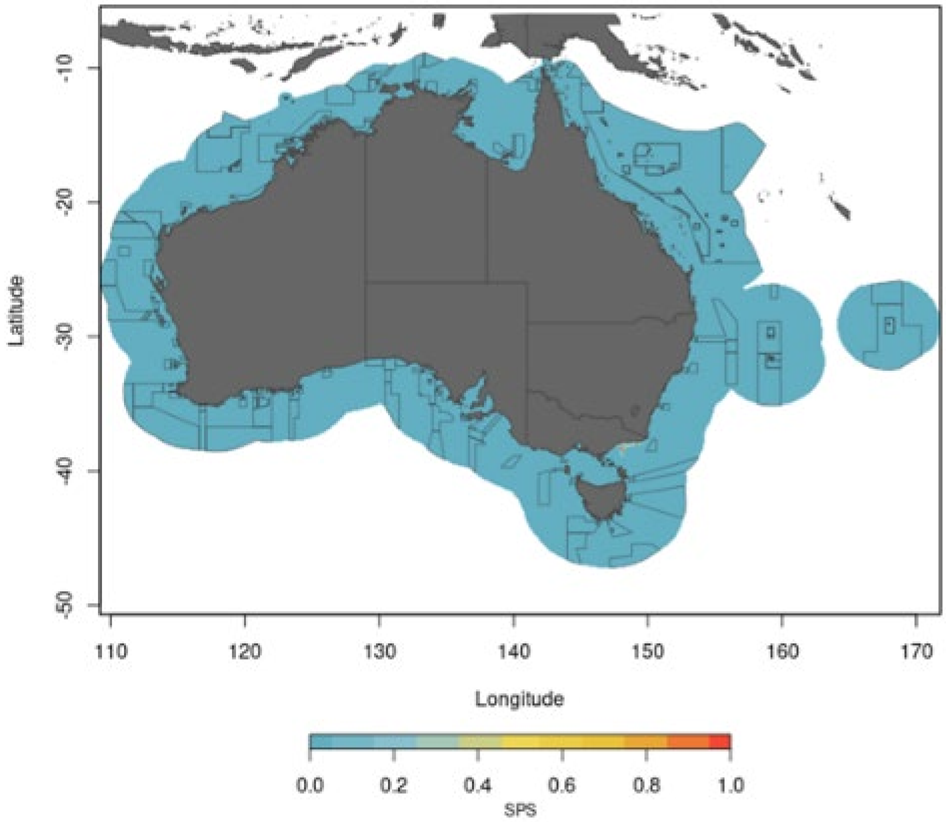

Figure B7 Pressure map for the Danish seine sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B7: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
DS_2013070120180631_hours_01res_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au	Manageable

Demersal trawl

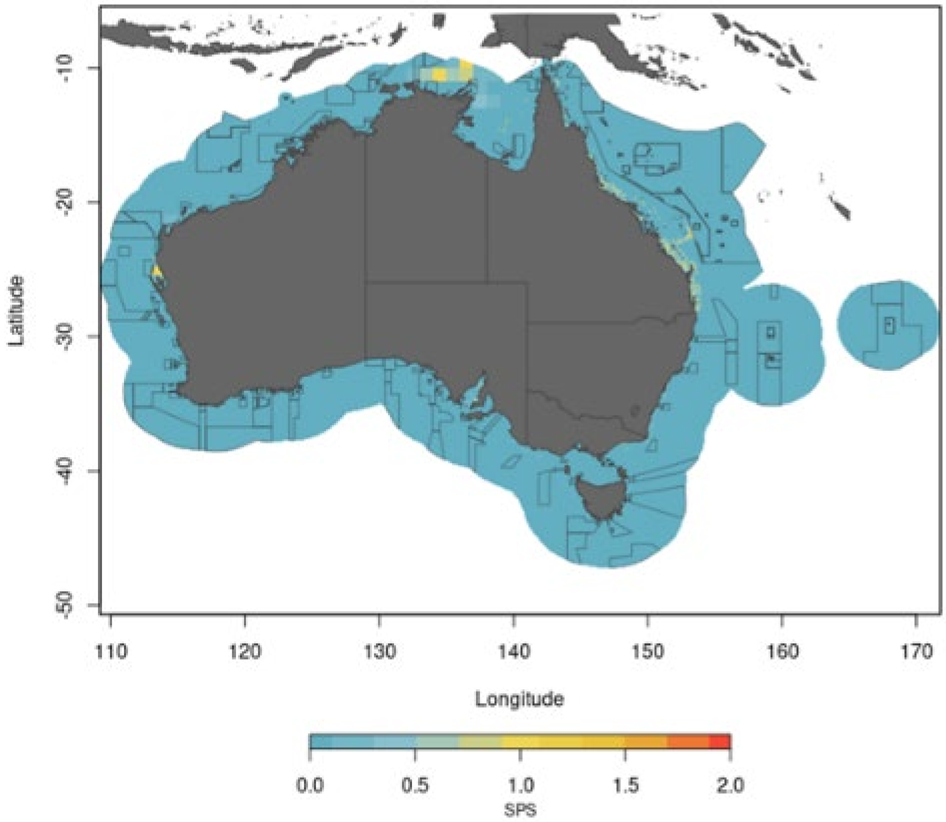

Figure B8 Pressure map for the Demersal trawl sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B8: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
TW_201307012018 0631_hours_01res_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au	Manageable
NSWTW_DS_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511	Manageable
Final_NT_effort_June2018_fieldID_A16_Demersal_trawl_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
qldeffort_Trawl20112015_Demersal_trawl_fieldID_Days_n_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/IelKC0YZ4yFLr1VMI9gSyN?domain=marlin.csiro.au	Manageable
SA_DT_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search	Manageable

	#/metadata/be790a20-eed5-4570-85dc-dd548ce606d6	
VICtrawling_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc	Manageable
trawl_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce	Manageable

Longline demersal auto-longline

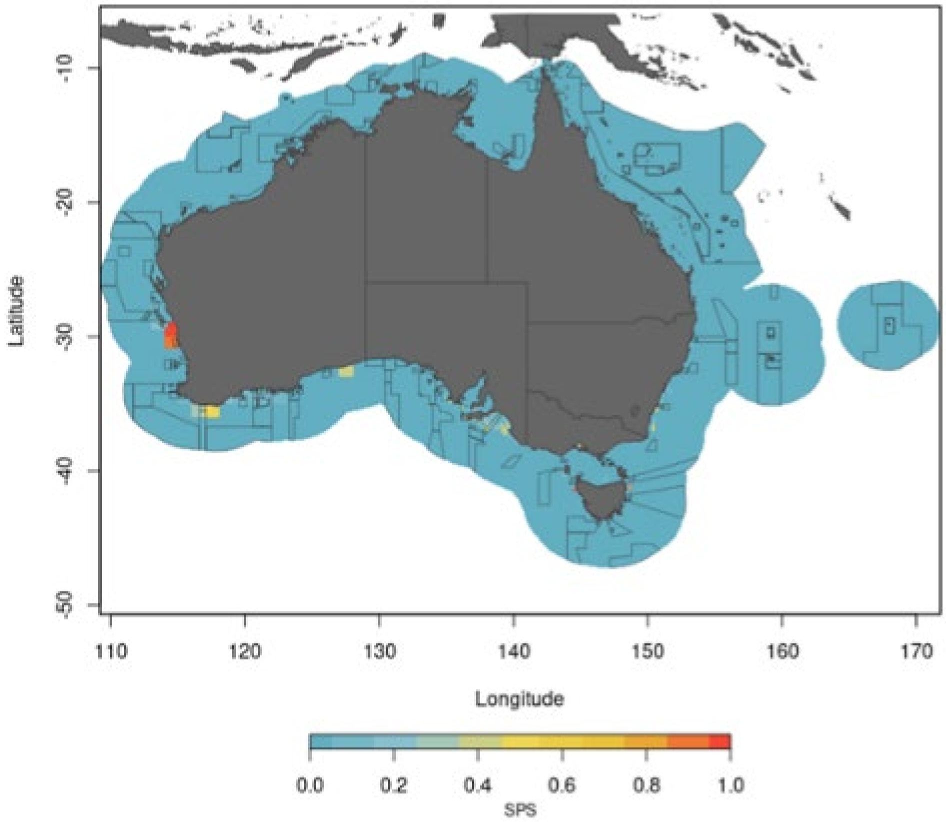

Figure B9: Pressure map for the Longline demersal auto-longline sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B9: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
AL_2013070120180631_hooksset_01res_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au	Manageable
BL_2013070120180631_hooksset_01res_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au	Manageable
NSWLL_DL_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511	Manageable
LL_DL_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961	Manageable

VICLLDL_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc	Manageable
ll_dl_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce	Manageable

Longline pelagic

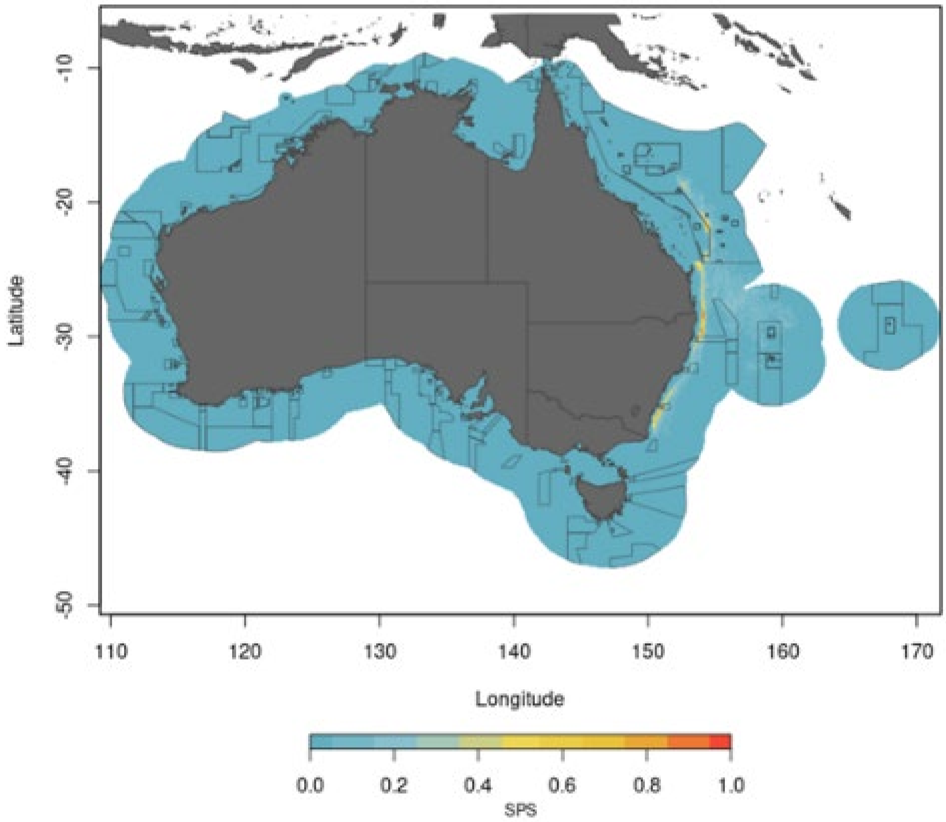

Figure B10: Pressure map for the Longline pelagic sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B10: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
LLP_2013070120180631_hooksset_01res_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au	Manageable

Minor line

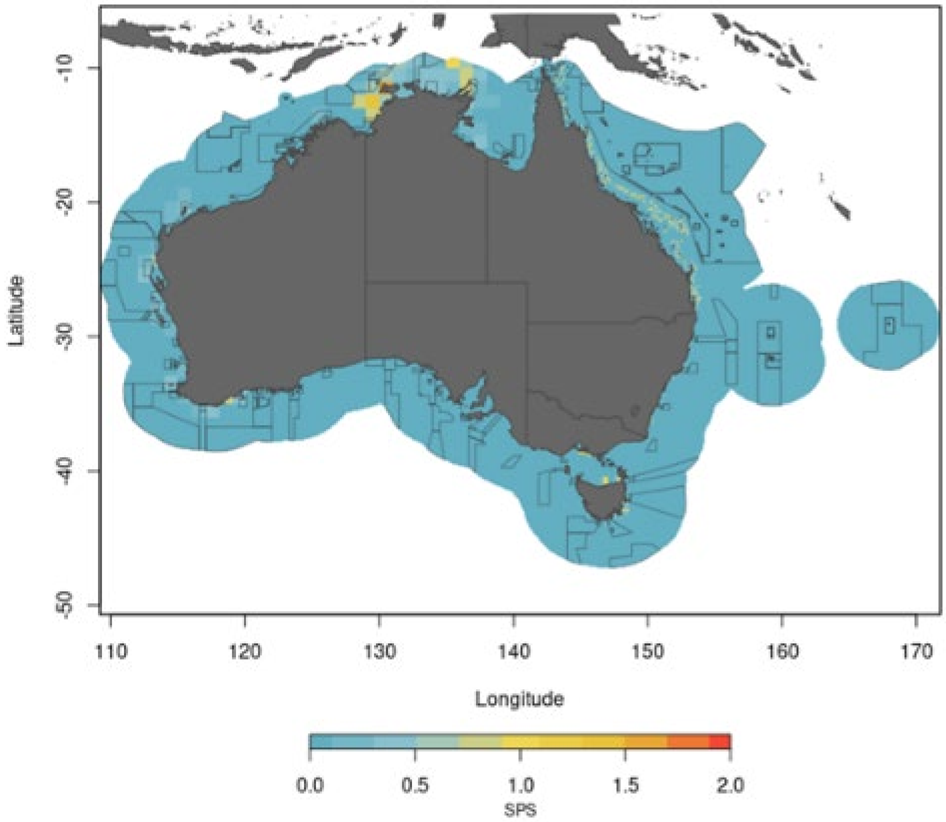

Figure B11: Pressure map for the Minor line sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B11: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
TR_2013070120180631_operations_01res_linearStd.1	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/aa53a4df-7fe6-46d1-93b7-2d3732f4883e	Manageable
NSWHL_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511	Manageable
Final_NT_effort_June2018_fieldID_A1_Minor_line_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
Final_NT_effort_June2018_fieldID_A4_Minor_line_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
Final_NT_effort_June2018_fieldID_A6_Minor_line_Spati	https://protect-au.mimecast.com/s/aL82C9	Manageable

allyProcessed_masked_linearStd	1Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	
qldeffort_Line20112015_Minor_line_fieldID_Days_n_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/IelKC0YZ4yFLr1VMI9gSyN?domain=marlin.csiro.au	Manageable
HL_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961	Manageable
JIG_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961	Manageable
VICHL_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc	Manageable
line_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce	Manageable

Net demersal

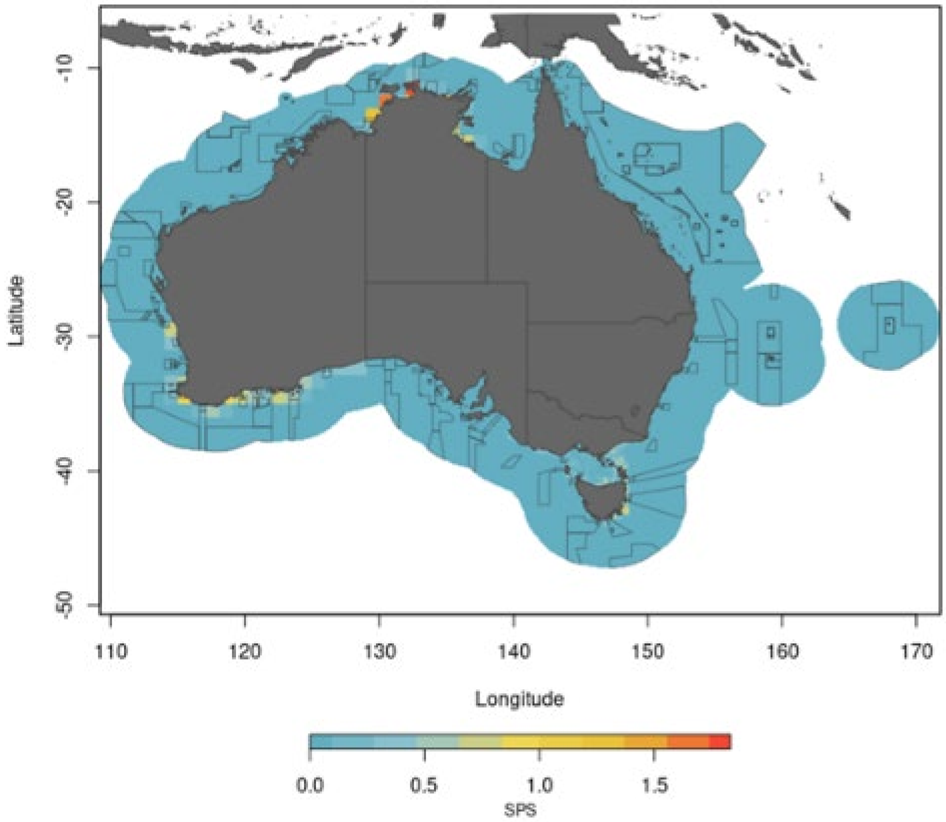

Figure B12: Pressure map for the Net demersal sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B12: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
GN_201307012018063I_hours_01res_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au	Manageable
NSWGN_MN_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511	Manageable
Final_NT_effort_June2018_fieldID_A2_Net_demersal_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
Final_NT_effort_June2018_fieldID_A3_Net_demersal_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
Final_NT_effort_June2018_fieldID_A7_Net_demersal_S	https://protect-au.mimecast.com/s/aL82C9	Manageable

patiallyProcessed_masked_linearStd	1Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	
GN_MN_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961	Manageable
gillnet_net_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce	Manageable

Purse seine

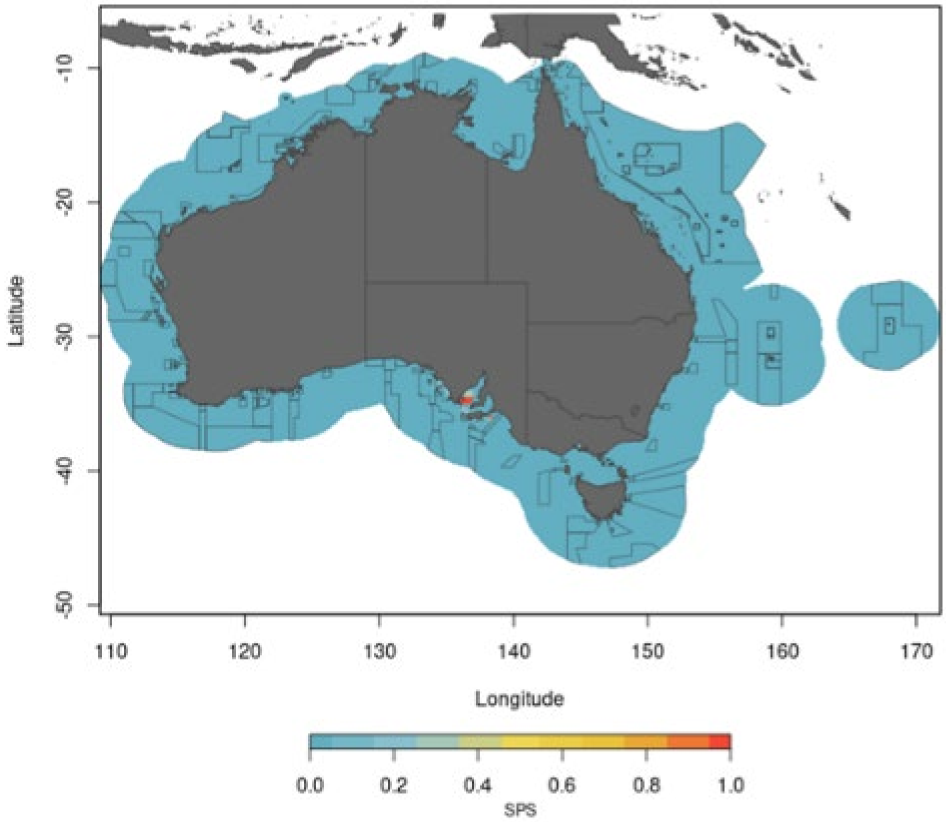

Figure B13: Pressure map for the Purse seine sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B13: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
PS_2013070120180631_operations_01res_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au	Manageable
NSWSeine_shots_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511	Manageable

Hand collection

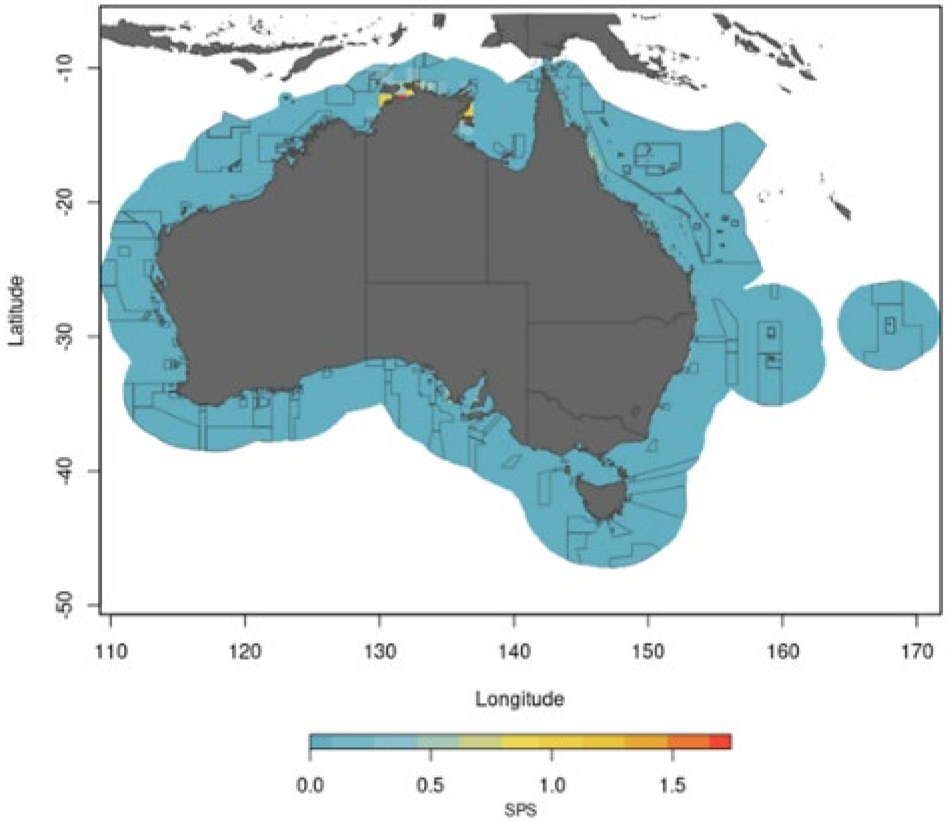

Figure B14: Pressure map for the Hand collection sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B14: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
NSWHG_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511	Manageable
Final_NT_effort_June2018_fieldID_A12_Hand_collection_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
Final_NT_effort_June2018_fieldID_A13_Hand_collection_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
Final_NT_effort_June2018_fieldID_A9_Hand_collection_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable

qldeffort_Harvest20112015_Hand_collection_fieldID_Days_n_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/IelKC0YZ4yFLr1VMI9gSyN?domain=marlin.csiro.au	Manageable
SA_HG_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/be790a20-eed5-4570-85dc-dd548ce606d6	Manageable
HG_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961	Manageable

