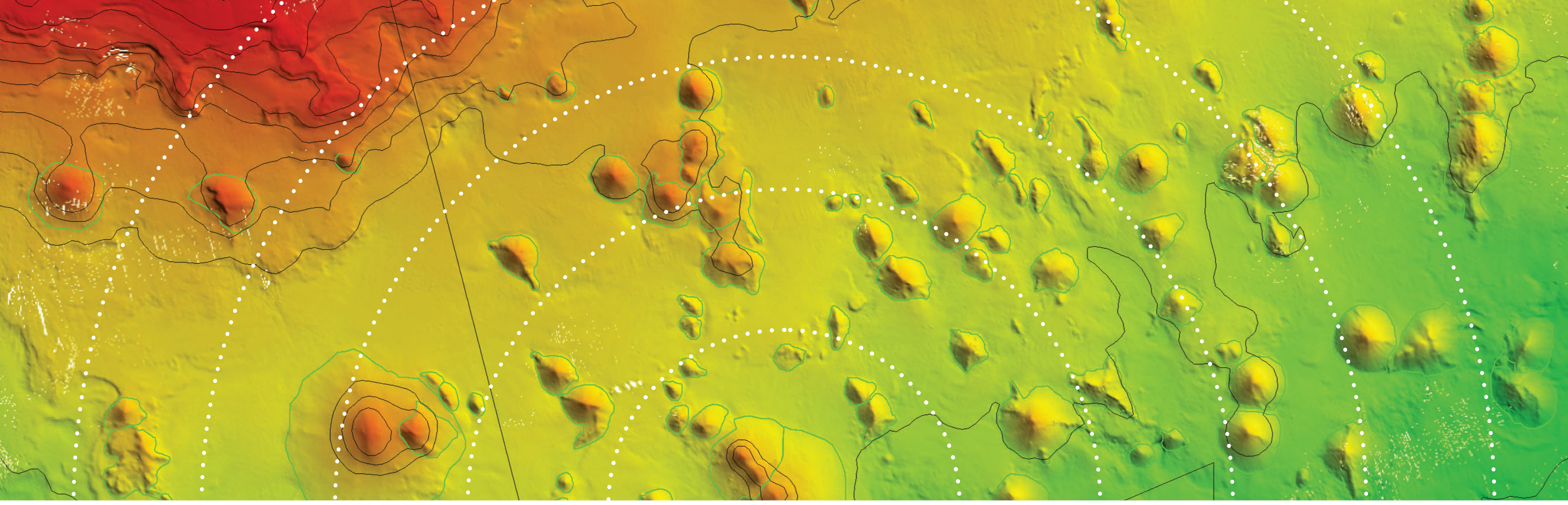

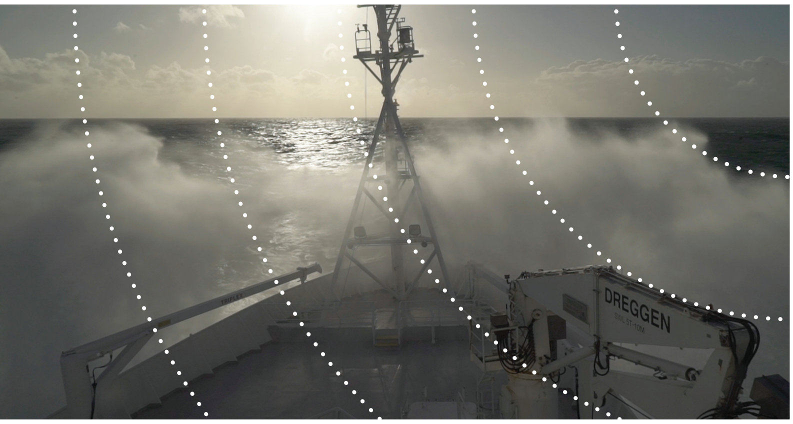

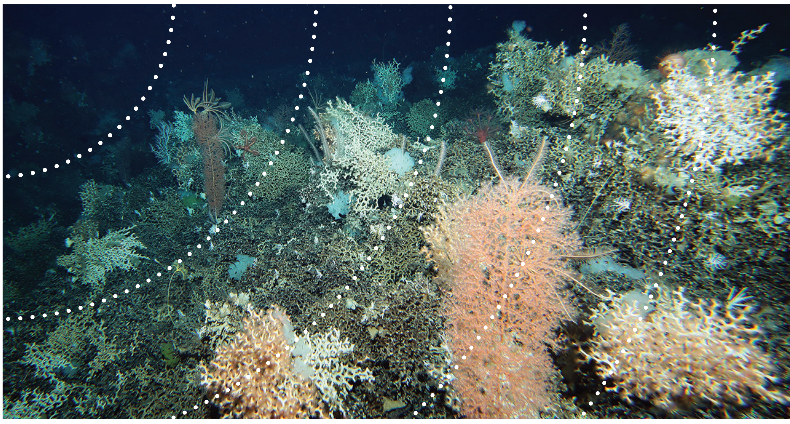

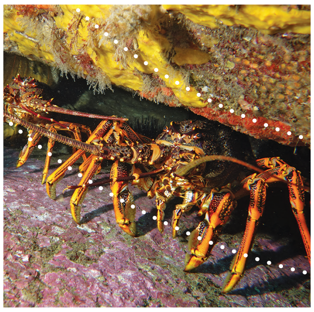

Designing a targeted monitoring program to support evidence-based management of

Australian Marine Parks

A pilot in the South-east Marine Parks Network

Marine Biodiversity Hub
National Environmental Science Programme

Australian Government
Director of National Parks

Australian Marine Parks

UNIVERSITY of TASMANIA

CSIRO

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

A pilot in the South-east Marine Parks Network

10th June 2021

NESP Marine Biodiversity Hub: Keith R. Hayes*, Piers Dunstan*, Skipton Woolley*, Neville Barrett*, Scott Foster, Jacquomo Monk, David Peel, Geoffrey R. Hosack

PARKS AUSTRALIA: Steffan A. Howe*, Cath R. Samson*, Renee Bowling*, Mitchell P. Ryan*, Scott O. Francis

**These authors contributed equally to the report*

A report for the NESP Marine Biodiversity Hub for projects:

D7 - *"Supporting the Monitoring, Evaluation, Reporting and Improvement System for Australian Marine Parks"* (RPV6, Milestone 4) and

SS2 - *"Interpreting Pressure Profiles"* (RPV6, Milestone 8)

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Important Disclaimer

Contents

EXECUTIVE SUMMARY

Parks Australia, supporting the Director of National Parks, manages 58 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, Evaluation, Reporting and Improvement (MERI) framework for the Australian Marine Park (AMP) estate. The MERI 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 MERI system consists of an overarching Framework, supporting MERI 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. This report documents the outcomes of this engagement.

The MERI 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 is hierarchical, and the structure has been deliberately chosen to provide a balance between sufficient detail to allow unambiguous interpretation, whilst being sufficiently succinct so that its role within the MERI system remains practical for management.

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 natural values common language identifies 22 benthic ecosystems and 4 pelagic ecosystems in AMPs, each allocated to an ecosystem complex (there may be multiple ecosystems in each ecosystem complex). Ecosystems are delineated by habitat, depth, and other biological and/or spatial features, in a manner that ensures that their boundaries are identifiable.

The MERI system also recognises the existence of Key Natural Values (KNVs) within the AMP network that warrant special consideration. KNVs for the South-east network were identified in a workshop and their boundaries were subsequently refined using additional information that was not available at the workshop. Indigenous values were not identified in this workshop as these will be identified through a separate, dedicated process.