Hand net

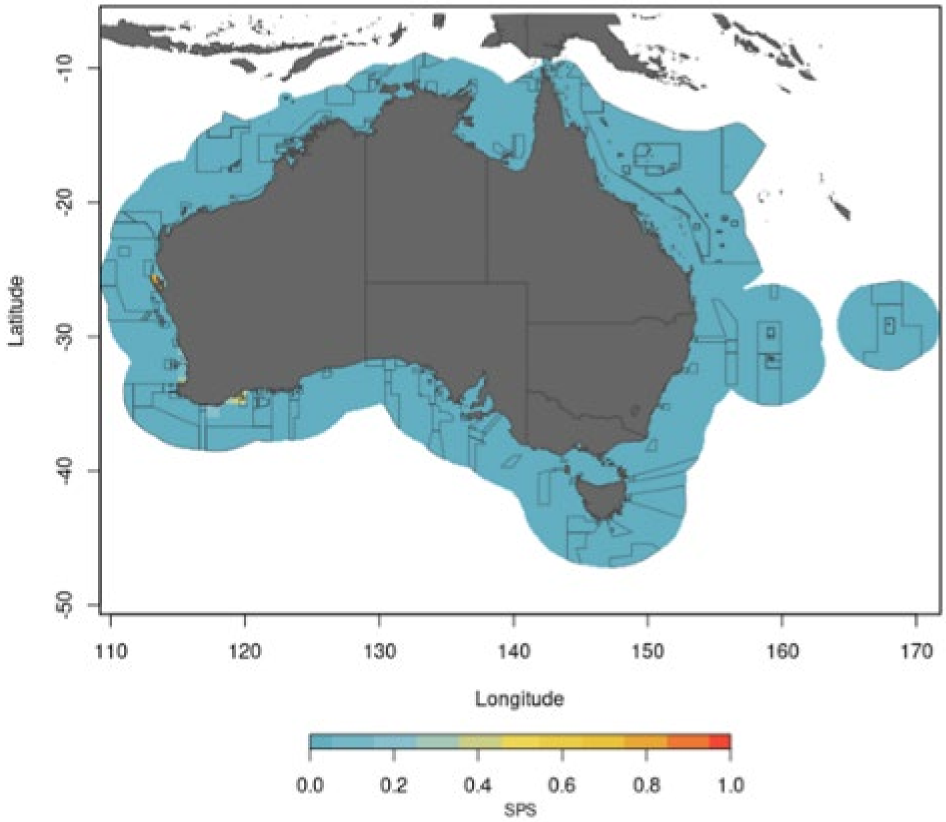

Figure B15: Pressure map for the Hand net sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B15: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
NSWSeine_setnet_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511	Manageable
Seine_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961	Manageable
VICseine_net_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc	Manageable
seine_and_haul_nets_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce	Manageable

Pot and trap

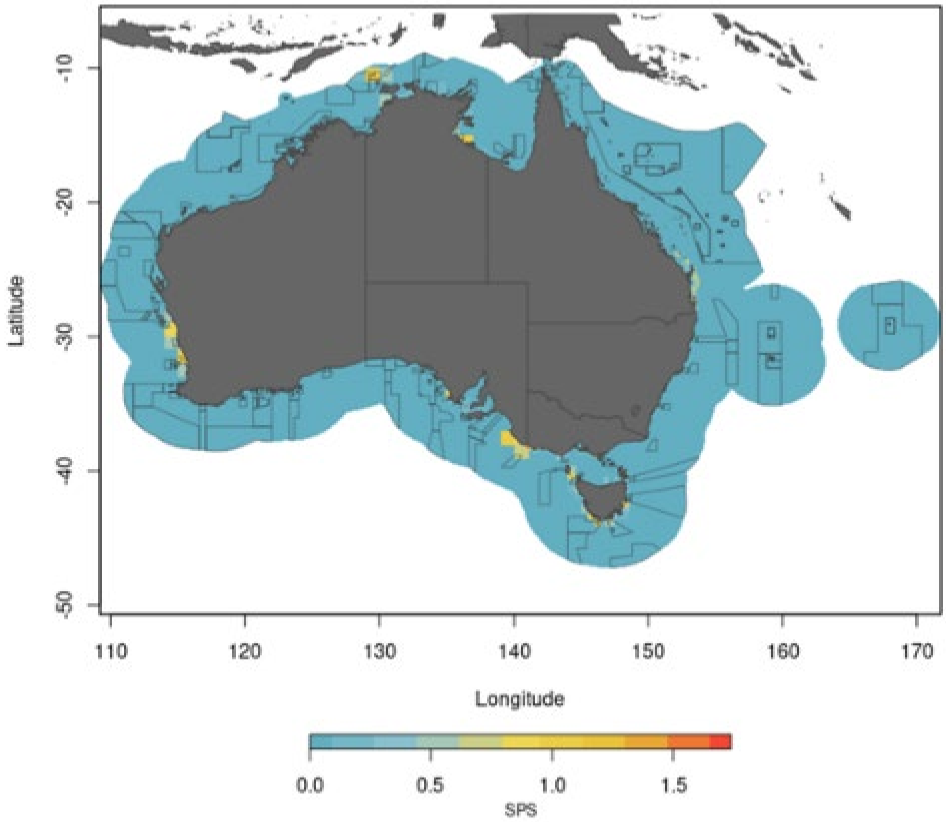

Figure B16: Pressure map for the Pot and trap net sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B16: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
NSWTrap_pot_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511	Manageable
Final_NT_effort_June2018_fieldID_A18_Pot_and_trap_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
Final_NT_effort_June2018_fieldID_A8_Pot_and_trap_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
qldeffort_Pot20112015_Pot_and_trap_fieldID_Days_n_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/IeIKC0YZ4yFLr1VMI9gSyN?domain=marlin.csiro.au	Manageable

SA_MSF_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/be790a20-eed5-4570-85dc-dd548ce606d6	Manageable
SA_POT_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/be790a20-eed5-4570-85dc-dd548ce606d6	Manageable
DN_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961	Manageable
Pot_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961	Manageable
VICtrap_pot_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc	Manageable
trap_and_pot_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce	Manageable

Net pelagic

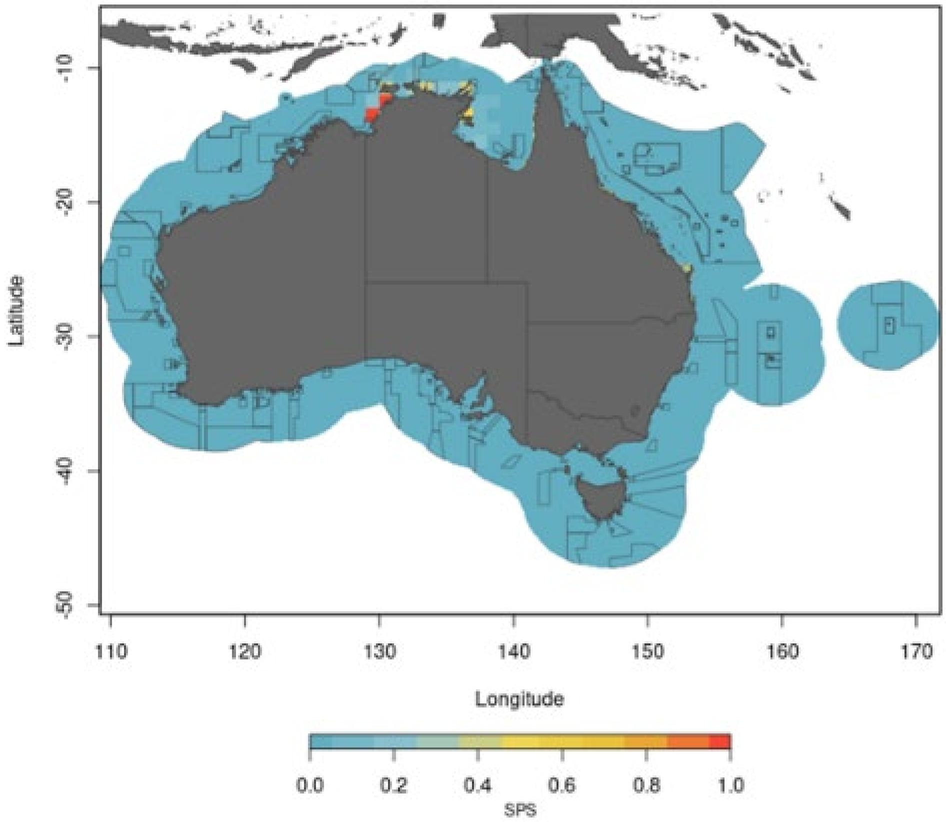

Figure B17: Pressure map for the Net pelagic net sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B17: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
Final_NT_effort_June2018_fieldID_A5_Net_pelagic_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au	Manageable
qldeffort_Net20112015_Net_pelagic_fieldID_Days_n_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/IelKC0YZ4yFLr1VMI9gSyN?domain=marlin.csiro.au	Manageable

Trotline

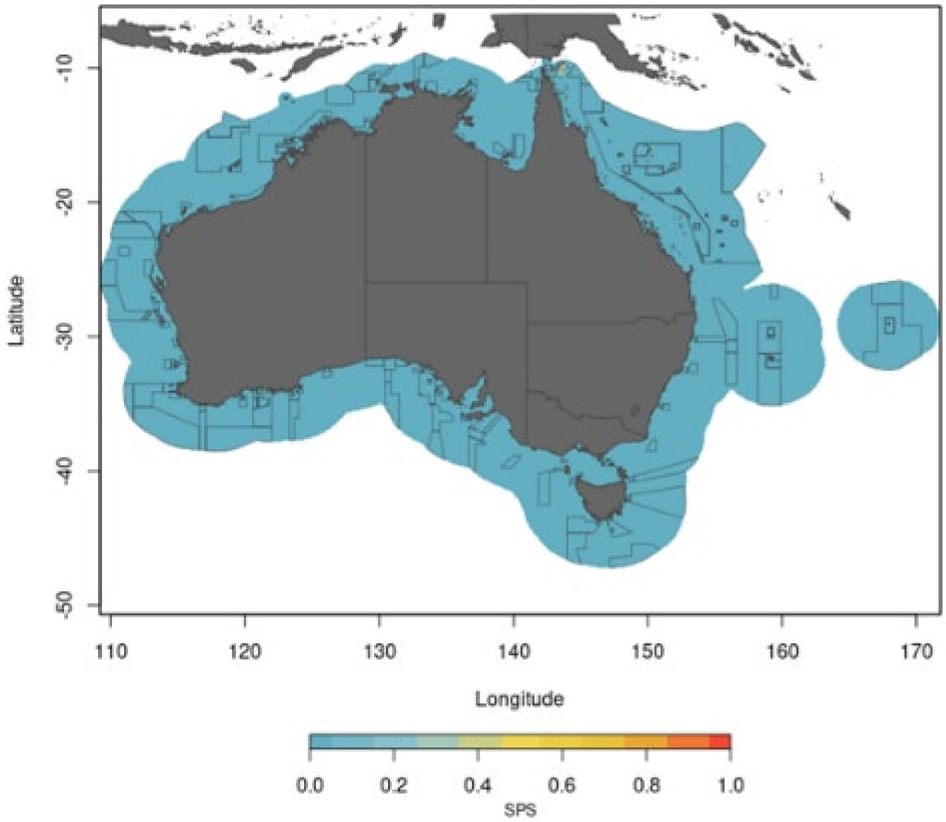

Figure B18: Pressure map for the Trotline net sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B18: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
TR_2013070120180631_operations_01res_linearStd.2	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/aa53a4df-7fe6-46d1-93b7-2d3732f4883e	Manageable

Vessel transiting

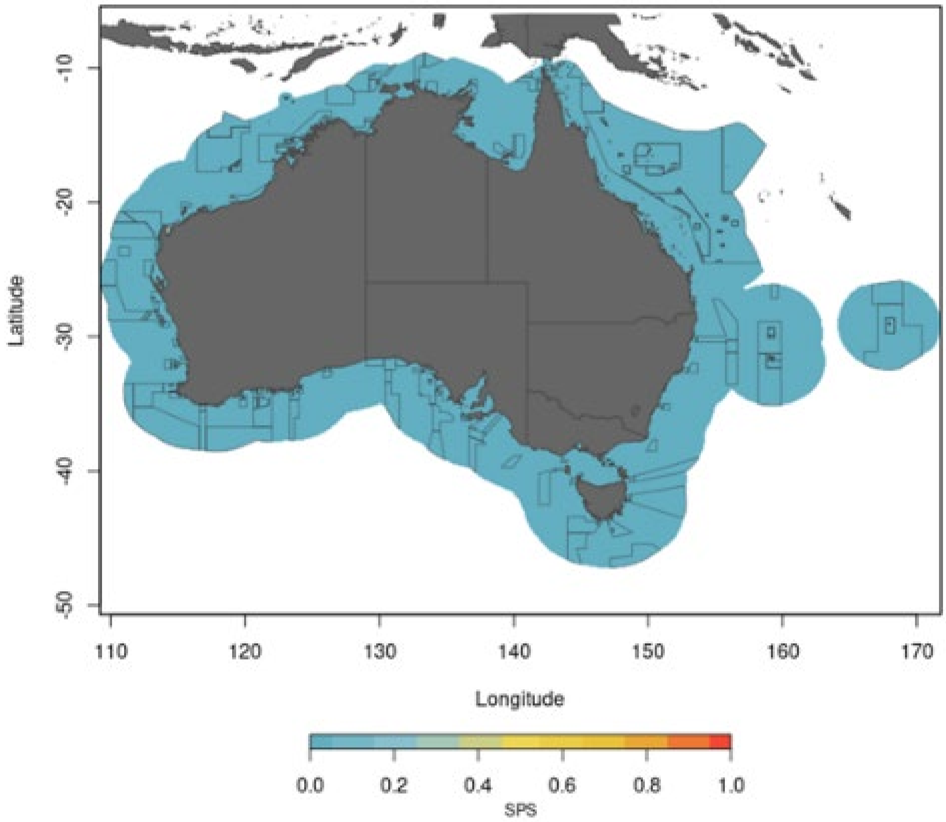

Figure B19: Pressure map for the commercialfishing activity, vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B19: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
transiting_distance_fishing_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f	Manageable

Commercial shipping

Anchoring

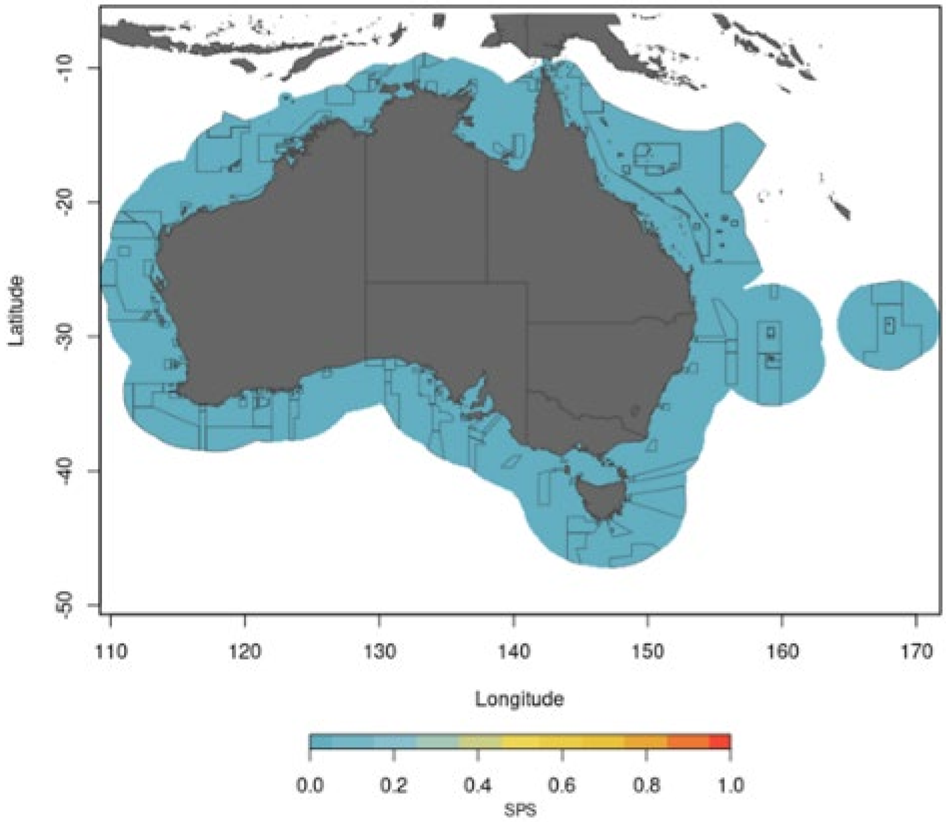

Figure B20: Pressure map for the commercial shipping activity, anchoring sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B20: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
Anchorages_temporal_sum_years_2013.2016_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f	Manageable

Vessel transiting

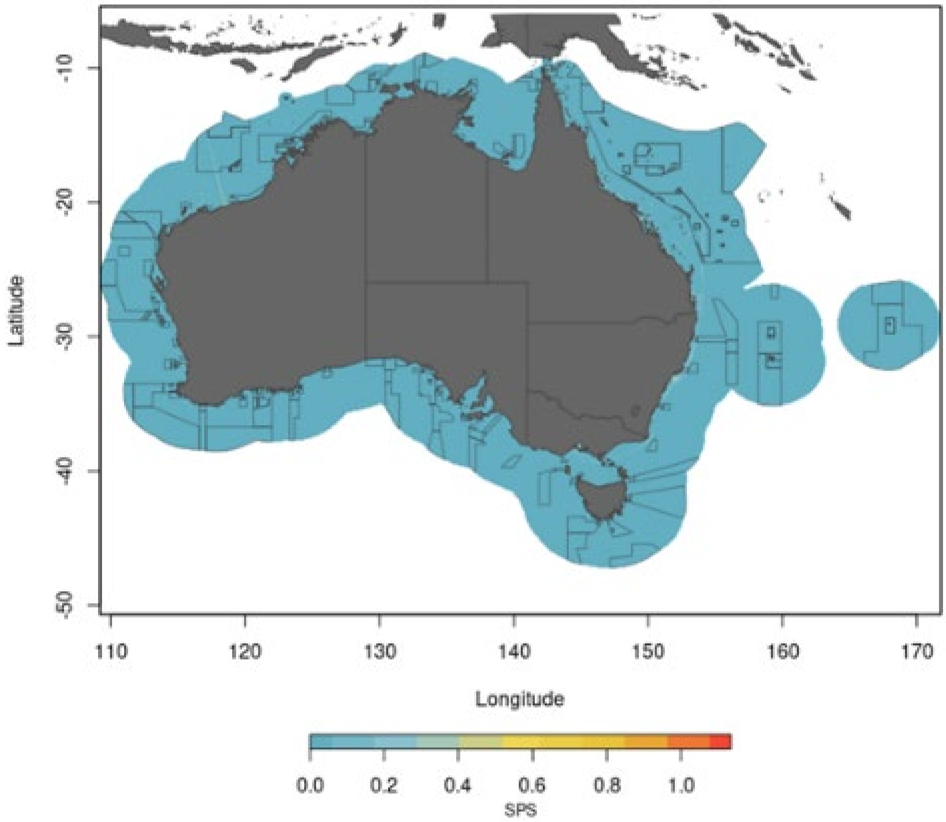

Figure B21: Pressure map for the commercial shipping activity, vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B21: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
NESPpressureNoise_SpatiallyProcessed_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f	Manageable
transiting_distance_shipping_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f	Manageable

Commercial tourism

Charter fishing tours

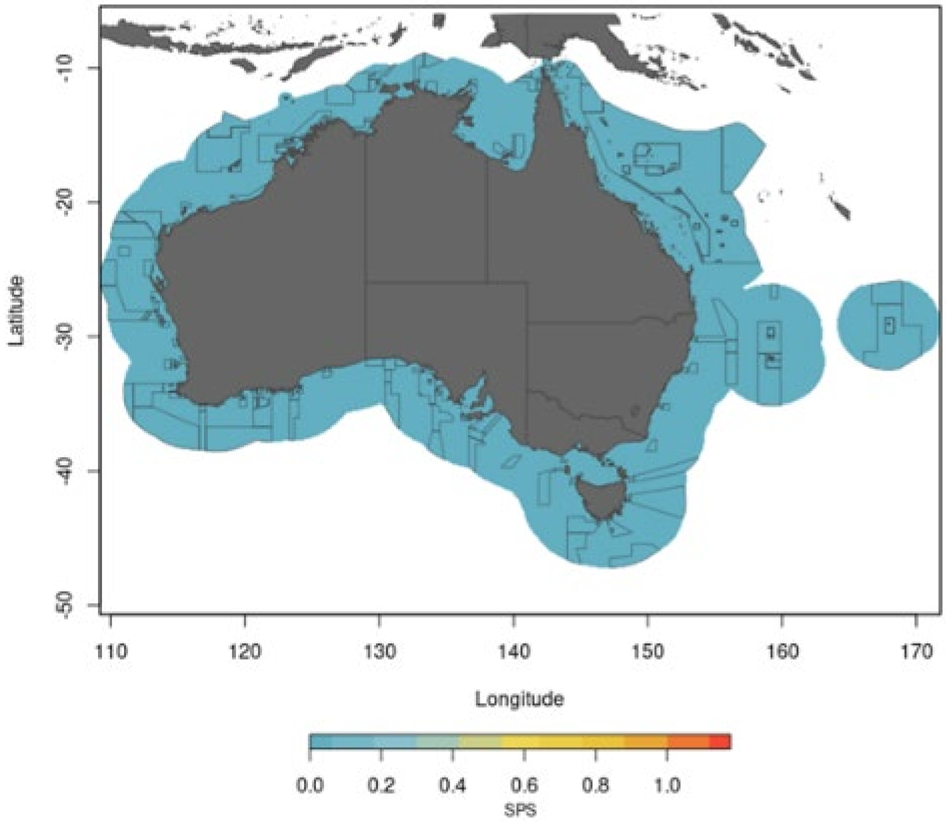

Figure B22: Pressure map for the charter fishing tours sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B22: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
parks_authorised_vessels_anchorages_temporal_mean_years_2013_2018_linearStd.1	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f	Manageable
parks_authorised_vessels_distance_temporal_mean_years_2013_2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f	Manageable

General use access and waste management

Ballast water discharge and exchange

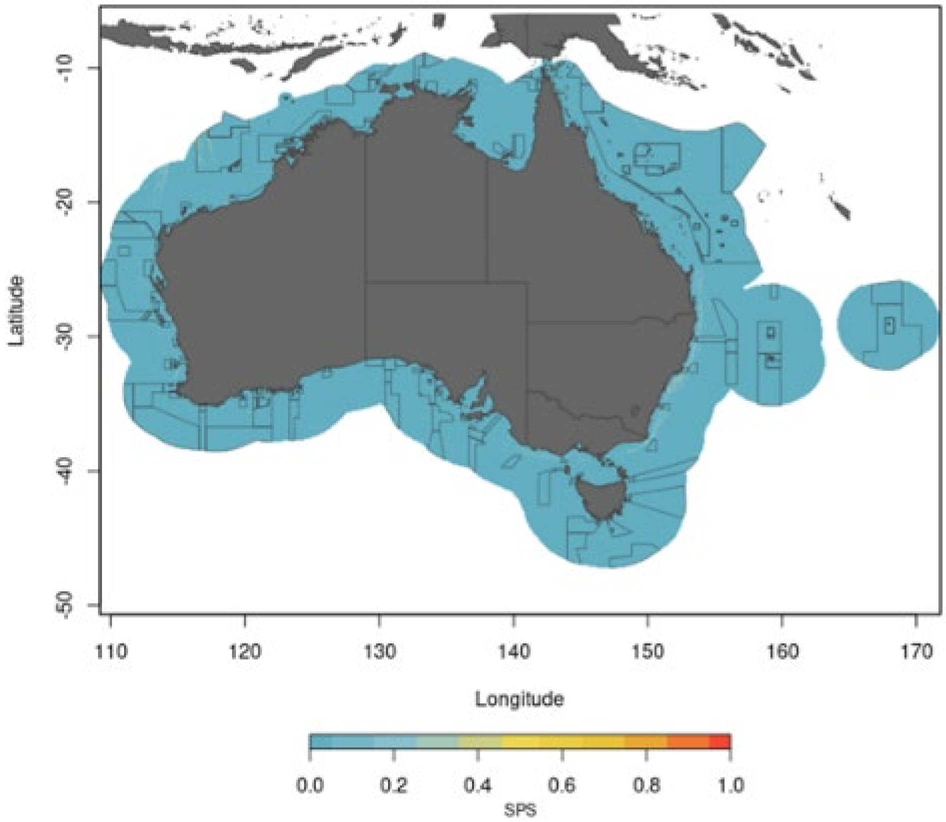

Figure B23: Pressure map for the Ballast water discharge and exchange sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table 1.23: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
ballast_exchange_volume_SpatiallyProcessed_linearStd		Manageable

Recreational use boating including vessel transiting

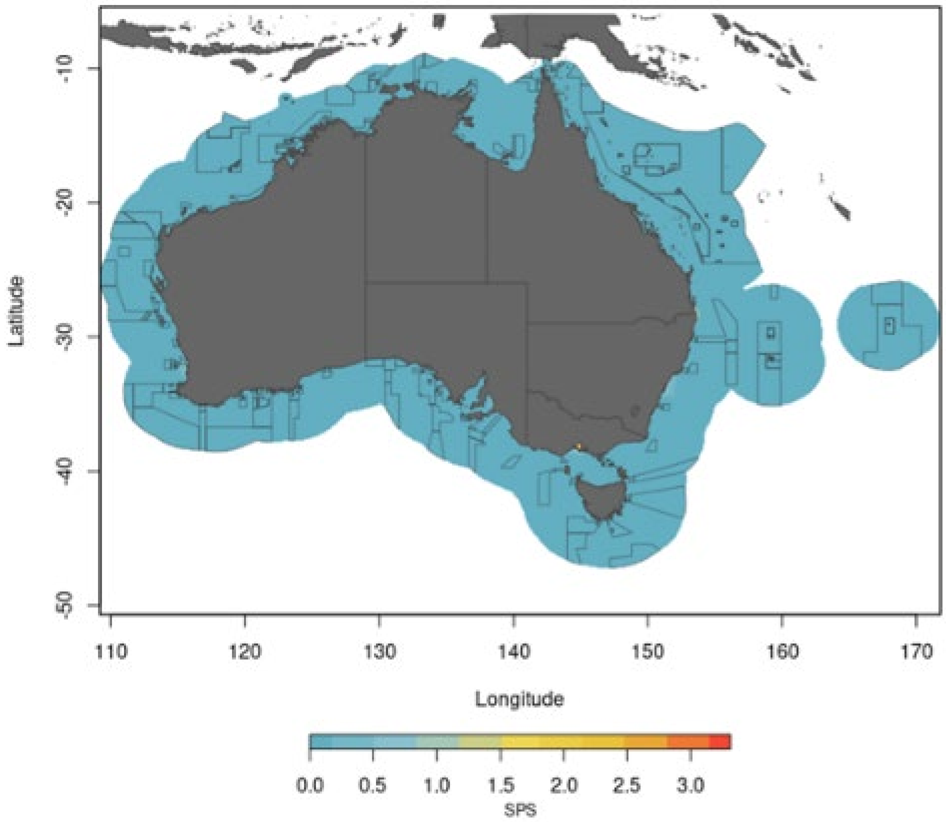

Figure B24: Pressure map for the Recreational use boating including vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B24: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
logV1_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc	Manageable
logV2_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc	Manageable
logV3_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc	Manageable
logV4_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc	Manageable

logV5_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc	Manageable

Land use intensification

Point discharges

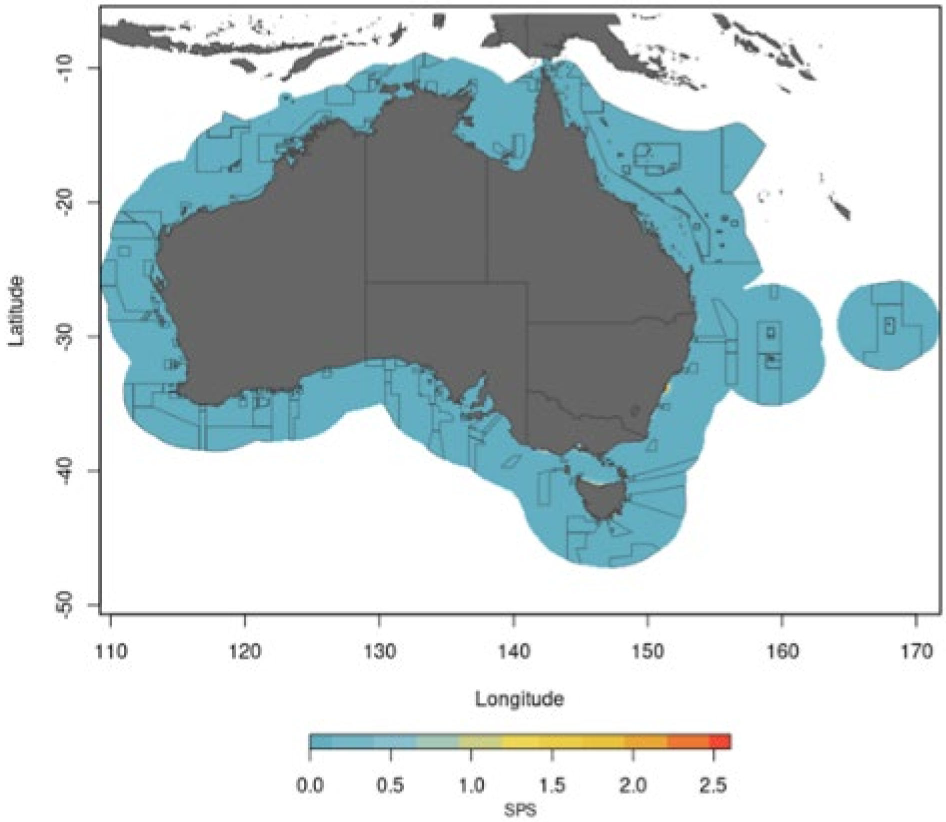

Figure B25: Pressure map for the Point discharges sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B25: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
NESP_NOD_ammonia_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mIJcoa4?domain=metadata.imas.utas.edu.au	Unmanageable
NESP_NOD_nitrate_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mIJcoa4?domain=metadata.imas.utas.edu.au	Unmanageable
NESP_NOD_nitrogen_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mIJcoa4?domain=metadata.imas.utas.edu.au	Unmanageable

NESP_NOD_pathogens_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mIJcoa4?domain=metadata.imas.utas.edu.au	Unmanageable
NESP_NOD_phosp_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mIJcoa4?domain=metadata.imas.utas.edu.au	Unmanageable
NESP_NOD_TSS_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mIJcoa4?domain=metadata.imas.utas.edu.au	Unmanageable

Marine pollution

Light pollution

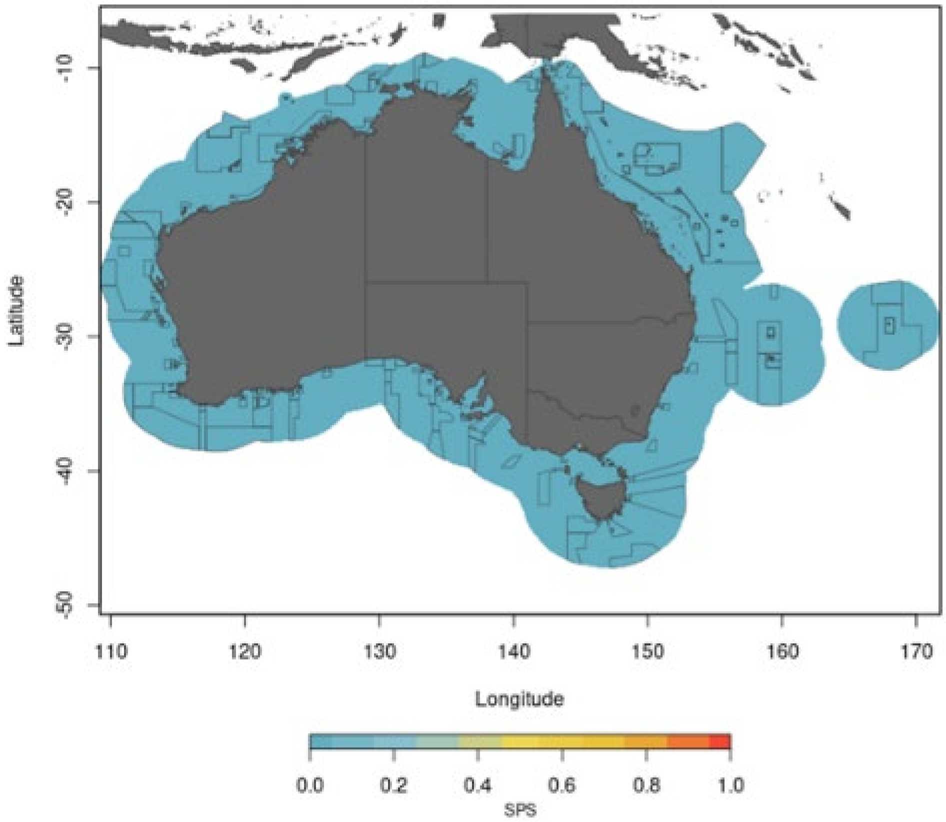

Figure B26: Pressure map for the Light pollution sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B26: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
BlackMarble_temporal_mean_years_2002and2016_masked_linearStd	https://viirsland.gsfc.nasa.gov/Products/NASA/BlackMarble.html	Unmanageable

Marine debris including microplastics

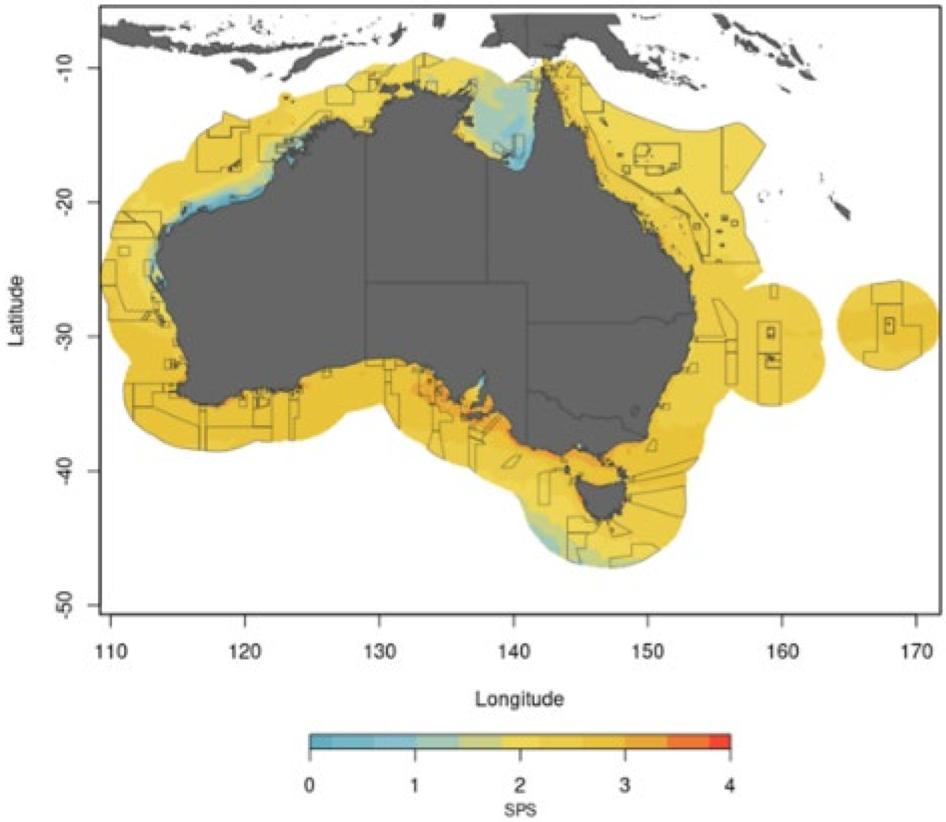

Figure B27: Pressure map for the Marine debris including microplastics sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B27: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
weight_density_size1_360SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/qSQNCjZryVCvyW83i2DvG-?domain=marlin.csiro.au	Unmanageable
weight_density_size2_360SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/qSQNCjZryVCvyW83i2DvG-?domain=marlin.csiro.au	Unmanageable
weight_density_size3_360SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/qSQNCjZryVCvyW83i2DvG-?domain=marlin.csiro.au	Unmanageable
weight_density_size4_360SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/qSQNCjZryVCvyW83i2DvG-?domain=marlin.csiro.au	Unmanageable

Noxious substances including chemicals and heavy metals

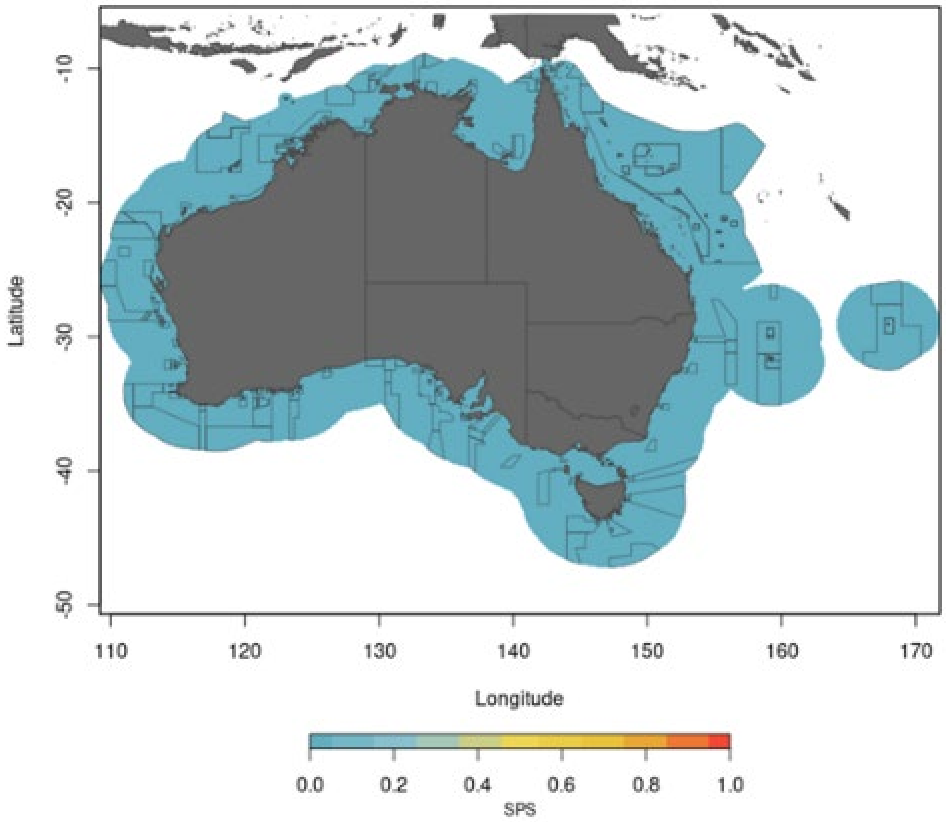

Figure B28: Pressure map for the Noxious substances including chemicals and heavy metals sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B28: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
organic_chemical_pollution_temporal_mean_years_2008.2013_masked_linearStd	https://knb.ecoinformatics.org/view/resource_map_doi:10.5063/F12805ZF	Unmanageable

Oil fuel spill or leak

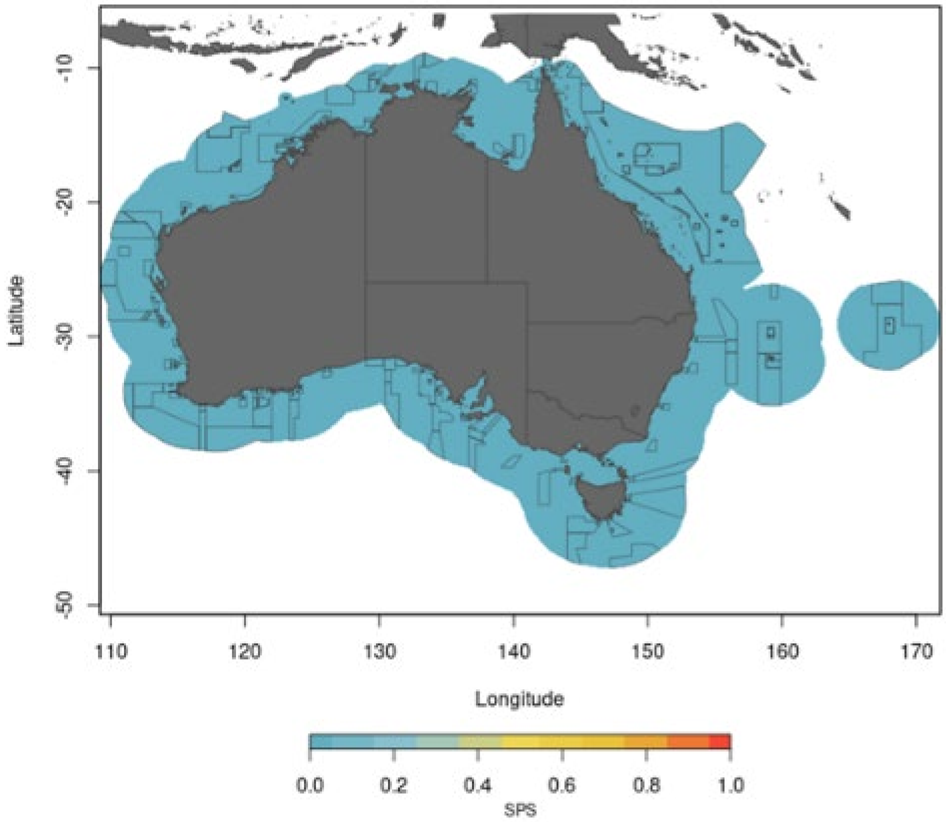

Figure B29: Pressure map for the Oil fuel spill or leak sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B29: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
oil_spills_sum_fieldID_total_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/42cQCk8vzVfpqx9rurLms9?domain=marlin.csiro.au	Unmanageable

Mining

Mining operations including exploration

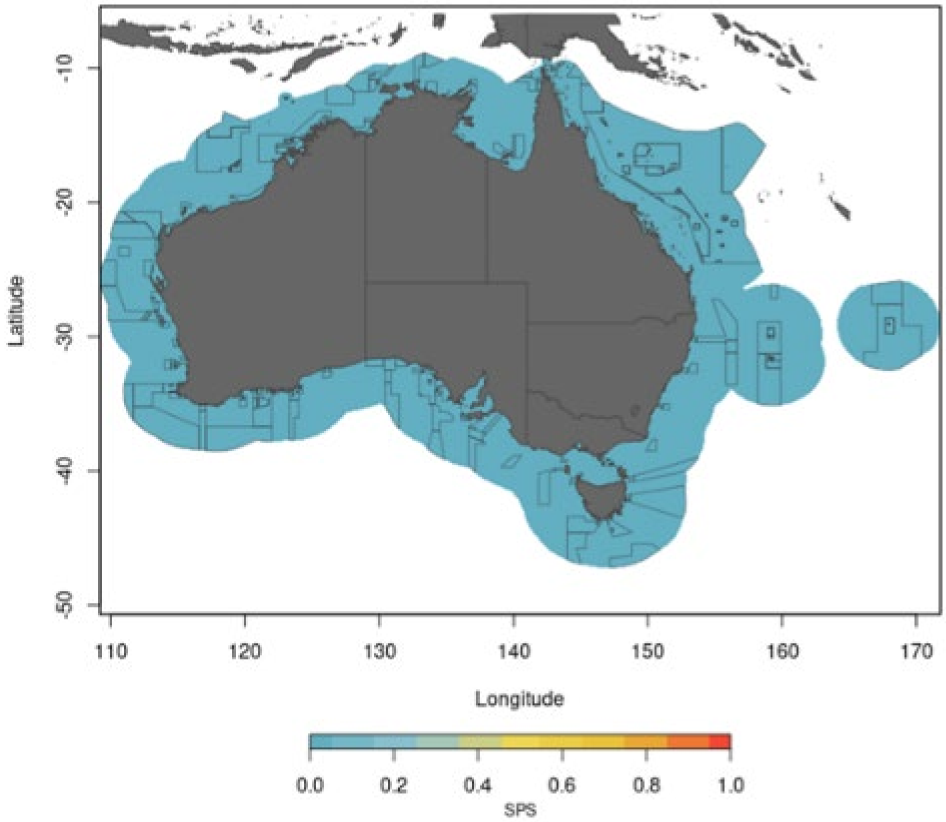

Figure B30: Pressure map for the Mining operations including exploration sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B30: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
wells_count_res01_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/2eddbe26-0276-4468-a210-0c00ada8bf39	Manageable

Mining seismic survey

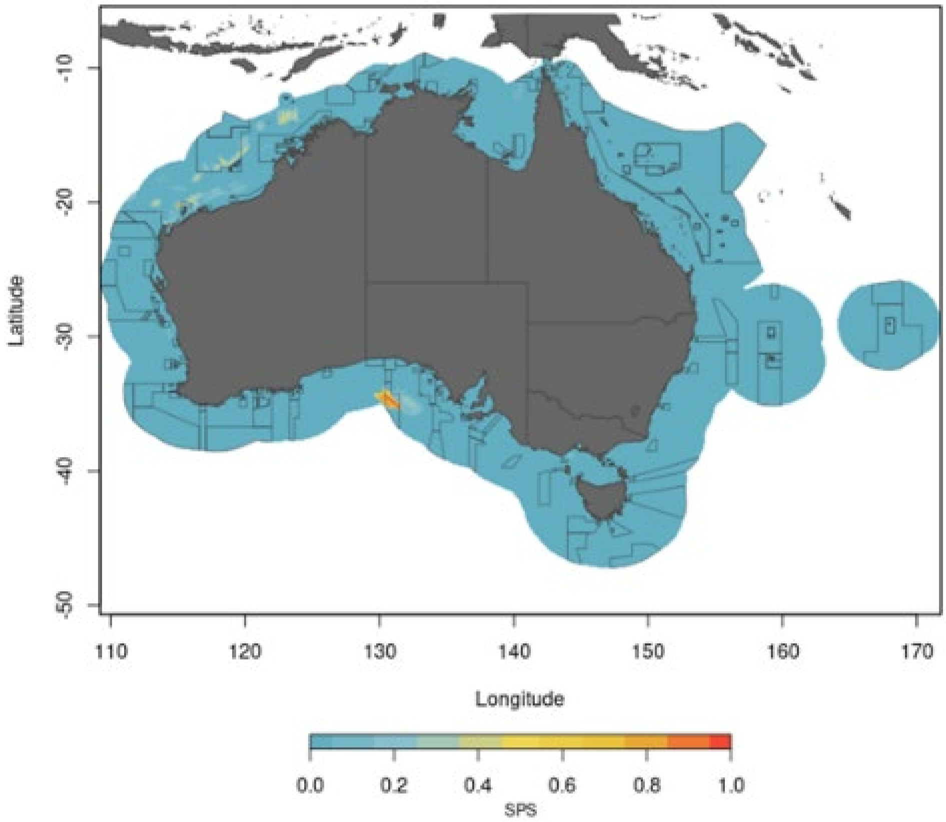

Figure B31: Pressure map for the Mining seismic survey sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B31: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
seismic.seismic3d_sum_2011to2015_ais_fieldID_sum_metres_SpatiallyProcessed_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/17249677-2be0-43a0-a9b5-da01e0be3fa7	Manageable