Anthropogenic activities in the common language are defined at two levels: 1) activities, and 2) sub-activities. This hierarchy and nomenclature is based on the AMP management plans. Activities and sub-activities identify things that occur in the AMPs. The controlled language distinguishes 16 activities that are sub-divided into 58 activity–sub-activity combinations. The largest number of sub-activity categories occur within the commercial fishing activity. Together with vessel transiting, the language identifies 15 commercial fishing sub-activities. The language also identifies 24 specific pressures that arise through one or more sub-activities. For example, the language distinguishes habitat modification due to physical disturbance and removal; changes in nutrients and organic matter; and suspended sediments and smothering.

By defining ecosystems via a combination of depth and characteristic habitat, the common language enables the creation of an Australian marine ecosystem map. The map was created in a series of sequential applications of the common language definitions, that starts by assigning sediment-based ecosystems to their appropriate depth ranges. Geoscience

Australia's 2009, 250m resolution bathymetry serves as the basis for the map. From this a 16,411 row by 29,161 column raster of the commonwealth marine area (and adjacent state waters) was created, with 478,561,171 depth-labelled cells that were subsequently used to geo-locate the depth boundaries between different ecosystems.

A significant proportion of the project resources were directed towards developing a new predictive model of hard substrate (reef) on the Australian continental shelf to map the shallow rocky reef, mesophotic rocky reef and rariphotic reef ecosystems. The new model appears to over-predict reef at certain locations such as the west and north coasts of Tasmania. Some of these apparent over-predictions (those within AMPs) were subsequently manually edited based on the results of more recent, but largely invalidated, fine-scale multibeam mapping.

The common language identities 199 unique combinations of activity/sub-activity–pressure. The project collated existing, and generated new, data products that directly measure (45) or serve as proxies for (83) of these combinations usually for the period 2011 to 2015 inclusive. 14 activity/sub-activity–pressure combinations did not occur in the South-east marine region during this period. Data was also available for 18 pressures, but these could not be attributed to an activity/sub-activity and no data was available for 39 combinations.