Vessel transiting

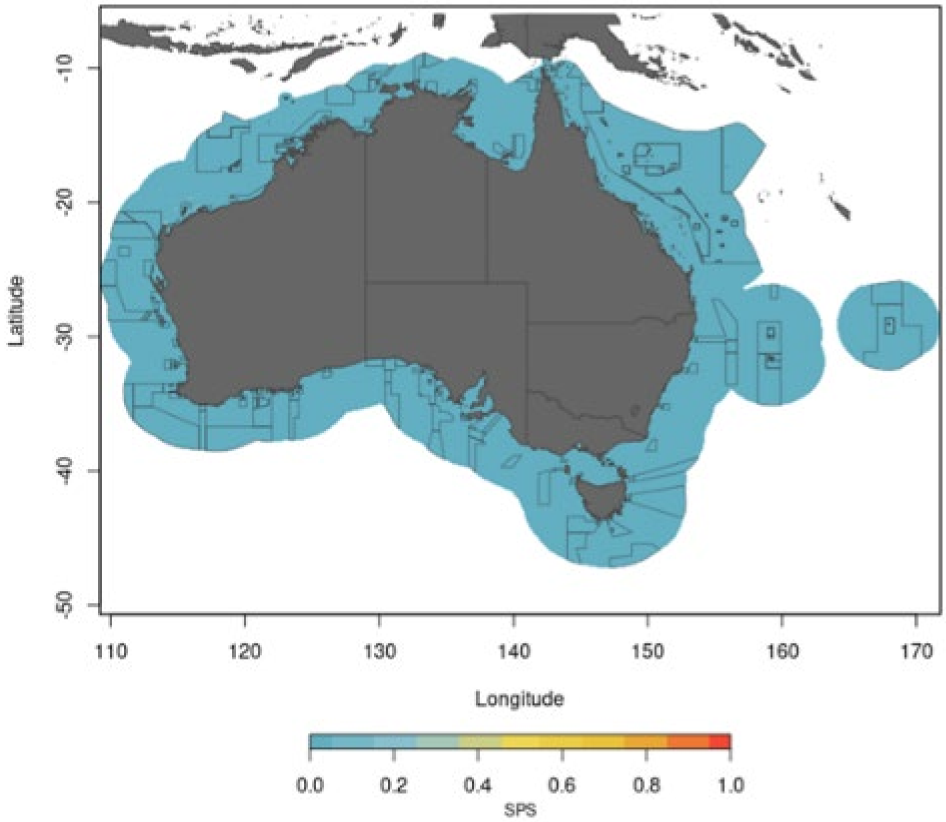

Figure B32: Pressure map for the Mining vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B32: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
transiting_distance_working_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f	Manageable

Recreational fishing

Vessel transiting

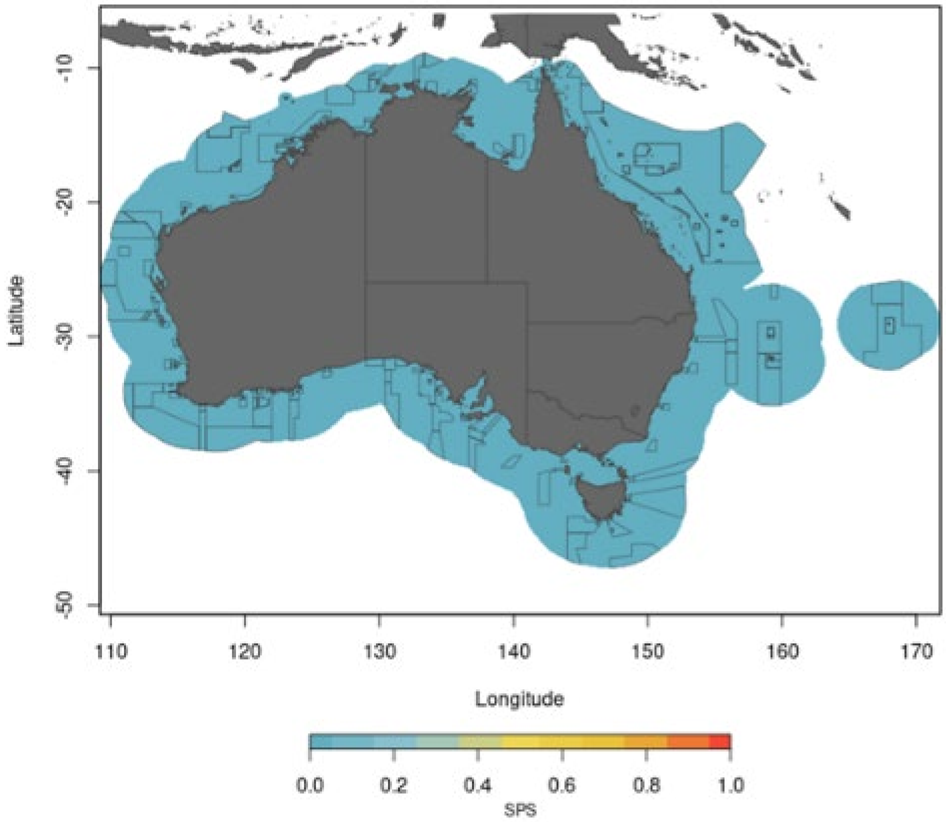

Figure B33: Pressure map for the Recreational fishing activity, vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B33: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
meanTripsY_log1p_01res_linearStd	https://www.nespmarine.edu.au/document/social-and-economic-benchmarks-australian-marine-parks	Manageable
transiting_distance_recreation_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f	Manageable

Renewable energy

Wave tidal and wind

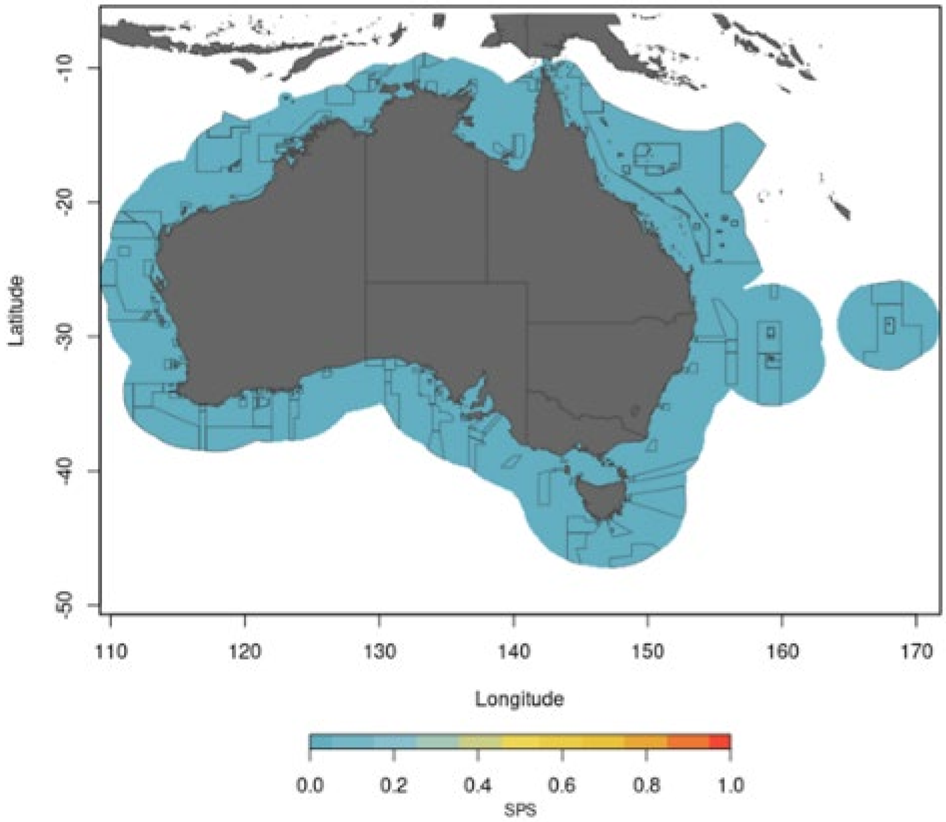

Figure B34: Pressure map for the Wave tidal and wind sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B34: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
areana.renewable.energy.2016_fieldID_count_SpatiallyProcessed_masked_linearStd	https://arena.gov.au/projects/?project-value-start=0&project-value-end=200000000	Unmanageable

Structures and works

Fish aggregating devices

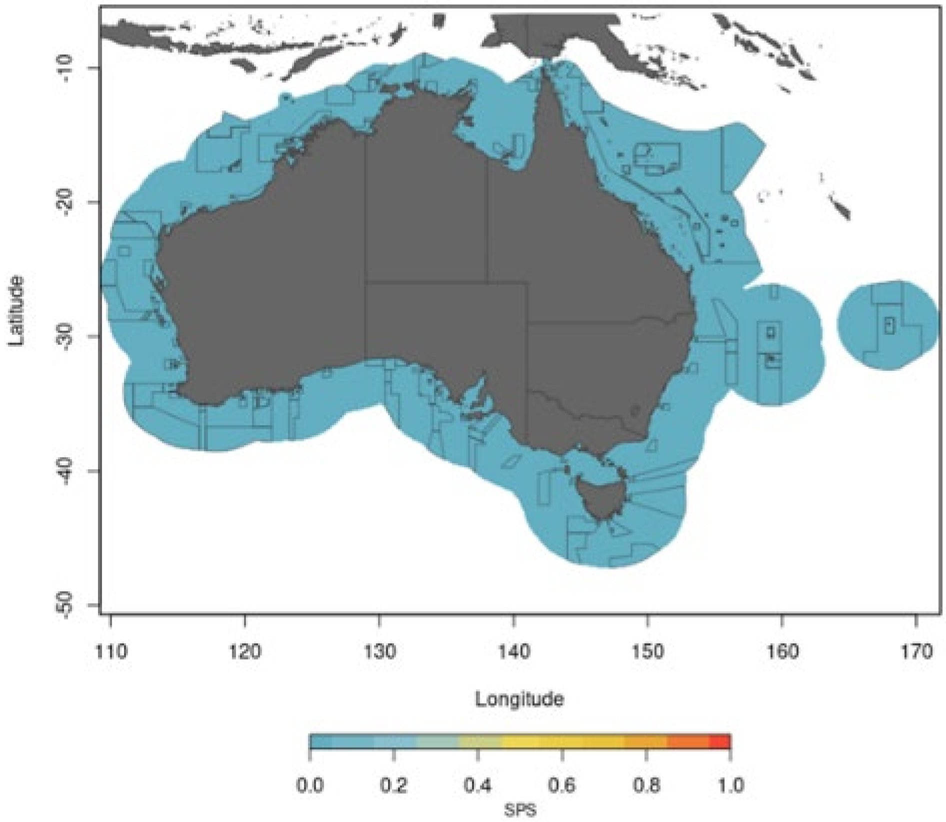

Figure B35: Pressure map for the Fish aggregating devices sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B35: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
fads_AU_linearStd	Parks	Manageable

Moorings

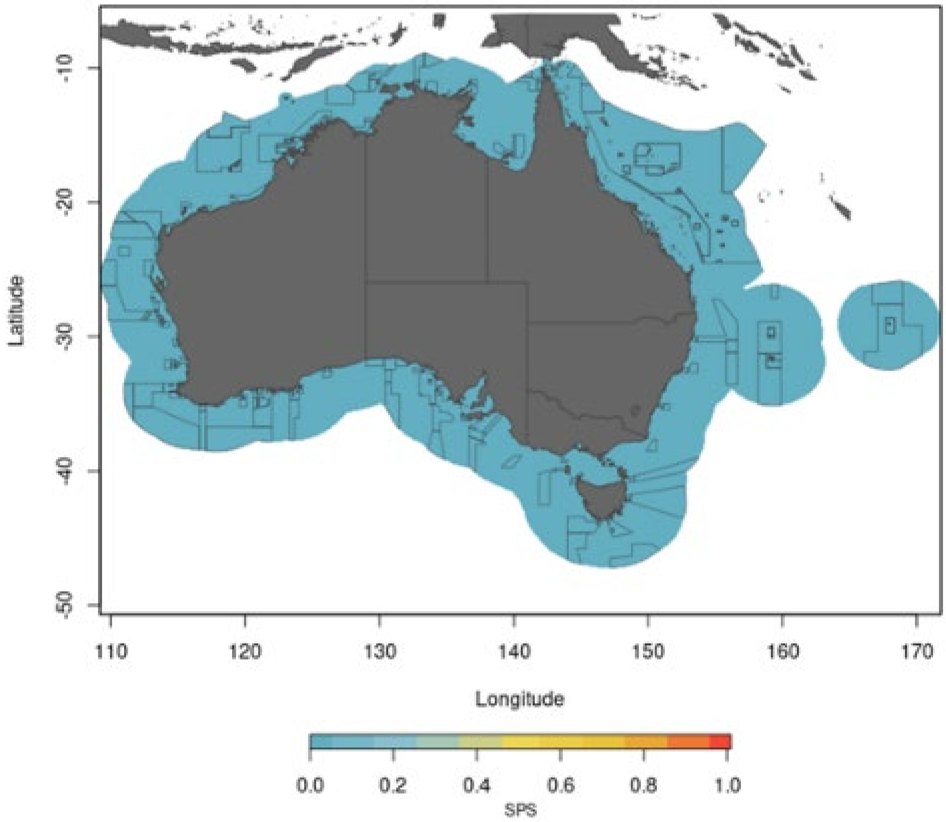

Figure B36: Pressure map for the Moorings sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in Australia's EEZ, together with the location and zone boundaries of the Australian marine parks

Table B36: Standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data

Data layer	Metadata record	Managed
parks_authorised_vessels_anchorages_temporal_mean_years_2013_2018_linearStd.2	Parks	Manageable
SpatiallyProcessed_temporal_sum_years_MooringsAll_masked_linearStd	Parks	Manageable

Appendix C - Updated shelf reef model

This is a re-fiiting and a re-predicting of the reef model developed in the MERI project (Hayes et al. (2021)). Also see the document entitled ReefPredictOverview3.pdf for original detail of that model and prediction (also in the appendix of the Hayes et al. (2021) report). So, why is re-fitting and re-prediction required? Well, another project has been funded (MERI2) that has obtained more habitat data from a number of sources: Towed video from WA state government, AUV from SA state government, towed video from Vic, and AUV from USyd. This additional sources provide a large amount of data, in terms of megabytes and hopefully in terms of information/signal.

Like the previous pdf document, this exists for a few reasons: 1) to get details out of the authors' heads so that the space can be cleared for other things; 2) expediting (accurate) incorporation into a project report; and 3) communication within the project team. It is not meant to be a polished document, but it is meant to contain the information from which a more polished document can draw upon. For this reason, given the likely end audience, I have tried to keep the technical details to an easily communicated level. Warning!

Topic

We describe an analysis of the data and GIS and/or algorithmic output whose purpose is to predict the presence of hard-substrate reef throughout the Australian mainland's continental shelf (up to 200 m depth). Unlike the previous analysis, this one only predicts the reef using a single model type and a single habitat data type. There is no comparison of different analysis methods and no comparison of these predictions to other data sources (e.g. Tier 1 product from previous comparison). For the purposes of prediction there are a number of different data sources available. Firstly, there are the physical covariates that describe the environment. These are the same data as were used in the previous predictive modelling.

250 m Grid

• GA Bathymetry and Derivatives

• Depth and seabed structure data - Gridded depth, aspect, relief, slope and seabed surface rugosity were obtained from the Australian bathymetry and topography grid (2009, version 4). The aspect data represents the degree of aspect of a slope surface and is a proxity for exposure to currents (https://researchdata.edu.au/bathymetry-derived-topographic-aspect-grid/1244962). The relief data represents the difference in elevation between the highest and lowest point within a specified area. The slope data represents the degree of slope of an area of seabed (https://researchdata.edu.au/bathymetry- derived-topographic-relief-grid/1272499). The seabed surface rugosity data represents seabed rugosity of an area of seabed. The rugosity was measured as surface area. Higher surface area corresponds with higher rugosity (https://researchdata.edu.au/bathymetry-derived-topographic-rugosity-grid/1221565). The slope data represents the difference in elevation between the highest and lowest point within a specified area (https://researchdata.edu.au/bathymetry-derived-topographic-slope-grid/1223668). All structure derivatives were generated using a 3 x 3 rectangular cell window.

• Sediments data - Sediments gridded data (i.e. percent mud, sand and gravel) is from Geoscience Australia (Seabed Sand Content Across the Australian Continental EEZ, 2011). This dataset provides the spatially continuous data of the seabed sand content (sediment fraction 63-2000 mm) expressed as a weight percentage ranging from 0 to 100%. The lineage of this datset is from Geoscience Australia's Marine Sediments database (MARS). For these gridded datasets, a subset of this data was selected for use in predicting spatial distribution of mud, sand and gravel content based on a set of criteria (similar to those reported by Li et al. (2012)). Predicting the spatial distribution of mud, sand and gravel content at a 0.01 decimal degree resolution was undertaken by averaging the predictions of a combined method of random forest and ordinary kriging and of a combined method of random forest and inverse distance squared (the methods used is similar to that reported by Li et al. 2012). The spatial interpolation method used was experimentally selected from over 40 methods/sub-methods based on assessment of predictive errors. It should be noted that the underlying MARS data assumes that substrata is not rock.

• Velocity data - Two measures of current velocity was used (i.e. east-west and north-south velocities). These two gridded datasets were accessed from Geoscience Australia's data portal. Both datasets were generated from the HYbrid Coordinate Ocean Model (HYCOM, see www.hycom.org for more details) and represent current velocity (v - m/s) in either north-south or east-west directions.

• Additional to the published environmental variables, a new delineator of space that we call radial measure is calculated. This is designed to give a bearing around the country, from a single internal location. It performs the same/similar role that the string distance variable did in the IMCRA analysis (Last et al. (2011)). To create this variable, an arbitrary location is chosen within the centre of the country and angles, in radians, is calculated for each location within the grid. The centre point is (longitude=137, latitude=-27), and was chosen subjectively so that there was not too much confusion between sites in Victoria and Tasmania, and between sites in the southern part of WA. The radial measure ranges from $-\pi$ to π and increases in an anti-clockwise direction (so that Perth has a smaller value than Sydney).

To understand the spatial extent, and to get some idea of some of the gridded data, a few of the variables are plotted now. Note that some of the covariates (relief, slope and surface) were transformed to avoid the undue influence of a small number of observations. Sensible transformation of covariates will have beneficial effect on prediction, but comes at the price of making the relationship harder to interpret. Fortunately, we are only interested in prediction for this analysis.

Habitat data

The description of these data sets is quite brief. The truth is, and much to his shame, he doesn't know much about them. For more details, and as a point of first contact, please contact Jac Monk.

• Global Archive - These habitat data were annotated from the background in the field of view in each BRUV sample. A 5 x 4 grid was superimposed for each BRUV sample to identify the dominant benthic composition (biota and substrata), field of view and relief. Information on benthic relief (using a 0-5 estimate Polunin and Roberts (1993); Wilson, Graham, and Polunin (2007)) and benthic composition (based CATAMI classification scheme; Althaus, Hill, and Rees et al. (2015)) was collected from each BRUV sample using TransectMeasure from SeaGIS (seagis.com.au). The proportion of reef used in the subsequent models was generated by converting BRUV samples that contained 'any reef' as reef and samples without reef as 'not reef.' Note that there is no survey design at the national scale. Rather it is an amalgamation of individual surveys, which targetted different environments (e.g. deep reefs in Southern Tasmania and seagrass in Geographe Bay). This lack-of-design may confound spatial location with survey-objectives, but we hope not and note that we may have to try and model accommodating these confounders.

WA Towed Video These data come from length(grep("WA", names(table(dat$source)))) different projects and span sum(table(dat$source)[grep("WA", names(table(dat$source)))]) different grid cells. These data will suffer all the same foibles as those described previously.

SA AUV These data come from length(grep("SA", names(table(dat$source)))) different projects and span sum(table(dat$source)[grep("SA", names(table(dat$source)))]) different grid cells. These data will suffer all the same foibles as those described previously.

Vic TV These data come from length(grep("Vic", names(table(dat$source)))) different projects and span sum(table(dat$source)[grep("Vic", names(table(dat$source)))]) different grid cells. These data will suffer all the same foibles as those described previously.

USyd AUV These data come from many different projects, which are un-named and are lumped together into a single category, and span sum(table(dat$source)[grep("squidle", names(table(dat$source)))]) different grid cells. These data will suffer all the same foibles as those described previously.

We included all national image data to fit the model too. Predictions were made only to southern sites that are less than 200m deep.

Modelling

General principles of modelling strategy

In the previous project we tried a number of different modelling strategies and a number of different calibration exercises. The take-home messages were that: none of the previous habitat data sources (images or 2x derived from geography) agreed very well, and 2) flexible models were not going to work very well due to the manner in which the data were collected. The end-point was that a simple GLM should be used that contained quite-stiff regression spline terms for the environmental covariates. The GLM model (on the presence or absence of reef in the image) was passed through a backwards selection process to remove environmental covariates that did not explain substantial deviation. The backwards selection was performed using BIC.

Details of modelling approach

Many of these data sources produce images that are spatially located near each other. So close, in fact, that they many share common covariates (within a grid cell) and are likely to be very highly correlated. For this reason, the image data were ‘simplified’ into grid cells, where the collation consisted of the number of images containing reef, the number not containing reef. Images were not combined between projects within a grid cell – so a single grid cell may contain an entry from (e.g.) GlobalArchive and one from WA state government. As already mentioned the data are often located very close to each other. This is highly likely to induce a spatial auto-correlation, especially with covariates at coarser resolution. The implication is that these groups of data are unlikely to provide independent information and hence it may be totally inappropriate to assume that they do. Unfortunately, this is the assumption that is made when using a GLM or any of its derivatives. One solution to this inferential problem is to weight the observations (number of images per source per cell) so that they all have equal weight. This is, probably, the other extreme where the observations from densely observed cells have too little weight in the model. The truth is probably in between, but where is unknown and probably unknowable.

While the weighting is a possible solution/patch to the autocorrelation/information problem, it adds a new parameter to the model – the amount of weighting. Here, we use an approach that intends to explore the sensitivity of the predictions to the amount of weighting. In particular, we provide weights as $wn_i + (1 - w)1$ where n_i is the number of images for an individual observation and $w \in [0, 1]$ is the weighting parameter that controls if the weights should represent all-images-within-cell-independent ($w = 1$) or all-images-within-cell-dependent ($w = 0$). Loosely speaking, the case where $w = 0$ corresponds to a presence-absence analysis at the cell level rather than the image level. The difference is that the observation in the weighted scheme is the proportion of reef images, whereas in the presence-absence scheme the outcome is the presence of any reef. Despite this difference, the similarities are enough to draw useful intuitive concepts. These weights rely on the representation of binomial data as the sum of individual Bernoulli observations. In the glm() function in R, this just means that the formula ‘outcome’ is the proportion of reef, and these observations are weighted using the weights argument. The above weighting will not produce integer observations and R will through a warning message. This can safely(!?) be ignored.

Predictive model

The form of the model followed closely to that previously. Here’s the previous description: The predictive model is a very simple form of a generalised additive model (GAM, see Hastie and Tibshirani (1990),Wood (2006)). In particular, it is a regression spline approach (see Hastie and Tibshirani (1990),Venables and Ripley (2002)), where the expectation of the reef variable is modelled as a smooth function of the covariates. The wiggliness of each smooth function is set prior to estimation, and we choose to have minimal wiggliness to avoid over-fitting the reef data. The environmental covariates are assumed to act independently of one-another, so that (for example) water velocity has the same effect on reef/not-reef irrespective of whether it is at 50 m or 180 m depth. The smooth curve for each of the environmental covariates was a natural cubic spline with 2 internal knot points. The smooth for longitude, latitude and depth was, once again, a natural cubic spline but with 3 internal knot points. Finally, the smooth for radial measure was a cyclic spline with 4 knot points (but the first is constrained to be the same as the last). The cyclic spline is beneficial to make sure that the ends of the radial measure ($-\pi$ and π) agree with each other – no discontinuities are wanted.

We found that the low-order regression spline approach worked passingly well. At least compared to more-flexible approaches. This was surprising as the more flexible approaches were expected, a priori, to perform better. We further simplified the model by using backwards selection (see Neter et al. (1996) and Miller (2002)), which removes covariates from the model if they are shown to be unimportant in explaining variation in the reef/not-reef variable. In addition to these environmental effects, terms for the source (project within state and also GlobalArchive/Squidle+) and the locally-derived image density were added. The source was added as some projects may have been purposefully targetting reef or sediments, in which case their probability of observing reef would change greatly. A linear term for the number of images per cell (effectively density) was also added as it is could be that higher image density may be related to reef probability. For both these variables, predictions were made as though we were predicting a BRUV drop with a single image per cell. This keeps the output consistent with the previous work.

Weights

The weights described earlier need to be dealt with in some consistent manner. They actually make quite a large difference in the model predictions (see following figure): as the weighting increases some regions 6become highly probable whilst others become improbable. This in itself shows that the results are highly dependent on the choice of weighting and that the data (coupled with the modelling approach) do not contain a large amount of information at the national scale. Nevertheless, we can try to produce ‘robust’ summaries, that are intended to be insensitive to the choice of weights. To perform this prediction, we first fit models with a range of different weights. We randomly draw the weighting parameter w from the interval [0, 1], and do so 100 times. For each weighting parameter, we fit the model and predict from it. This produces 100 maps/rasters that demonstrate the range of possible values. Since we have no knowledge of what a good weighting parameter might be, a conservative map can be constructed by taking the cell-wise minimum of the raster. This is conservative as it gives the minimum prediction for each and every location, with the range indexed by the weight parameter. If a prediction is high in this combined map, then it is high under all values of weighting – it is insensitive to the parameter. The consequence of this is that the meaning of the prediction map is different from the previous version. This could cause confusion. Previously the map was an expected value of a selected model. In this work, the map is a minimum of a set of expected values from many selected models. It is likely that the minimum is going to be substantially smaller than the straight prediction.

Maps of Predictions

The plot of the minimum, over all different weighting schemes, is given in the following plot. Also presented there are dichotomised versions: with cutoff of p = 0.6, 0.7, 0.8. These cutoff values cannot be directly compared with the previously produced (for previous project) as the underlying map has a different interpretation. Previously it was a prediction of an expected value. Here it is a minimum of a set of expected values.

Predicting where reef is:

Previously, we had binarised the probability maps into those areas where reef is likely to be. This is done by choosing an arbitrary cutoff (0.6 say) and mapping which pixels' predictions exceed that cutoff. See following map. There aren't many areas where all the weighting schemes agree (or there aren't very many reefs)

Predicting where reef is NOT

In the previous work, we looked at trying to get a gauge on where reef was not likely to be. This was done by looking at the locations with small predicted probabilities. The same thinking can be applied to the current prediction process. The difference will come when summarising over the set of predictions using different weights. Instead of the minimum, we will want the maximum. The following plots identify those areas that are all below a threshold, over different weights. That is the maximum is below the threshold.

Uncertainty is Missing

During this map-generation process we have almost completely ignored uncertainty. This is unfortunate and goes against almost every bone in a body. The exception is that we have tried to account for uncertainty in the weights (reflecting the loss of information from spatially clustered images). This uncertainty is a big source, and it obviously changes the interpretation of the map substantially.

Appendix D - Network Level Maps

South-west Network

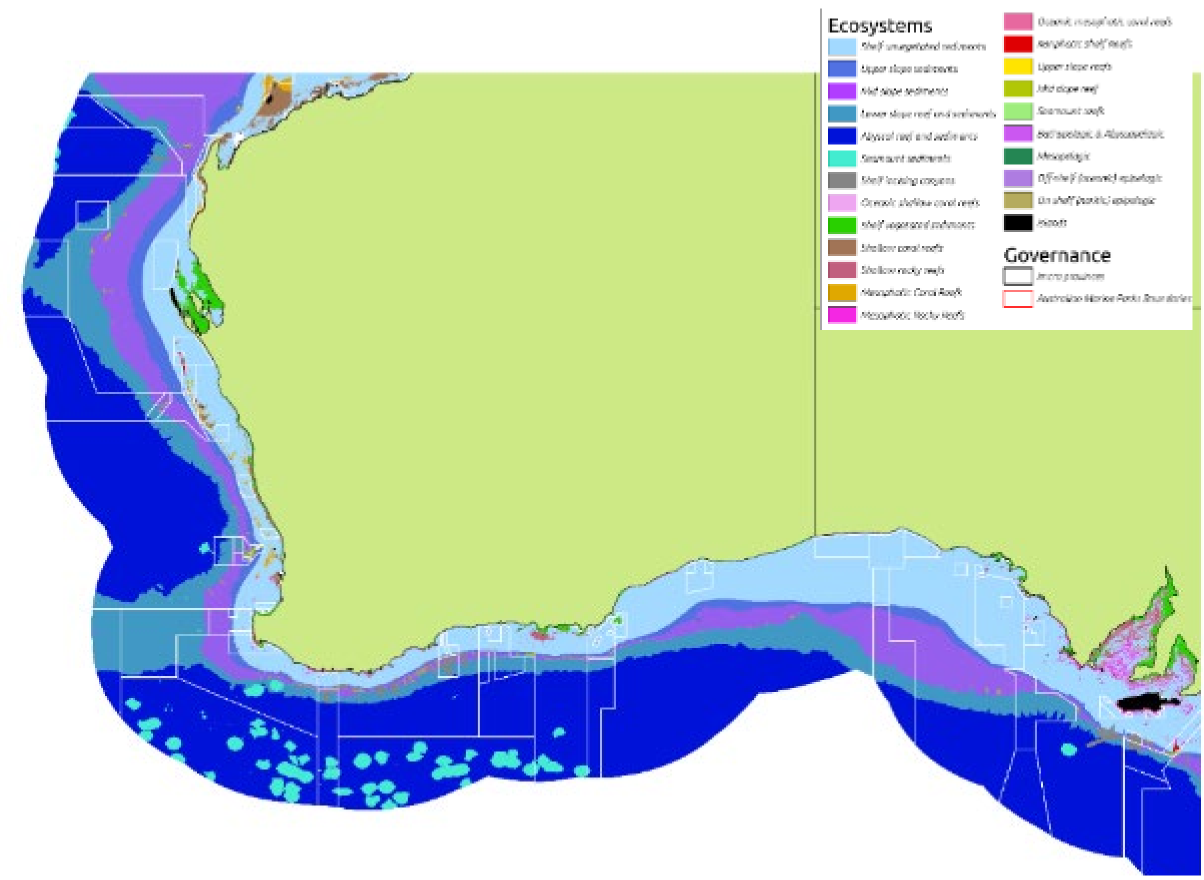

Figure D1: Ecosystems in the South-west Network

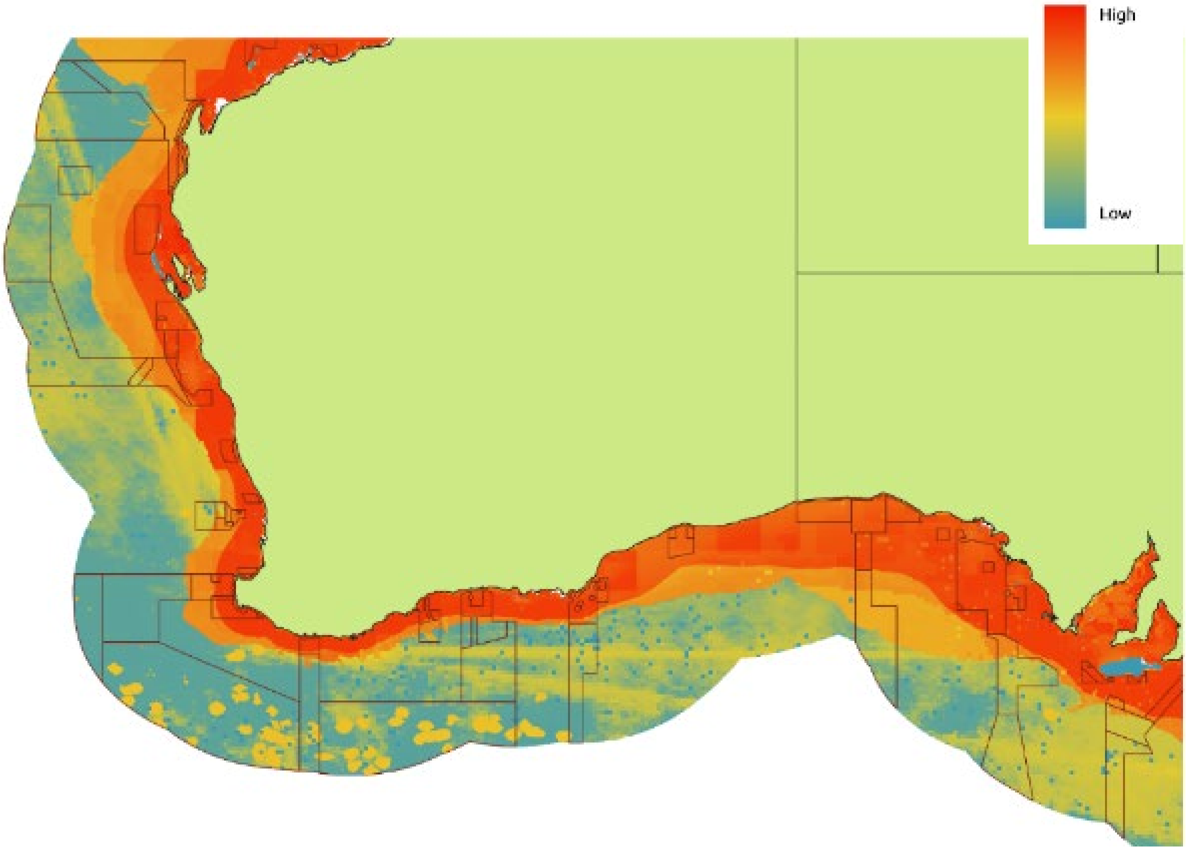

Figure D2: Benthic cumulative impacts for the South-west network

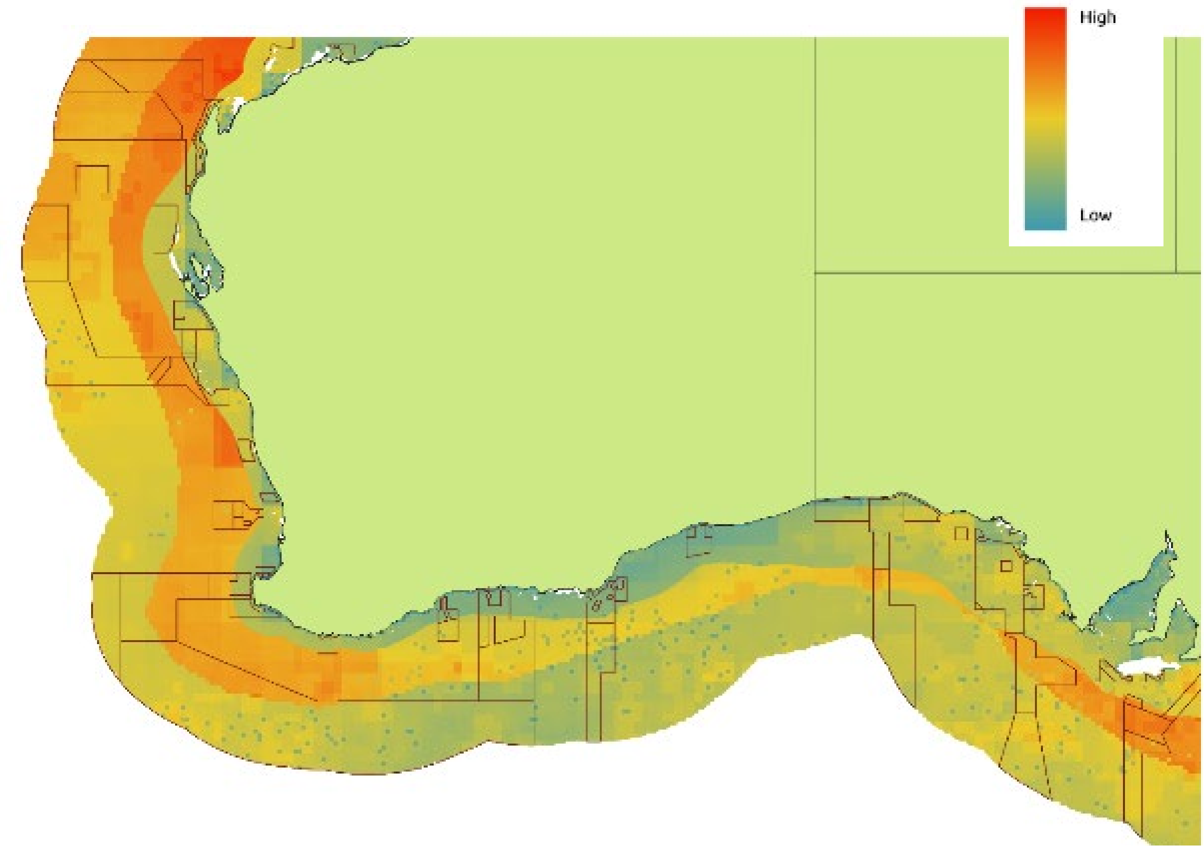

Figure D3: Pelagic cumulative impacts for the South-west network

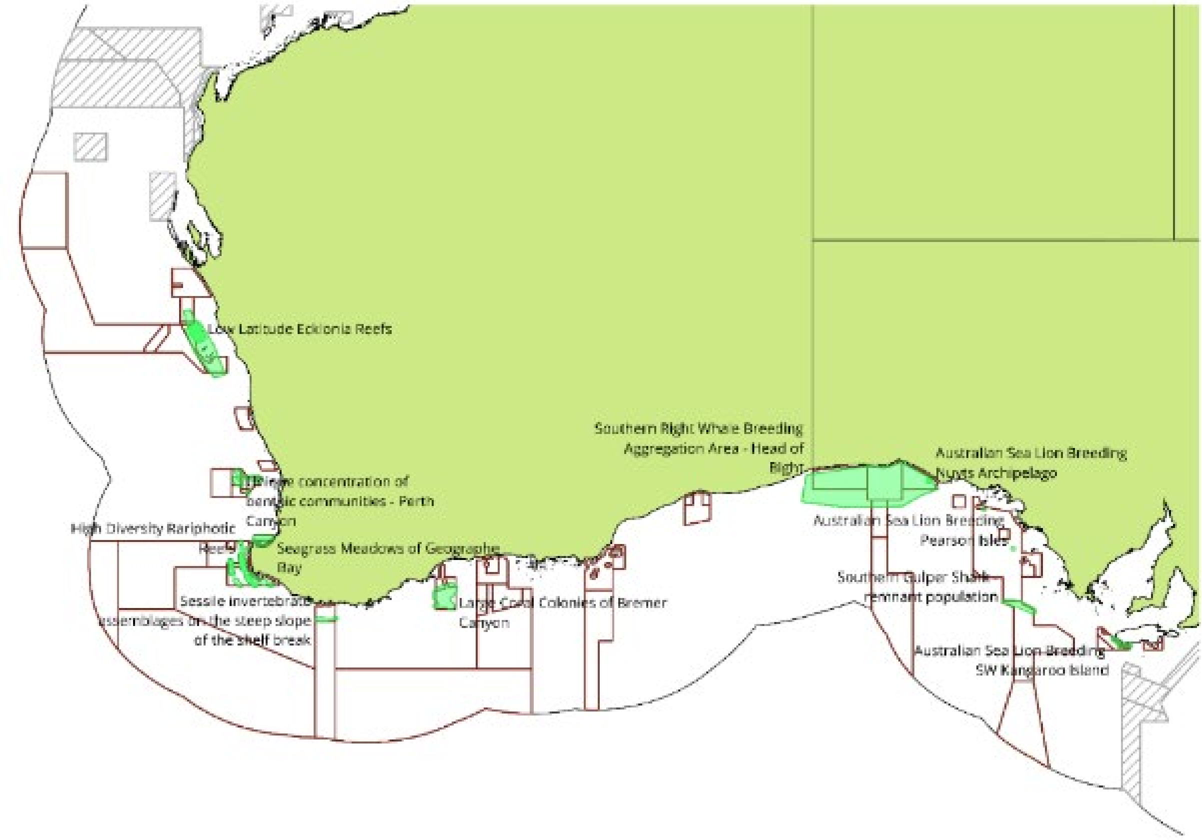

Figure D4: KNVs in the South-west network

Figure D5: Ongoing pressures responsive to management level 1 monitoring priorities for the South-west Network. Red is likely ongoing pressures, blue is possible and yellow is insignificant

Figure D6: Mitigation or removal of pressures level 1 monitoring priorities for the South-west Network. Red is likely reduction pressures, blue is possible and yellow is insignificant