Wherever possible (and permissible) each pressure data product was mapped to a 0.1 degree (approximately 10 kms^2) grid resolution raster, resulting in 309,870 cells across the commonwealth marine area. Each data product was then standardised to a maximum value of 1, averaged over the period of time that the data was available, identified as manageable (or not) under Parks Australia's current governance arrangements, and collated at the sub-activity level of the common language hierarchy.

The common language identifies 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. A cumulative impact assessment was started by considering all combinations of ecosystem components and specific pressures in a large (200 x 157) interaction matrix.

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 that were carried through to a vulnerability assessment.

In the vulnerability assessment experts were asked to score trophic impact, defined as the primary level of marine life affected per interaction with a sub-activity, on a scale of 0 to 4. This score was elicited for every sub-activity identified by the interaction matrix as having the potential to impact the ecosystem in question. Experts were then asked to score percent changes, defined as the degree to which the species, trophic levels or entire ecosystem's "natural" state is impacted per interaction with the sub-activity. The two scores were multiplied together to provide an overall assessment of each ecosystem's vulnerability to each sub-activity.

The results of the vulnerability assessment suggest that shelf vegetated sediments (seagrass beds) are the most vulnerable ecosystem in the South-east marine region, to both manageable and unmanageable sub-activities, but as far as we are aware this ecosystem is not found within any of the south east marine parks. The results also indicate a general pattern of decreasing vulnerability with depth, in terms of the number of different sub-activities that are potentially harmful, and the magnitude of the ecosystem's vulnerability.

The vulnerability scores and the cumulative sum of standardised sub-activities were then used to provide a relative assessment of the cumulative impacts of anthropogenic activities across the South-east marine region, where cumulative impacts are expressed as a weighted (by the vulnerability score) sum of pressure by ecosystem interactions across the previously defined ecosystems raster. The cumulative impact assessment provided the basis for a monitoring prioritisation process for the ecosystem values in the South east network.

The prioritisation process developed by the project has 4 levels. The first level uses the results of the cumulative assessment to identify where historic (or ongoing) pressures are having the most impact across ecosystems. A total of 34 zone/ecosystem combinations across the South-east network were identified as high priority monitoring locations by this level. A total of 18 of these locations are zone/ecosystem combinations where change is expected because of management reducing high levels of historic pressures. A total of 19 of these locations are where high pressure is expected to continue under the current management arrangements. Three of these locations are where both historic and ongoing pressures are likely to exist.

Level 2 is a manual step that uses a criteria-based approach (informed by MERI pre-requisites and other information) 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 areas with a poor compliance history, 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. This level identified 21 zone/ecosystem combinations across the South-east network as having adequate baselines. The final level of prioritisation is optional and dependent on how feasible it is to monitor the resulting list of priorities from the Level 3 prioritisation process. 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.

Monitoring questions and high-level indicators were then developed for ecosystems identified as priorities and their relevant ecosystem components that were subject to impact from pressures responsive to management. The high-level potential indicators were informed by ecosystem conceptual models developed by Parks Australia and a review of approaches used for MPAs in other jurisdictions.

The MERI framework described here represents a significant enabling-step towards an adaptive, integrated and place-based, management regime. This project was deliberately conducted on a pilot scale in the South-east network to trial the processes developed for prioritising monitoring, and provide an opportunity for reflection and learning, before rolling the process out nationally. The learnings from this pilot are reflected in several recommendations for the national roll-out and future development of the MERI framework.

1 INTRODUCTION

1.1 Australian marine parks

Parks Australia manages 58 Australian Marine Parks (AMPs), formerly known as Commonwealth Marine Reserves. They are located in Commonwealth waters that extend from the outer edge of state and territory waters, approximately 3 nautical miles (5.5 km) from the shore, to the outer boundary of Australia's exclusive economic zone, generally around 200 nautical miles (370 km) from the shore or relevant island baselines, and includes waters in Australia's external territories (Figure 1.1). The AMPs are vast, covering 2.8 million km^2, about 31% of Australia's marine jurisdiction. The AMPs are grouped into five networks (North, North-west, South-west, South-east and Temperate East) and the Coral Sea Marine Park (Figure 1.1).