North-west Network

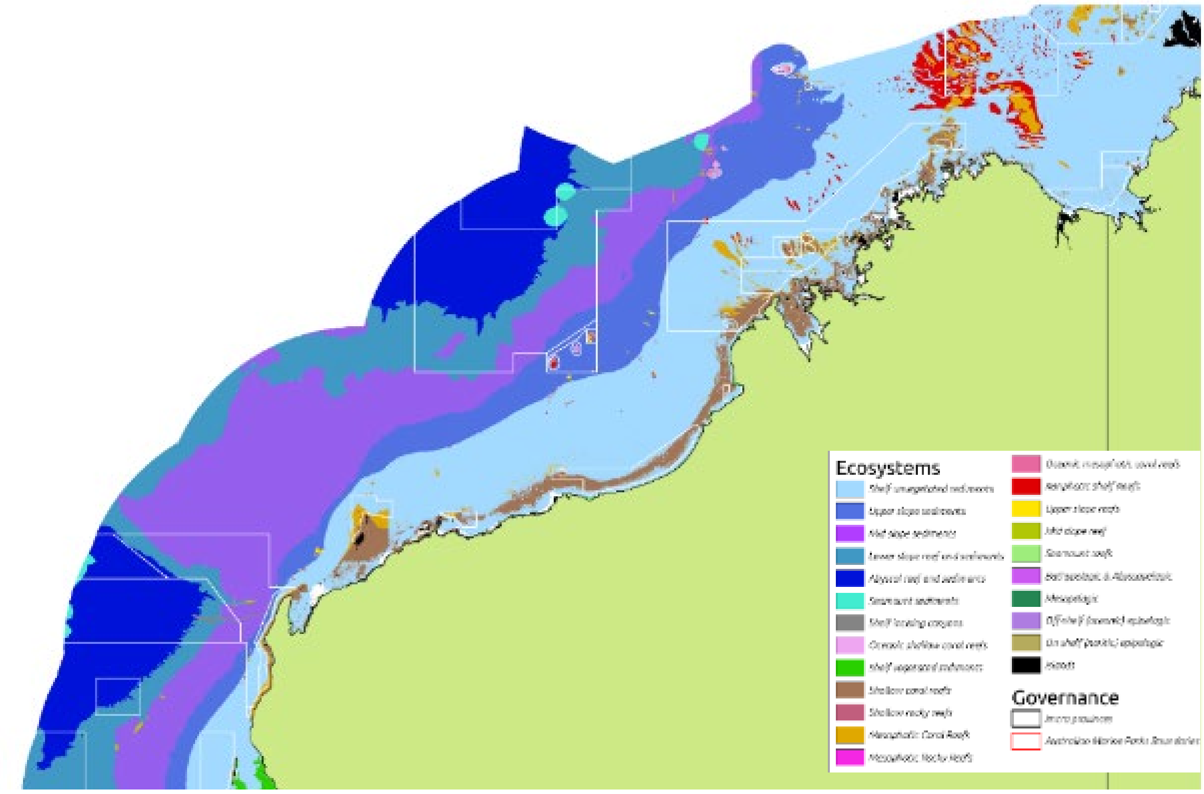

Figure D7: Ecosystems in the North-west network

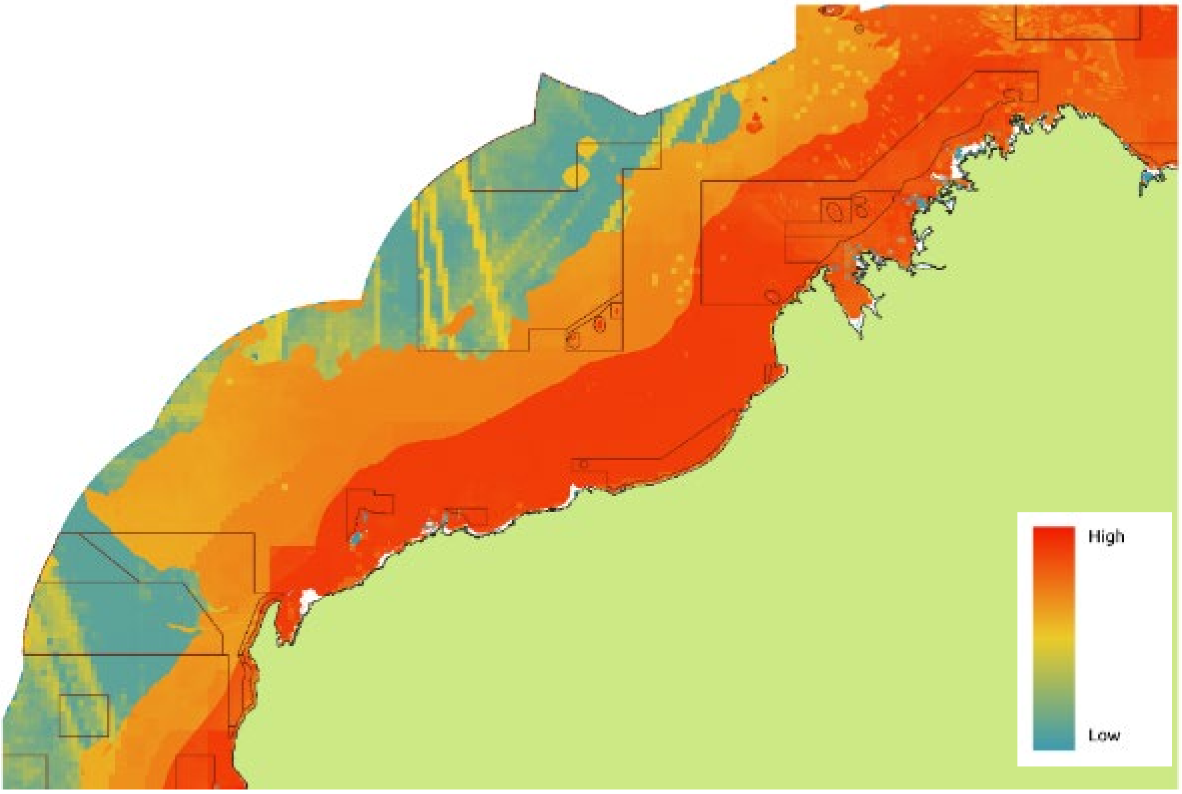

Figure D8: Benthic cumulative impact in the North-west network

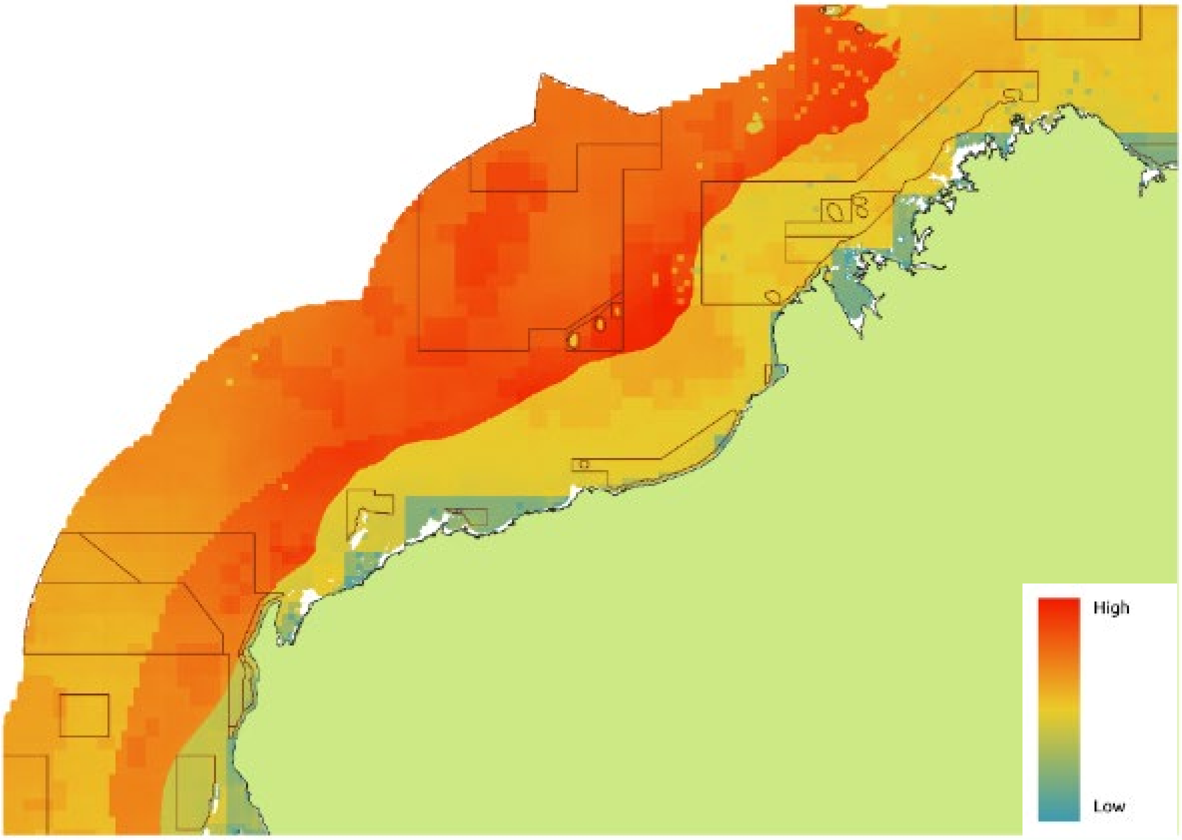

Figure D9: Pelagic cumulative impact in the North-west network

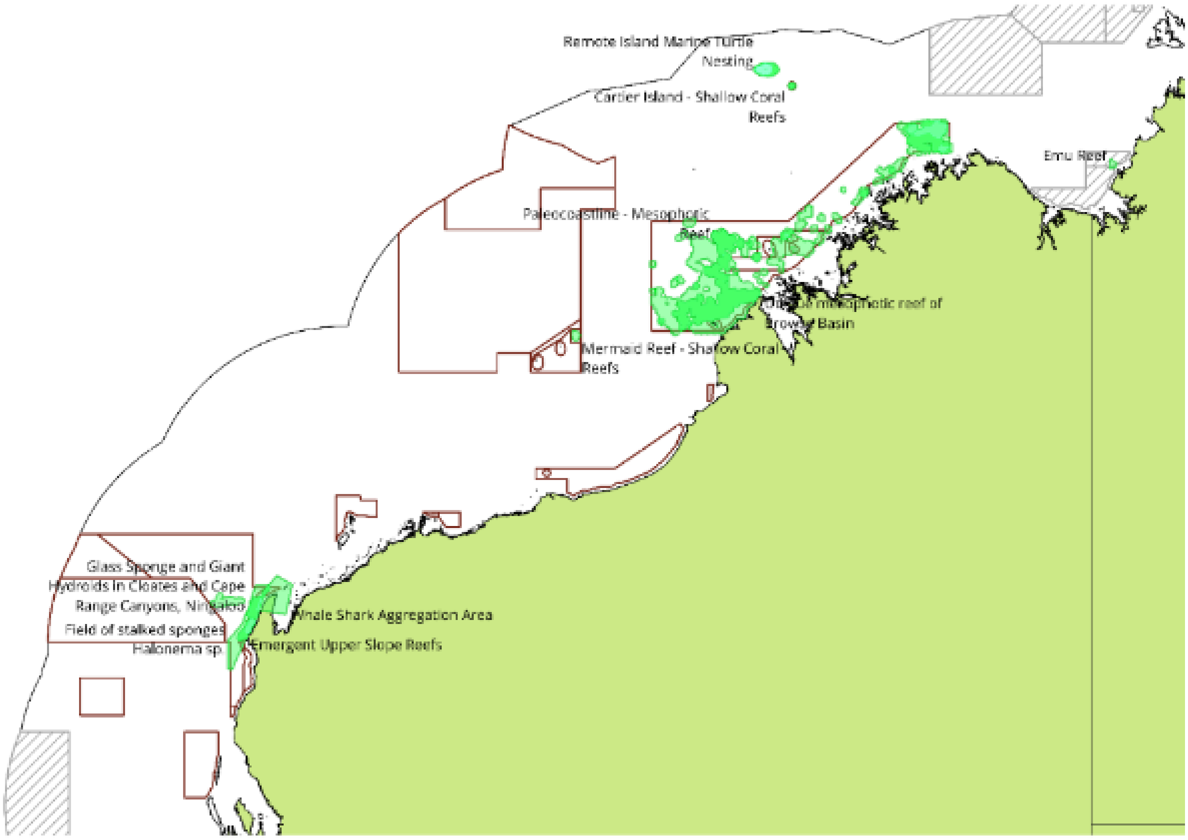

Figure D10: KNVs in the North-west network

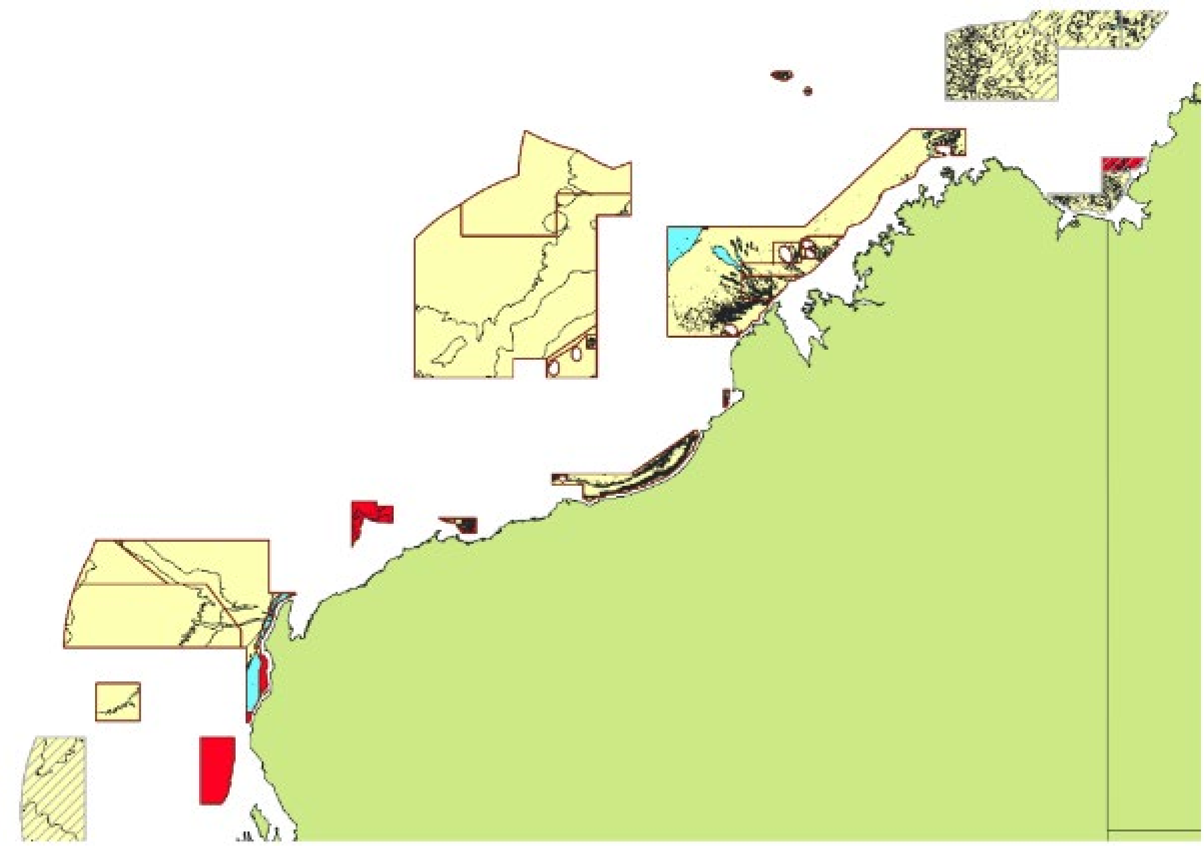

Figure D11: Ongoing pressures responsive to management level 1 monitoring priorities for the North-west Network. Red is likely ongoing pressures, blue is possible and yellow is insignificant

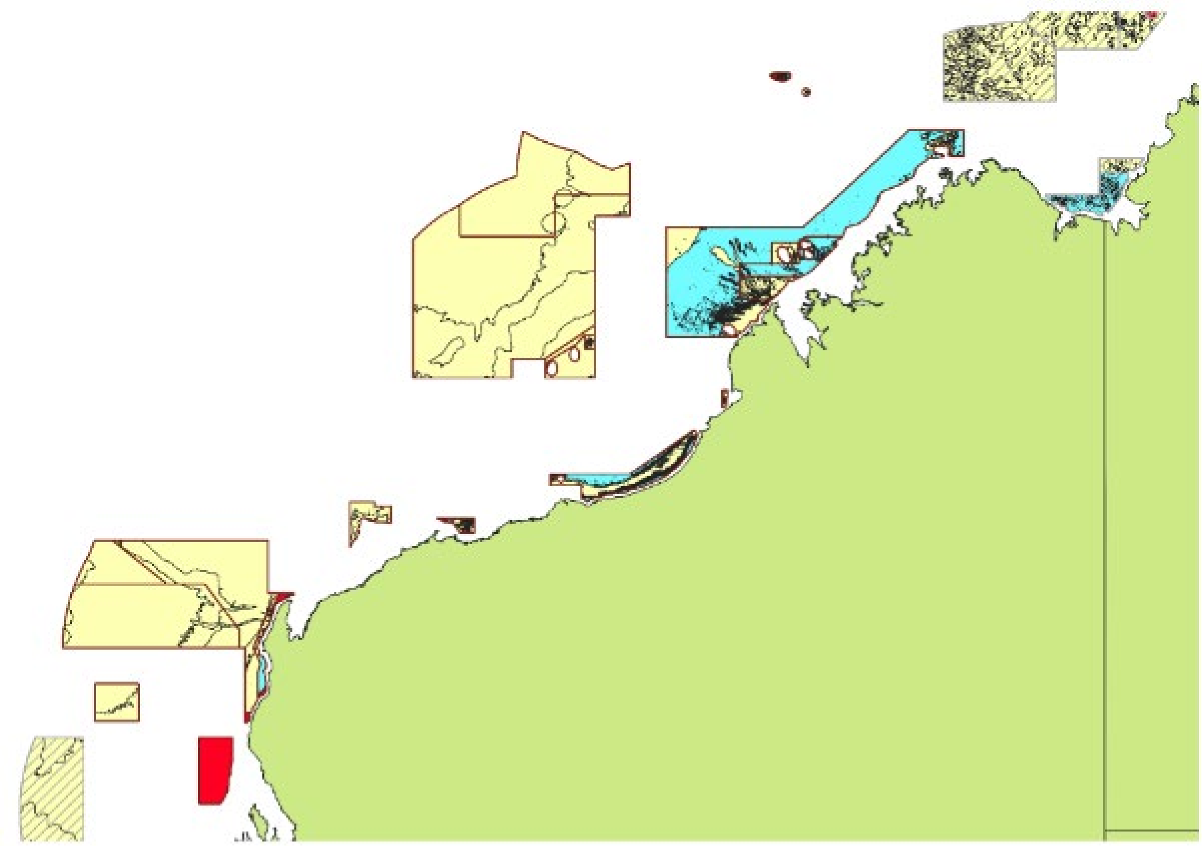

Figure D13: Mitigation or removal of pressures level 1 monitoring priorities for the North-west Network. Red is likely reduction pressures, blue is possible and yellow is insignificant

North Network

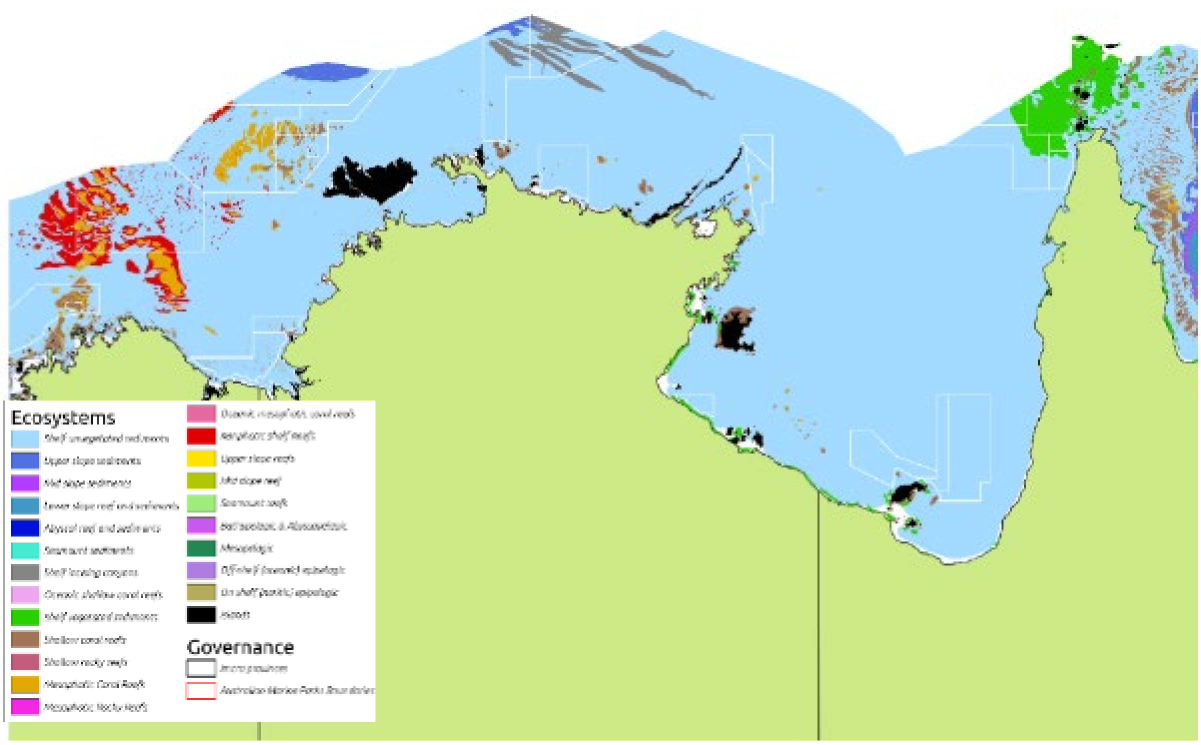

Figure D13: Ecosystems in the North Network

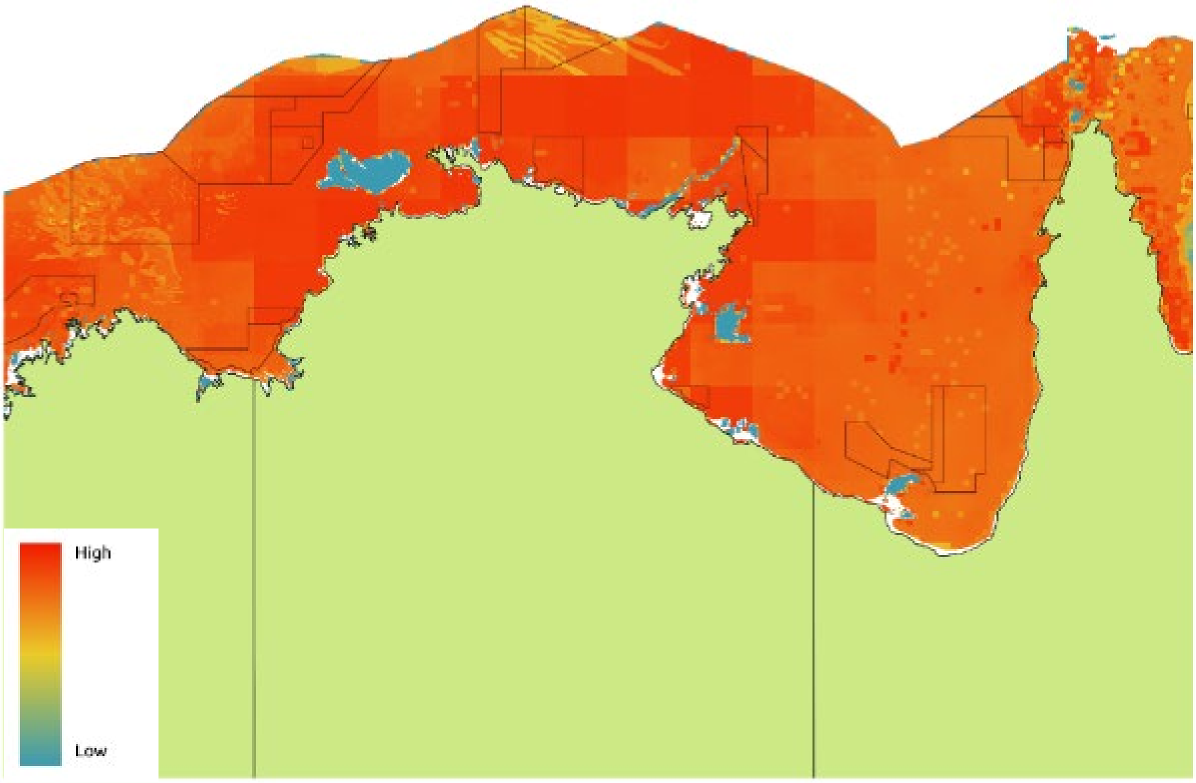

Figure D14: Benthic cumulative impact in the North network

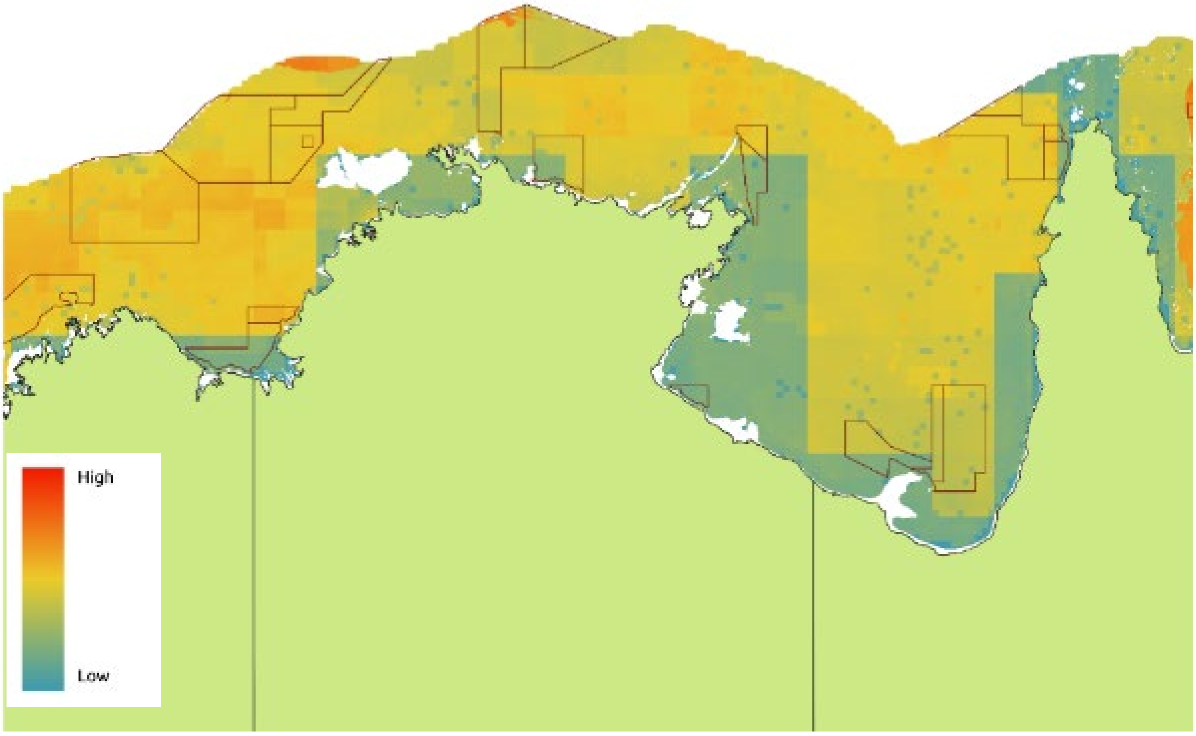

Figure D15: Pelagic cumulative impact in the North network

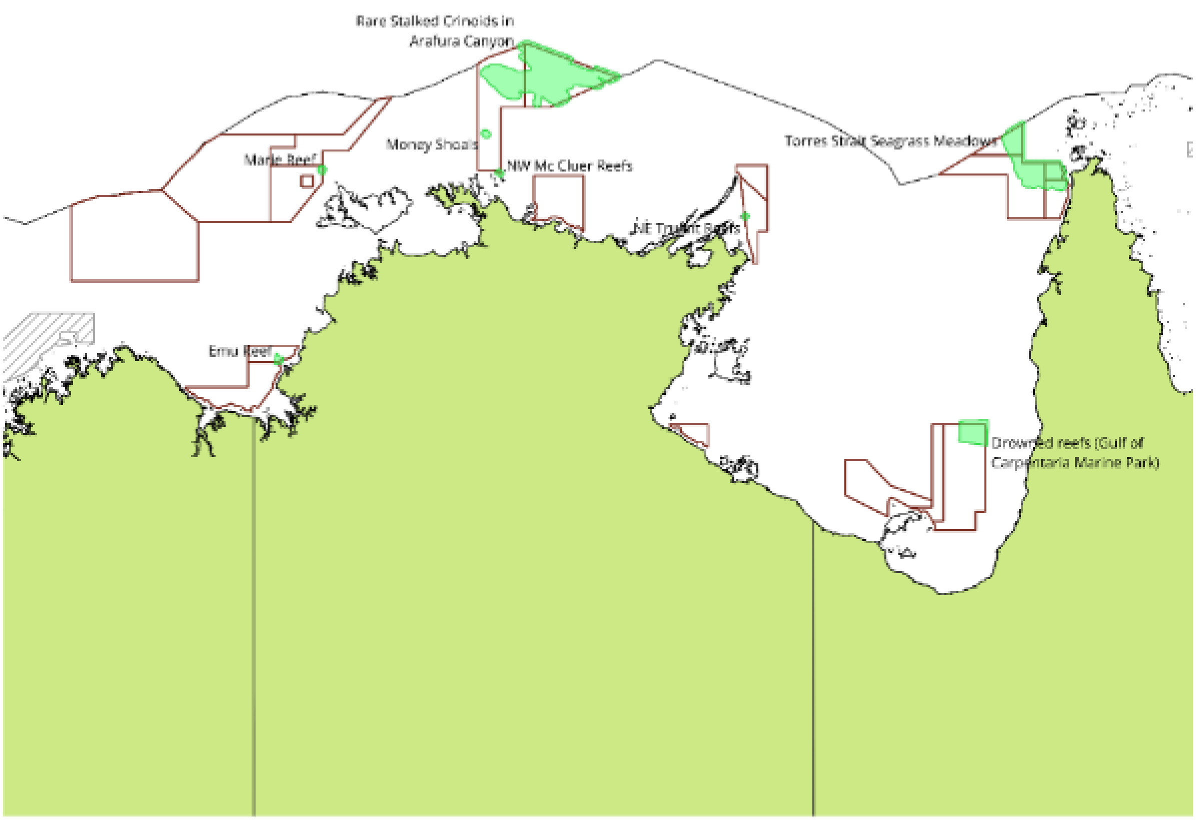

Figure D16: KNVs in the North Network

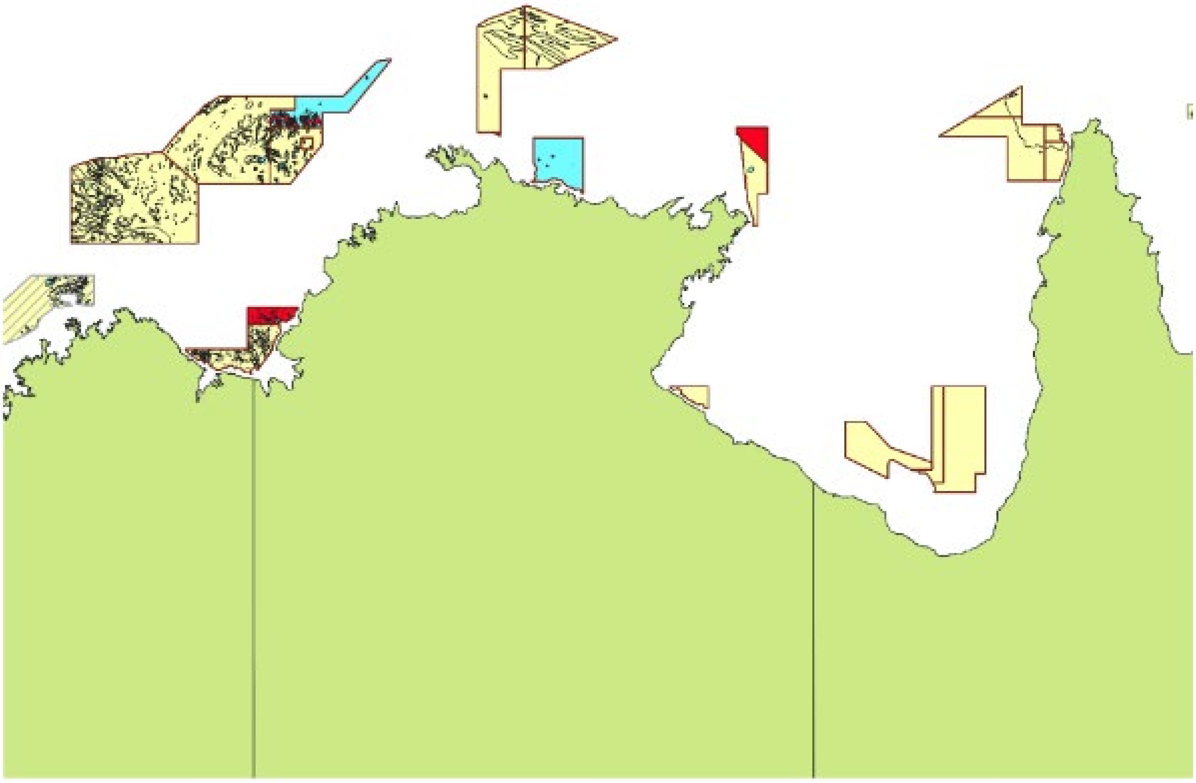

Figure D17: Ongoing pressures responsive to management level 1 monitoring priorities for the North Network. Red is likely ongoing pressures, blue is possible and yellow is insignificant

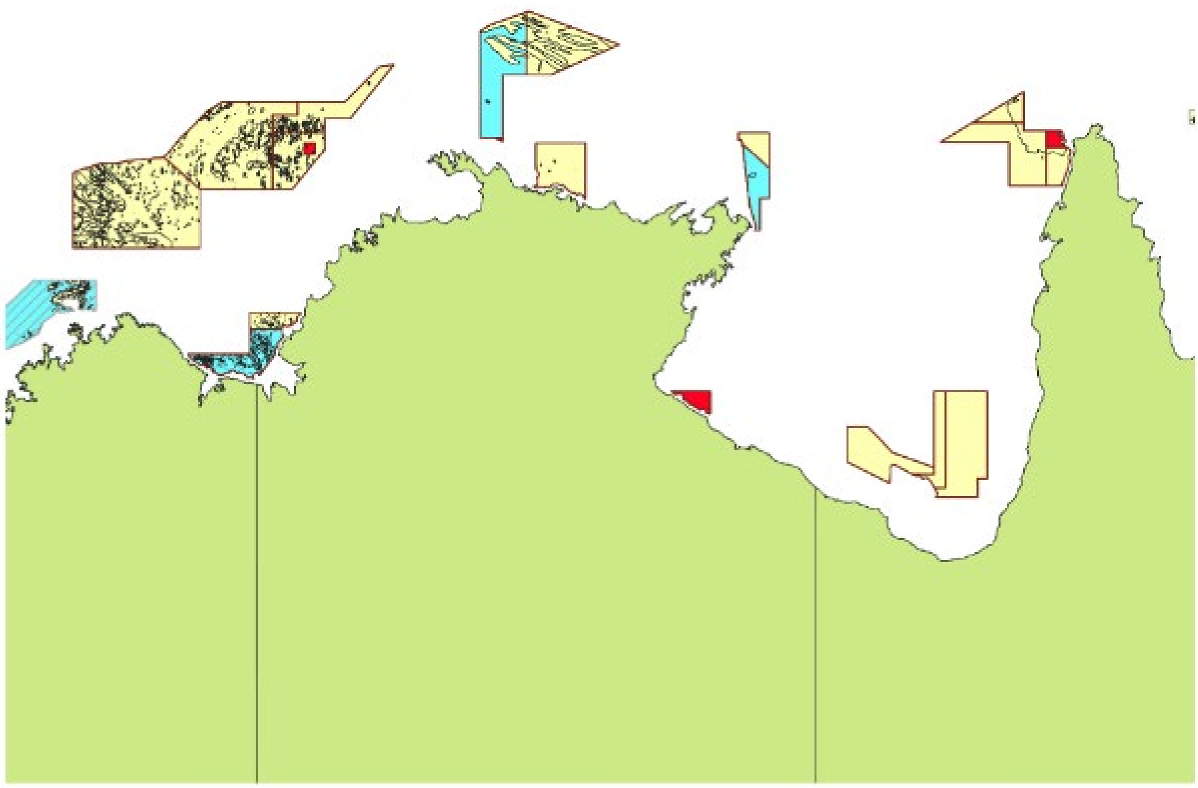

Figure D18: Mitigation or removal of pressures level 1 monitoring priorities for the North Network. Red is likely reduction pressures, blue is possible and yellow is insignificant

Temperate East Network

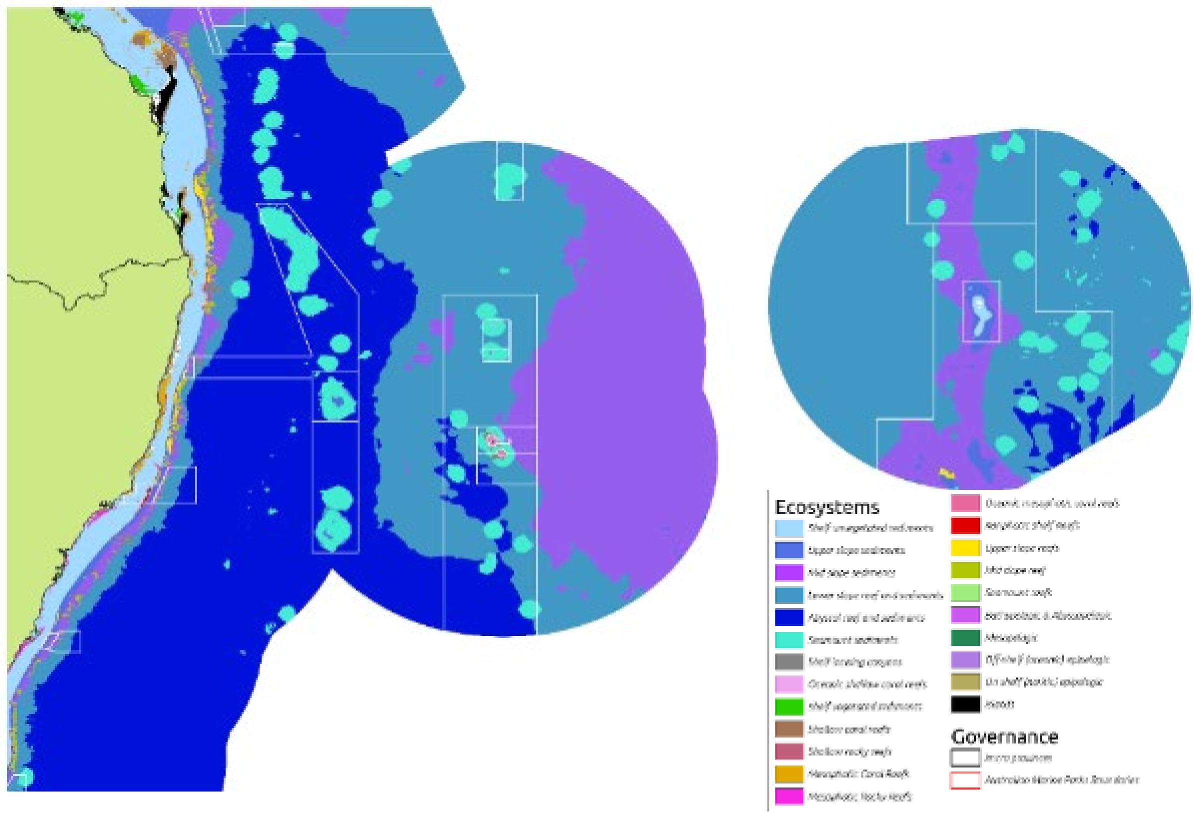

Figure D19: Ecosystems in the Temperate-east network

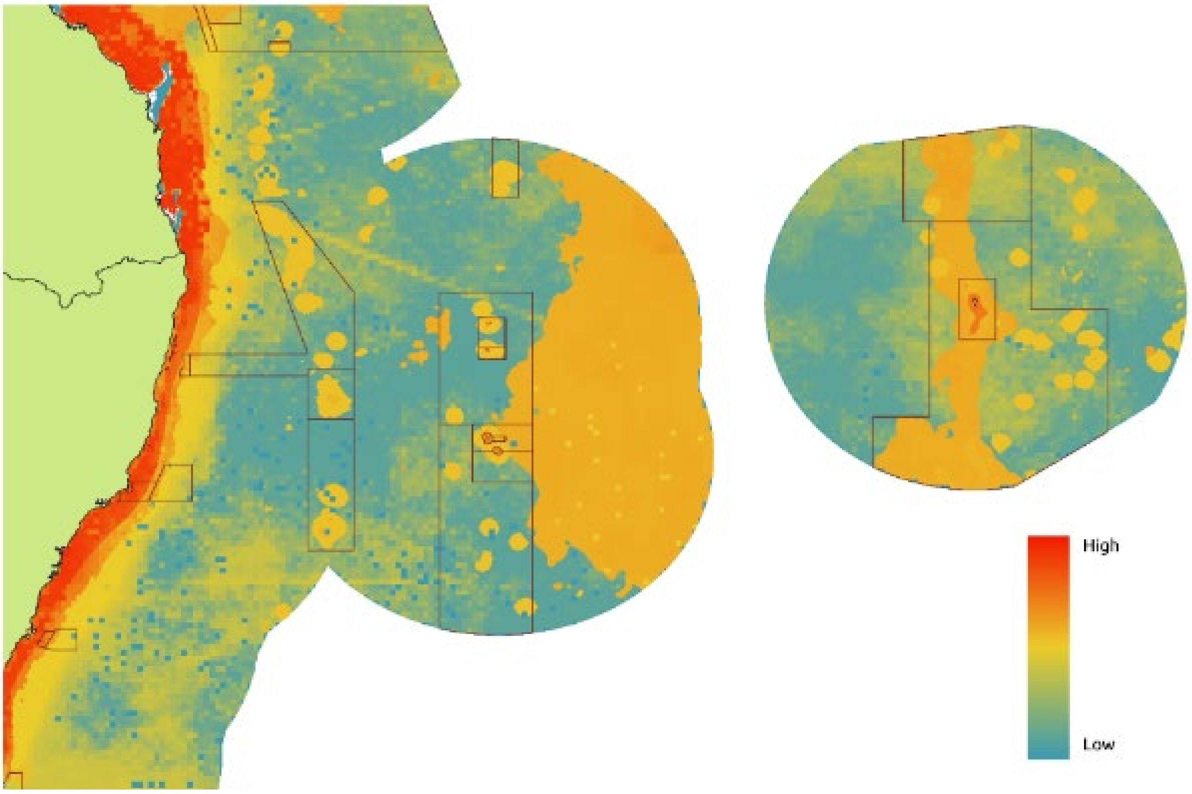

Figure D20: Benthic cumulative impact in the Temperate-east network

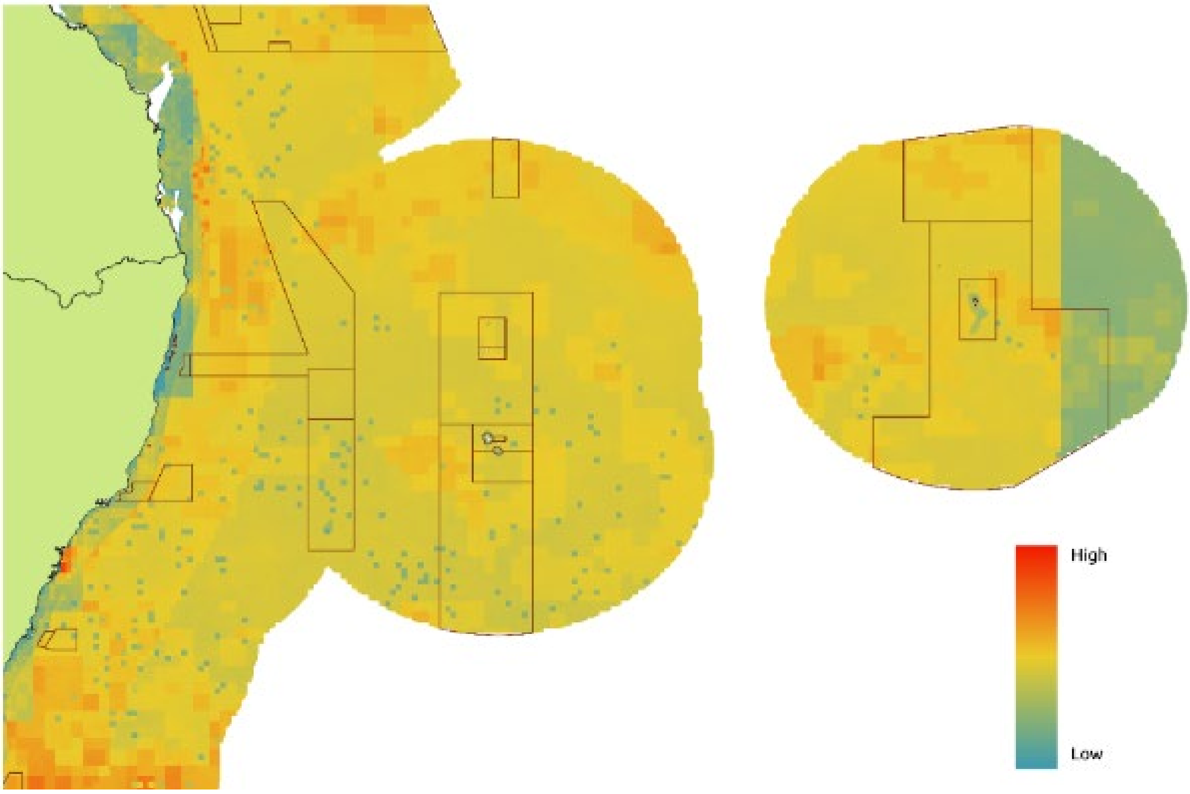

Figure D21: Pelagic cumulative impact in the Temperate-east network

Figure D22: KNVs in the Temperate-east network

Figure D23: Ongoing pressures responsive to management level 1 monitoring priorities for the Temperate-east Network. Red is likely ongoing pressures, blue is possible and yellow is insignificant

Figure D24: Mitigation or removal of pressures level 1 monitoring priorities for the Temperate-east Network. Red is likely reduction pressures, blue is possible and yellow is insignificant