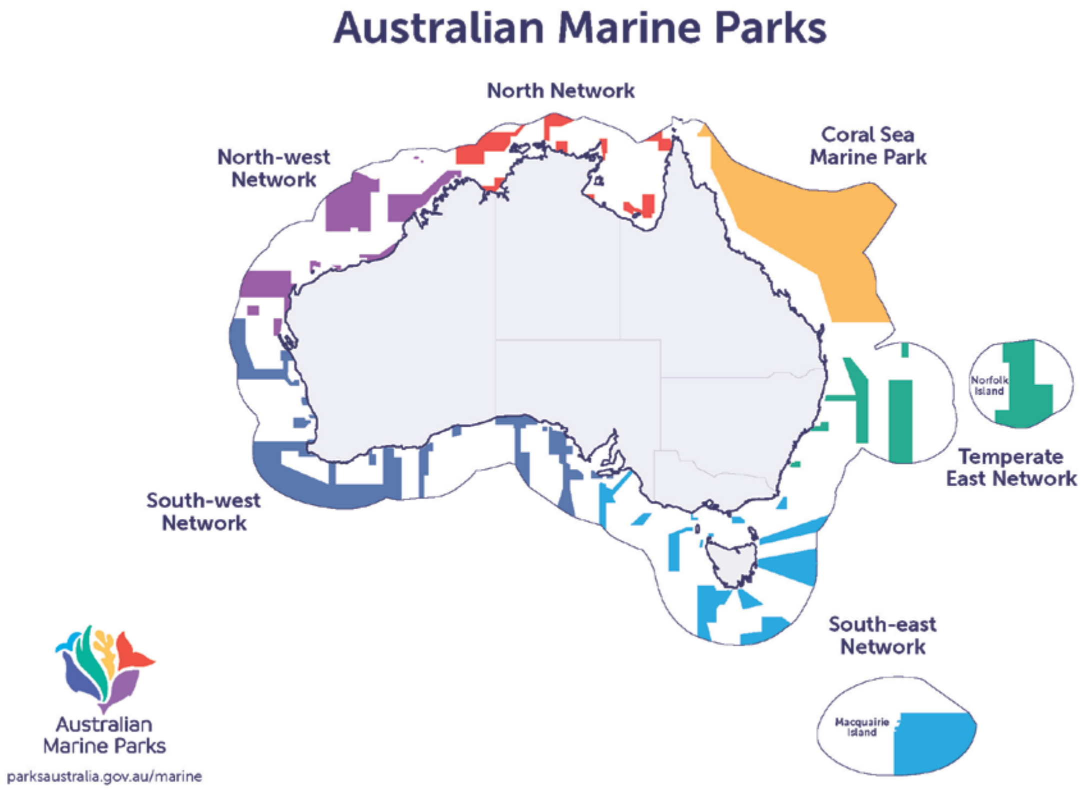

Figure 1.1: Australian Marine Parks – locations of the five networks and the Coral Sea Marine Park.

Four types of environmental features were used in the design of AMPs to help identify areas for protection. These features were identified based on the scientifically known relationships between biodiversity and the physical environment and include IMCRA bioregions, water depth, seafloor features and key ecological features.

AMPs protect a range of marine ecosystems found in Commonwealth waters, including reefs, islands, shelf incised canyons, seamounts and sediments in a range of depths, from islands to waters over 6,000m deep. These ecosystems are home to rich biodiversity including diverse fish life; marine invertebrates such as crabs, sea stars and worms; species that provide habitat such as seagrass, corals and sponges; small planktonic plants and animals; and iconic species such as whales, dolphins, seabirds and marine turtles.

Indigenous people have been sustainably using and managing their sea country, including areas now in many of the marine parks, for at least 60,000 years, and Indigenous cultural values are protected within the parks. World Heritage Areas, Ramsar wetlands and historic heritage values, such as shipwrecks are also protected in parks. These values have intrinsic worth, and Parks Australia is committed to the protection and conservation of these values to ensure a healthy and resilient marine environment.

AMPs also provide a range of social benefits, such as recreational experiences and scientific research, and economic benefits through uses such as sustainable fishing, tourism, shipping and mining. Parks Australia regulates activities within marine parks to ensure these uses are ecologically sustainable and compatible with conservation of these diverse values.

AMPs are managed through six management plans – one for each network and the Coral Sea Marine Park. The management plans provide a range of management options that the Director can use to give effect to the objectives of the plans:

1. To provide for the protection and conservation of biodiversity and other natural, cultural and heritage values; and
2. To provide for ecologically sustainable use and enjoyment of the natural resources, where this is consistent with objective (a).

AMPs have multiple zones that allow for a range of activities (Figure 1.2). 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.

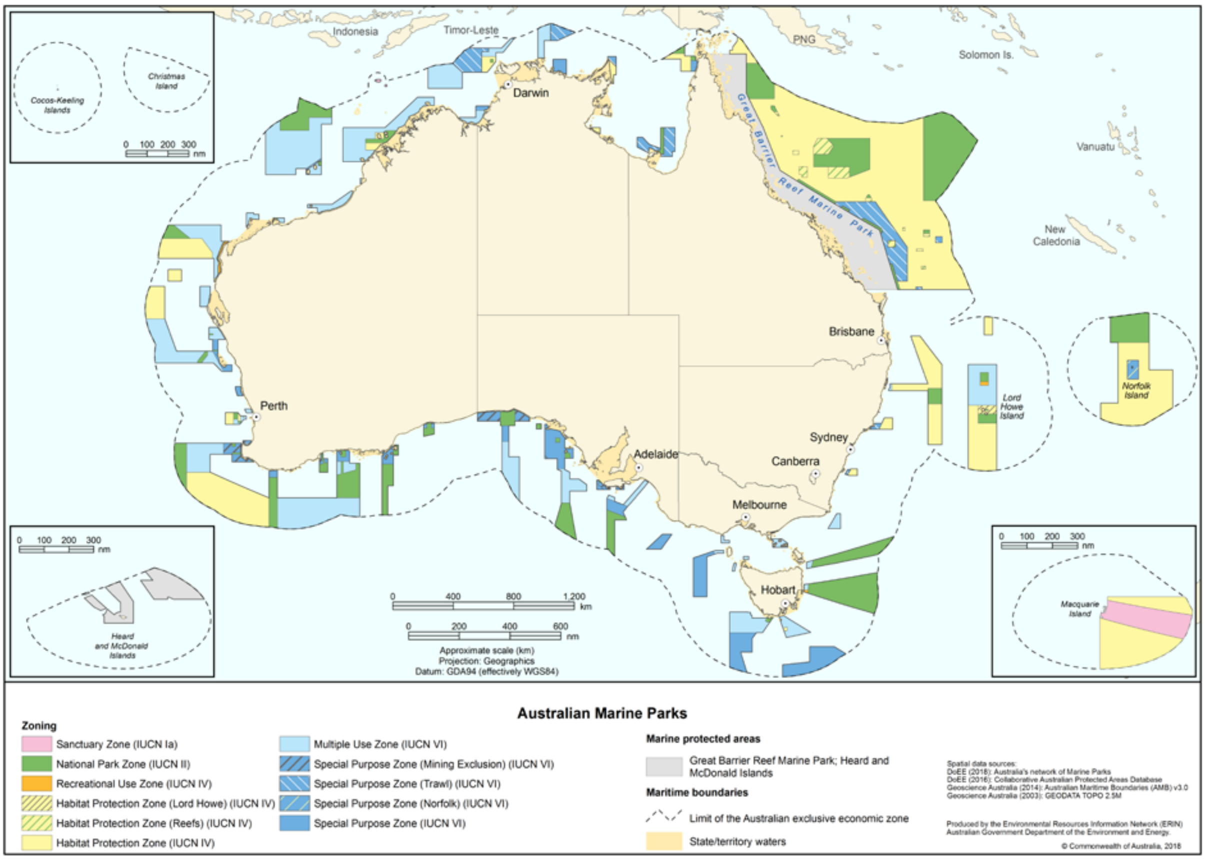

Figure 1.2: Australian Marine Parks – zoning.

1.2 Adaptive management of Australian Marine Parks

Adaptive management is a contemporary and widely accepted management approach that integrates project design, management and monitoring to systematically test assumptions, promote learning, and supply timely information for management decisions (Conservation Measures Partnership, 2013; Hockings et al., 2006; Parks Victoria, 2012; Tasmanian Parks and Wildlife Service, 2013). In essence, this means “learn as you go”, using evidence to assess performance and adjust management actions and priorities so they are as effective as possible in achieving management objectives.

The importance of developing and implementing adaptive management of AMPs was emphasised by the Expert Scientific Panel[1] in its final report to the federal government (Beeton et al., 2015) which recommended:

1. The Australian government adopt an adaptive management approach for AMPs.
2. The future management of AMPs should be evidence-based and supported by a research, monitoring and evaluation framework that is consistent with that used for environmental reporting in Australia.

[1] As part of the Commonwealth Marine Reserves Review between August 2014 and September 2016, an independent Expert Scientific Panel was appointed to provide advice to government

3. Existing and potential threats to AMPs should be identified and prioritised when developing the research, monitoring and evaluation framework, and baseline and benchmark sites within Australian Marine Parks should be established to help detect threats and assess their impacts.

The Australian National Audit Office review of Management of Commonwealth National Parks (Auditor General, 2019) also recommended the Director of National Parks improves:

1. Its risk management framework and supporting systems.
2. Its arrangements to monitor the implementation of corporate, park management and operational plans.
3. Its governance of projects including the maintenance of robust project monitoring arrangements.
4. The relevance, reliability and completeness of performance measures presented in the corporate plan.

The recent review of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) (Samuel, 2020) stressed the need for a coherent framework for monitoring, evaluation and reporting on the effectiveness of the EPBC Act to support adaptive management, achieve improved environmental outcomes and maintain public trust in the environmental management systems. It also calls for a national supply chain of information to set clear outcomes, effectively plan and invest in actions that deliver outcomes and to efficiently regulate development.

Parks Australia has committed to adaptive management of AMPs. 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 concept of MERI is firmly embedded in the “do”, “evaluate”, “report” and “improve” stages of the Adaptive Management Cycle (Figure 1.3).