Coral Sea MP

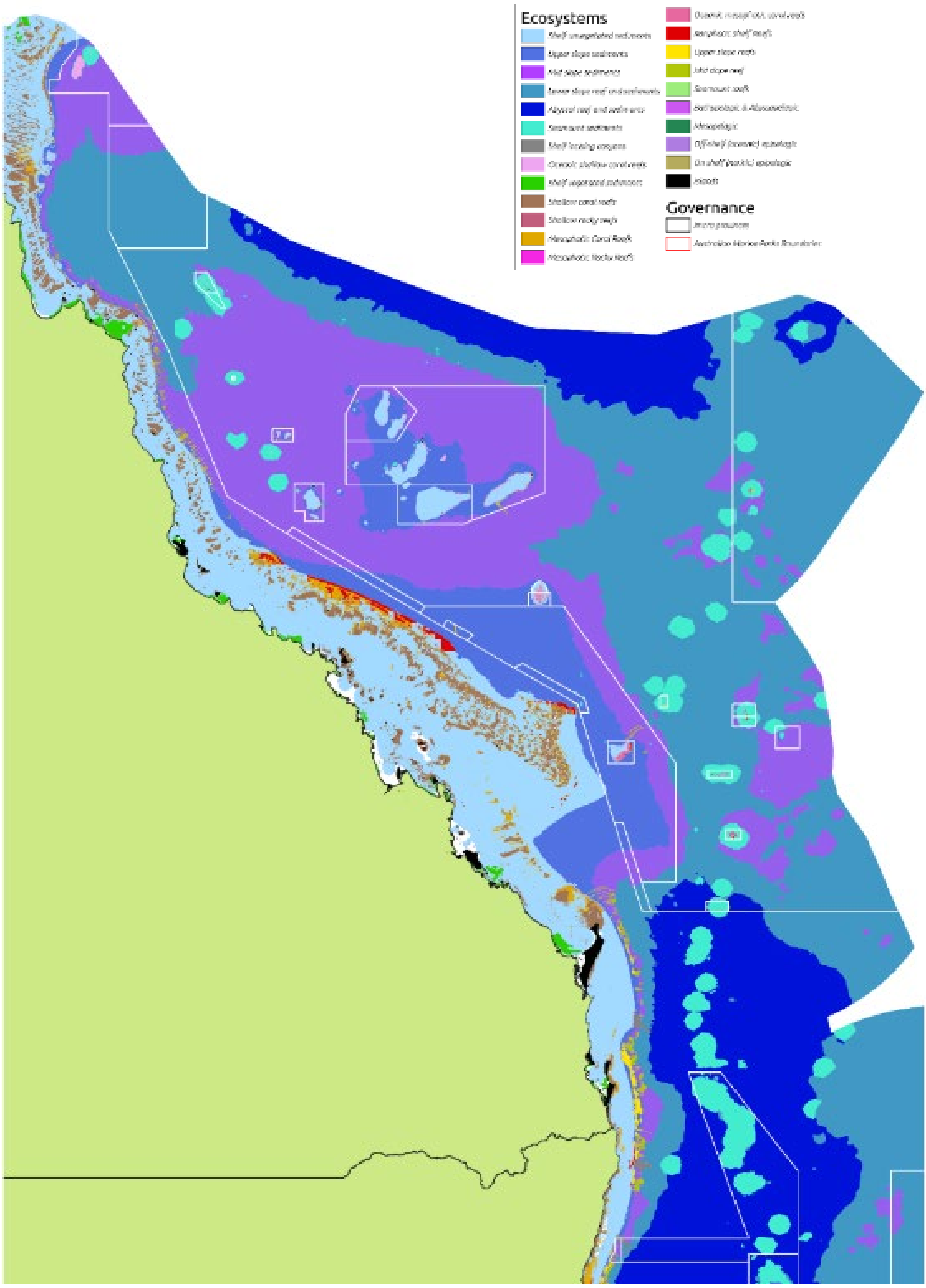

Figure D25: Ecosystems in the Coral Sea MP

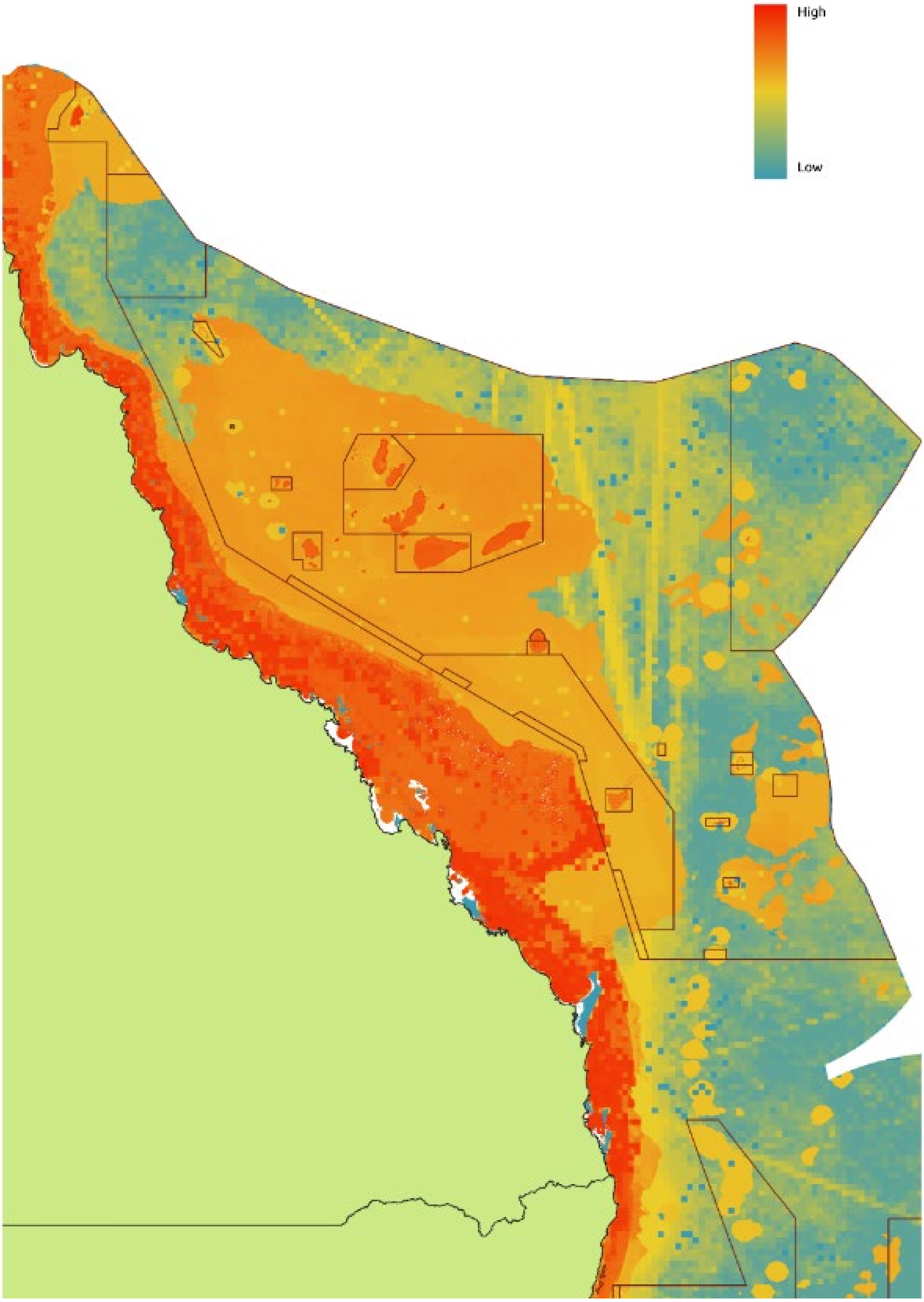

Figure D26: Benthic cumulative impact in the Coral Sea MP

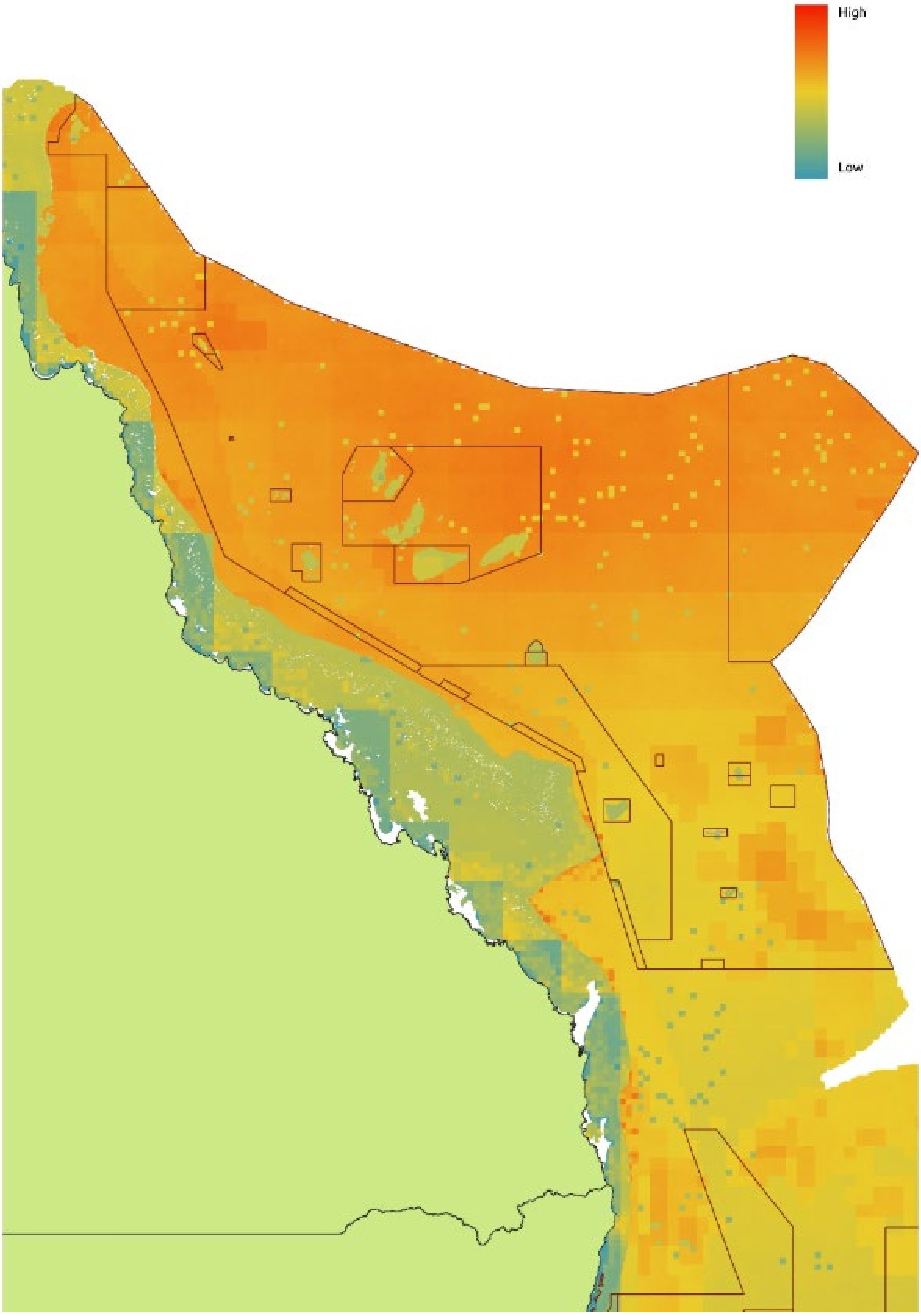

Figure D27: Pelagic cumulative impact in the Coral Sea MP

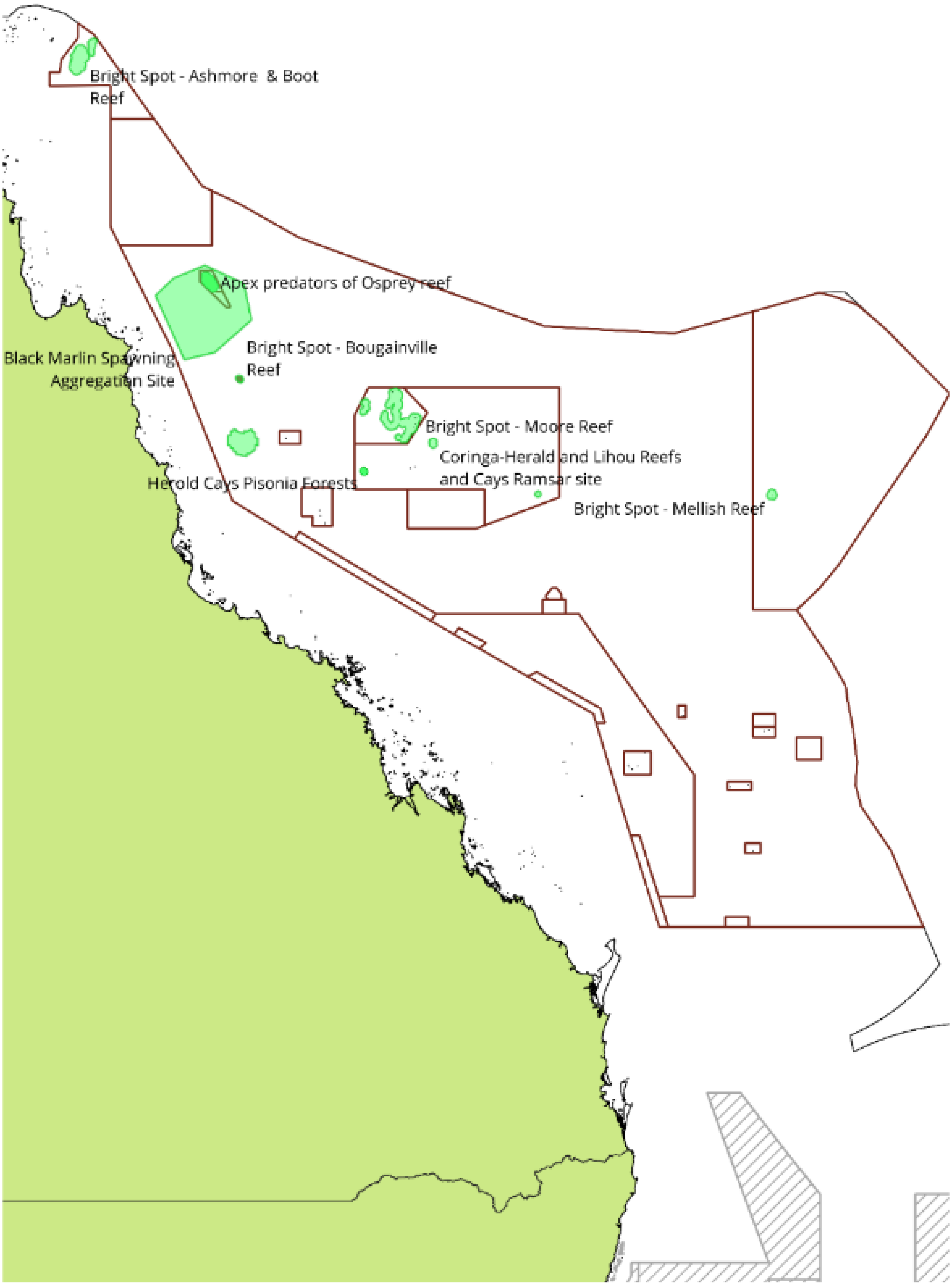

Figure D28: KNVs in the Coral Sea MP

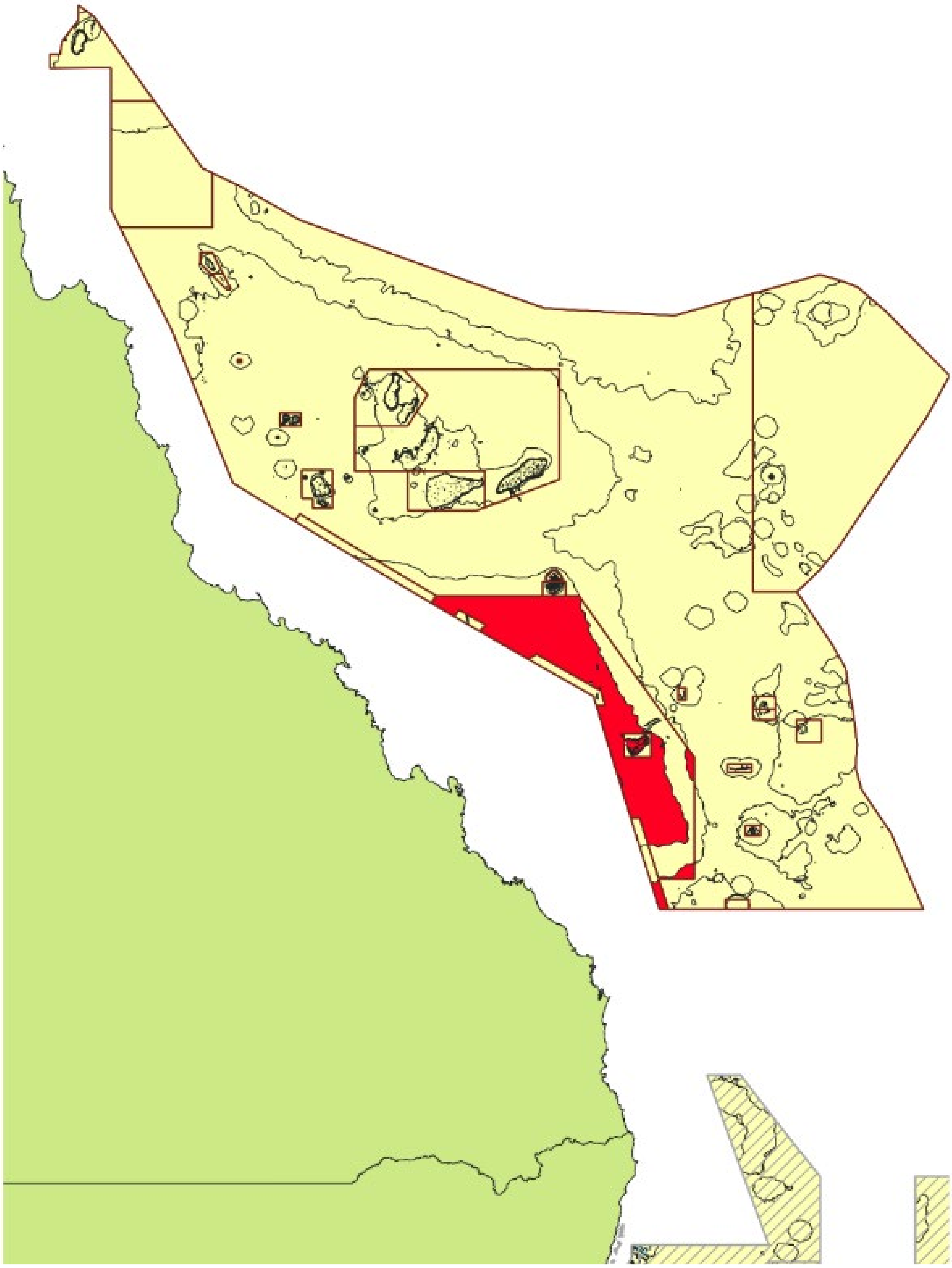

Figure D29: Ongoing pressures responsive to management level 1 monitoring priorities for the Coral Sea MP. Red is likely ongoing pressures, blue is possible and yellow is insignificant

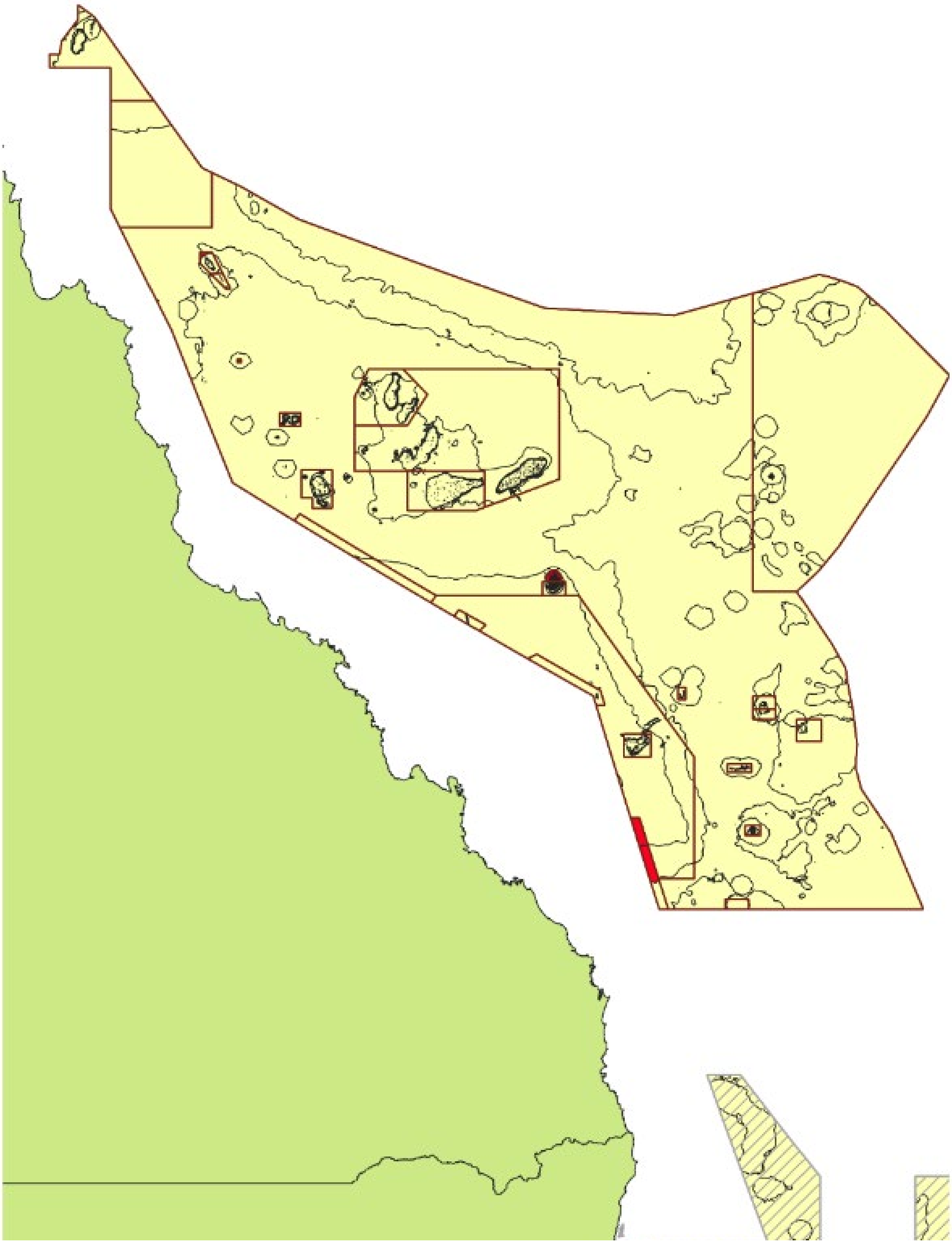

Figure D30: Mitigation or removal of pressures level 1 monitoring priorities for the Coral Sea MP. Red is likely reduction pressures, blue is possible and yellow is insignificant

Appendix E - National Maps

National Ecosystem Complex

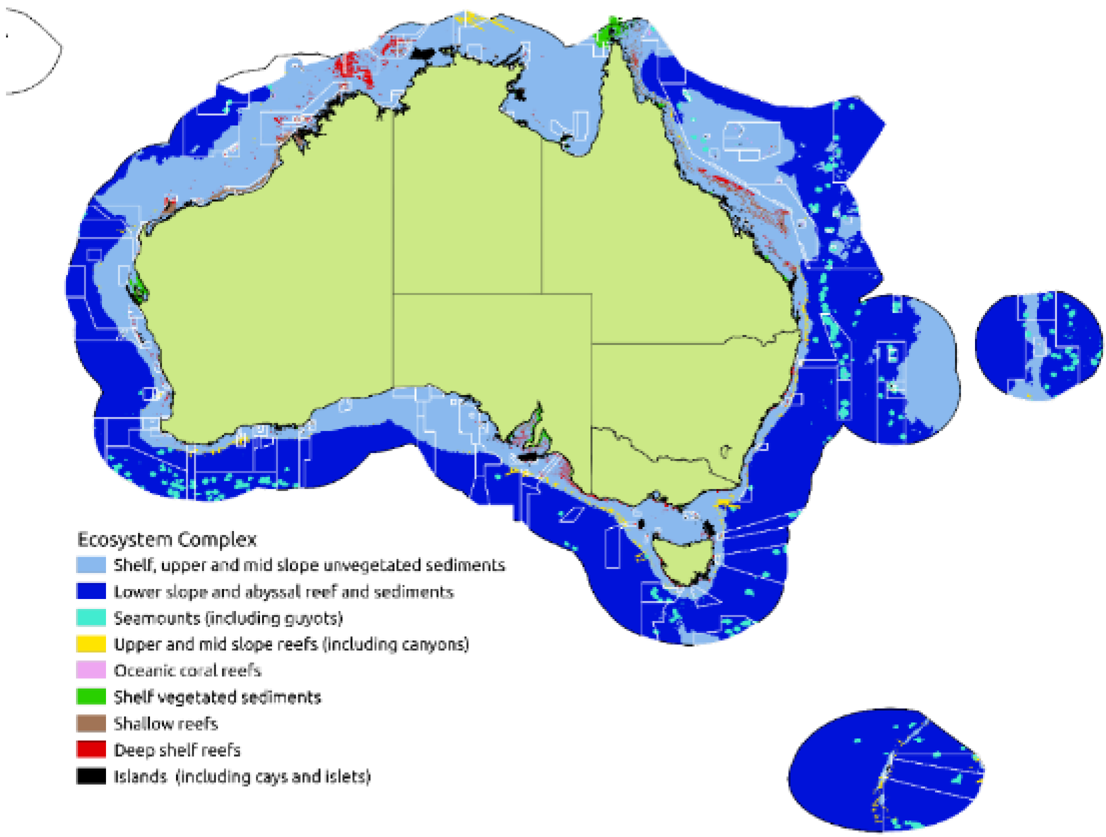

Figure E1: National Ecosystem complex map. Ecosystem complexes are provided for Macquarie Island. However, complexes around Macquarie should be treated with caution as data for this are derived from global data sets.

Appendix F - Participants of KNV workshops.

Table F8: Organisations invited to contribute to the identification of KNVs in the North, Coral Sea, Temperate East, South west and North West AMP networks. Note KNVs in the South east network were identified in Hayes et al. (2021).

Network	Organisation
Coral Sea	AIMS
Coral Sea	California Academy of Sciences
Coral Sea	CSIRO
Coral Sea	DAWE
Coral Sea	Geoscience Australia
Coral Sea	Great Barrier Reef Marine Parks
Coral Sea	Independent consultant
Coral Sea	James Cook University
Coral Sea	Museums Victoria
Coral Sea	Queensland Museum
Coral Sea	Sydney University
Coral Sea	University of Tasmania
North	AIMS
North	Charles Darwin University
North	CSIRO
North	DAWE
North	Geoscience Australia
North	Independent consultant
North	NSW Department of Primary Industries Fisheries
North	NT Fisheries
North	NT government
North	University of Tasmania
North	Western Australian Museum
NW	AIMS
NW	CSIRO
NW	DAWE
NW	Geoscience Australia
NW	Museums Victoria
NW	NT Fisheries
NW	University of Tasmania
NW	University of Western Australia
NW	University of Wollongong
NW	WA Department of Biodiversity, Conservation and Attractions
NW	Western Australian Museum
SW	CSIRO
SW	DAWE
SW	Geoscience Australia
SW	Museums Victoria

SW	SA Department of Environment and Water
SW	Scripps Institution of Oceanography (UCSD)
SW	South Australian Research and Development Institute
SW	South Australian Research and Development Institute
SW	University of Tasmania
SW	University of Western Australia
SW	VIC Department of Environment, Land, Water and Planning
SW	WA Department of Biodiversity, Conservation and Attractions
SW	WA Department of Primary Industries and Regional Development
TE	AIMS
TE	CSIRO
TE	DAWE
TE	Deakin University
TE	Geoscience Australia
TE	Independent consultant
TE	Museums Victoria
TE	NSW Department of Planning and Environment

Marine and Coastal

National Environmental Science Program

CONTACT

Name: Piers Dunstan

Email: piers.dunstan@csiro.au

Web: https://www.nespmarinecoastal.edu.au/

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