1.3 Overview of the Australian Marine Parks MERI system

A robust MERI 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 MERI system (Figure 1.4) will be guided by three main documents:

1. An overarching Parks Australia MERI Framework.
2. An AMP MERI Plan.
3. Network-level science plans.

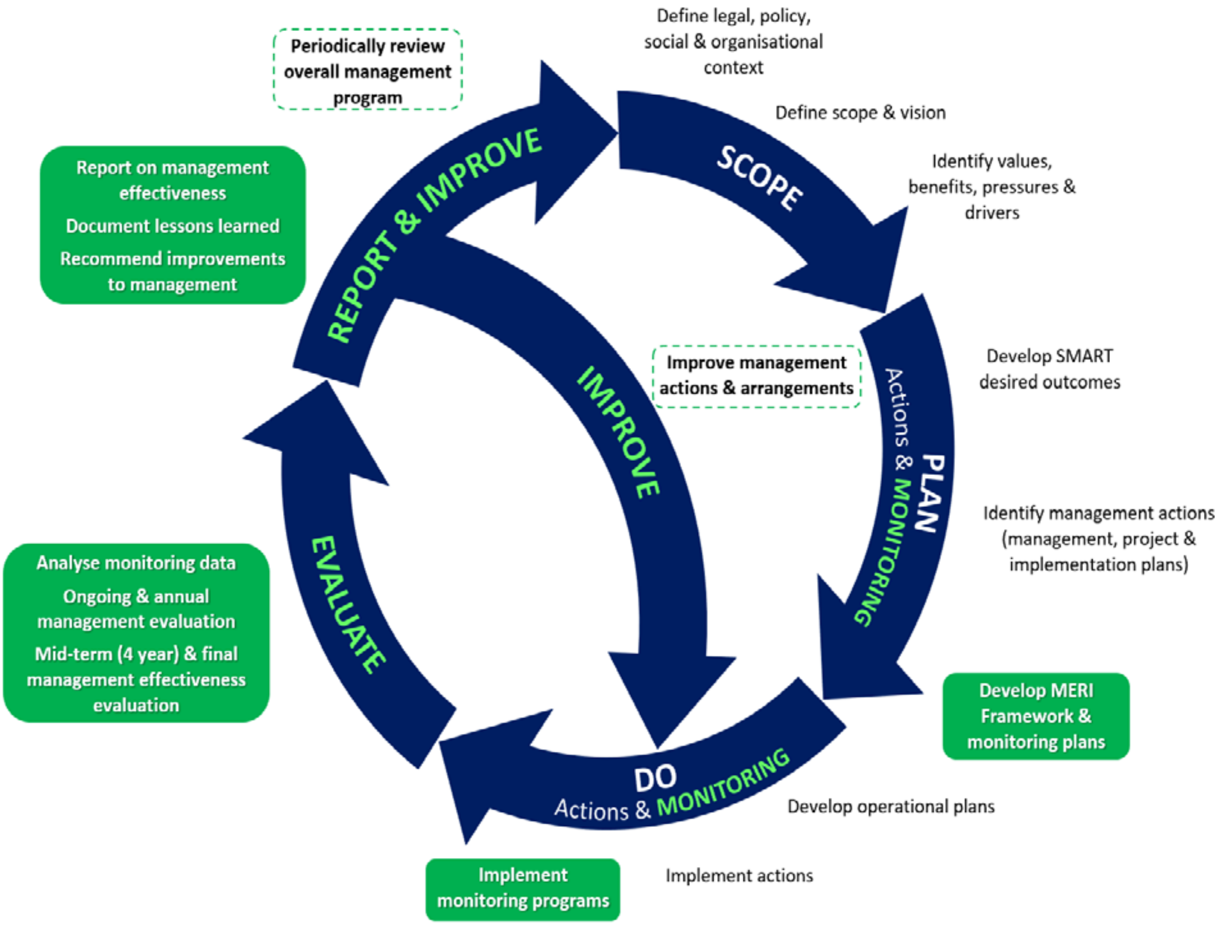

Figure 1.3: The role of Monitoring, Evaluation, Reporting and Improvement (MERI) within the adaptive management cycle (adapted from Tasmanian Parks and Wildlife Service, 2013; Parks Victoria, 2012; Conservation Measures Partnership, 2013).The Adaptive Management Cycle consists of six stages: scope, plan, do, evaluate report and improve. The MERI system is designed to support Parks Australia to implement the do, evaluate, report and improve stages. Elements in green text and boxes are part of the MERI system, while those with dotted outlines are informed by MERI.

It is anticipated that the Parks Australia MERI Framework will outline the key principles behind implementing MERI for the Commonwealth parks and gardens, including a set of seven Key Evaluation Questions (KEQs) (see draft KEQs in Table 1.1). The KEQs are the high-level questions that help guide evaluation of management effectiveness, and inform what data to collect, how to analyse it, and how to report it.

The AMP MERI Plan will describe the management context for the AMPs and outline Specific Evaluation Questions (SEQs) that provide more detail and are specific to AMPs (see draft SEQs in Table 1.1). This Plan will also likely incorporate indicators for mid-term (4-year) and final (8-year) management plan evaluations.

The six network-level science plans will outline conservation goals, state of knowledge, research and monitoring priorities for natural values, pressures, cultural values, heritage values and social and economic benefits.

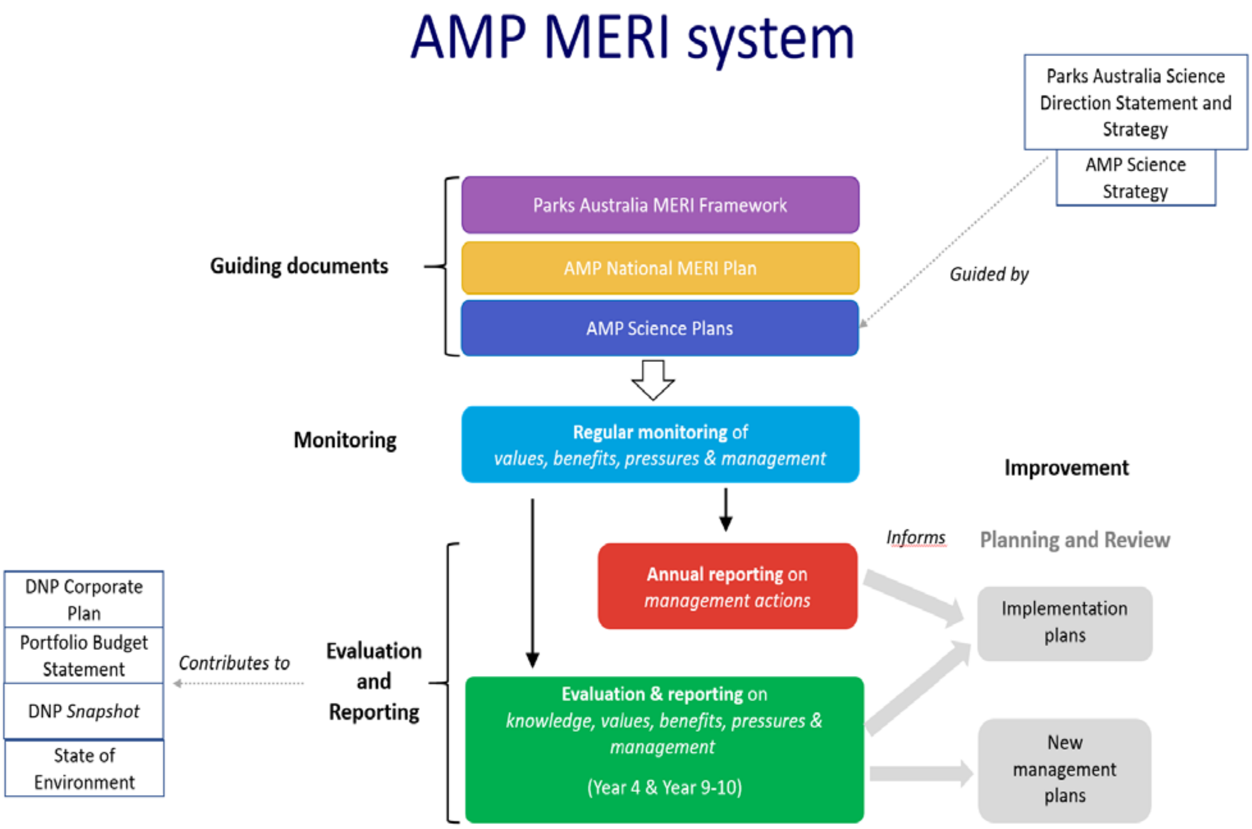

Figure 1.4: Overview of the AMP MERI system outlining the guiding documents that support the system.

Parks Australia acknowledges that there are several key challenges with implementing a robust MERI system for AMPs, including:

1. A low knowledge base for many of the AMPs.
2. The vastness, remoteness and great depths of the AMPs create logistical challenges that can lead to high costs for discovery surveys and monitoring, and other aspects of park management.
3. The need to distinguish the effects of park management from larger-scale pressures and drivers operating in complex marine ecosystems.
4. Ecological responses to management intervention can sometimes take decades to appear, and so it may not be possible to determine whether all aspects of management have been effective within the 10-year life of the management plans.

With increased understanding of park values and pressures over time, the MERI system will be improved as part of an adaptive management approach.

Table 1.1: Draft evaluation questions developed for the AMP MERI system

Key Evaluation Questions		Specific Evaluation Questions
1	Was adequate knowledge available to inform evidence-based adaptive management?	To what extent have critical knowledge gaps been identified and addressed for natural, cultural and heritage values in AMPs? To what extent have critical knowledge gaps been identified and addressed for social and economic benefits in AMPs? To what extent have critical knowledge gaps been identified and addressed for pressures and drivers acting on key AMP values? To what extent are monitoring programs providing relevant and appropriate information to enable adaptive management? To what extent has applied research focused on addressing the most critical knowledge gaps for AMP management?
2	What was the condition and trend of natural values in Australian Marine Parks?	To what extent was the condition and trend of natural values in AMPs in a desirable state in relation to zone objectives? How did park management influence the condition of natural values?
3	What was the condition and trend of cultural and heritage values in Australian Marine Parks?	To what extent were cultural values in AMPs protected from pressures? To what extent were heritage values in AMPs protected from pressures? What was the condition of cultural and heritage values in AMPs and how did park management influence these values?
4	What was the status and trend of social and economic benefits resulting from Australian Marine Parks?	What were the status and trends of social and economic benefits provided by AMPs? To what extent did AMP management provide employment and other social benefits for traditional owners and Indigenous rangers?
5	What was the status and trend of pressures acting on values and benefits in Australian Marine Parks?	To what extent were pressures and/or their impacts on AMP values minimised or maintained at acceptable levels? Were the status and types of activities in AMPs ecologically sustainable? Were there any new or emerging pressures acting on AMP values?
6	Were management activities effective in achieving program outcomes?	To what extent were management program activities and outputs delivered as planned? To what extent were management program outcomes achieved? Were other major AMP initiatives delivered as planned? What challenges were experienced in delivery and were any lessons learned that guide future actions? Were there any unintended consequences / impacts from delivery of management activities?
7	Did management systems and processes support adaptive management of Australian Marine Parks?	Were any determinations, zoning or other changes to the regulatory approach implemented over the management period? Were appropriate governance arrangements in place to support marine park management, relating to: risk management, business and operational planning, stakeholder engagement and public accountability? Were financial and human resources adequate to effectively manage AMPs? Were effective partnerships in place to support management of AMPs? To what extent was AMP reporting public, accessible and transparent? Were evaluation and reporting processes timely and appropriate to enable adaptive management of AMPs? How has Parks Australia responded to findings from review and evaluation processes? Were information management systems adequate to enable effective management of AMPs?

1.4 Conceptual models

Parks Australia has developed an overarching conceptual model to illustrate our understanding of the marine parks system, including key components and processes operating in the system, and the assumptions about how these are related (Figure 1.5). The conceptual model is based loosely on the DPSIR model (e.g. Bradley and Yee, 2015; Dambacher and Anthony, 2019), as well as various conceptual models for marine parks developed in South Australia and Victoria, and the situation analyses used as part of the Conservation Measures Partnership (2013).

These sorts of models help park managers and stakeholders to understand where action could influence components of the system to protect values and provide benefits. The model can also help to highlight knowledge gaps and prioritise research and monitoring effort. More detailed versions of this model were also developed for several ecosystem groupings (Appendix H).

The arrows in the conceptual model in Figure 1.5 indicate the direction of influence of one component on another. Solid lines show the main interactions that are likely to occur. The dotted line reflects the fact that there are very few management options that will influence social and economic drivers. For example, park managers can't influence social drivers such as demographics (e.g. population size or age structure) but may be able to influence communication and media drivers (e.g. media portrayal of marine parks) to some extent through a targeted communication, education and awareness program.

The key components of the model are:

1. **Values**[2] are the natural, cultural and heritage[3] features that require protection and conservation. They might be tangible, such as marine species, coral reefs, Indigenous sites and shipwrecks, or intangible such as Indigenous song-lines and sacred sites.
2. **Benefits** to people, businesses and the economy arise from the protection and sustainable use of these values.
3. **Pressures** are usually a result of human activity (direct or indirect) that may pose a risk to values or benefits. For example, pests and disease, marine debris, water pollution, incidental bycatch and climate change. Pressures often affect multiple values and benefits. In this model, pressures can usually be mitigated by management action, however, there are some instances where park-level action has limited influence over pressures, such as climate change.
4. **Drivers** are phenomena which can influence the state or condition of values and benefits, and in some cases may also influence pressures. These can be divided broadly into "bio-physical" and "social and economic" drivers. Bio-physical drivers are mostly of natural origin and are not influenced by marine park management. They can include natural variations in salinity, oceanic currents, and tides, as well as history of use. Social and economic drivers are usually of human origin and can be divided into categories including economic, social and cultural, demographic, political and management, communication and media, and science and technology (from Marshall et al., 2014). Park management may have some influence over a subset of social and economic drivers, such as environmental awareness or compliance with regulations.

[2] Note: social and economic values as defined in AMP management plans are captured as benefits in the MERI system

[3] Heritage refers to historic heritage values in this document. Refer to the glossary for a full description of natural, cultural and heritage values.

5. **Management actions** can be taken to reduce the pressures acting on key values, directly improve values, enhance benefits to park users, or exert some influence over a subset of social and economic drivers.

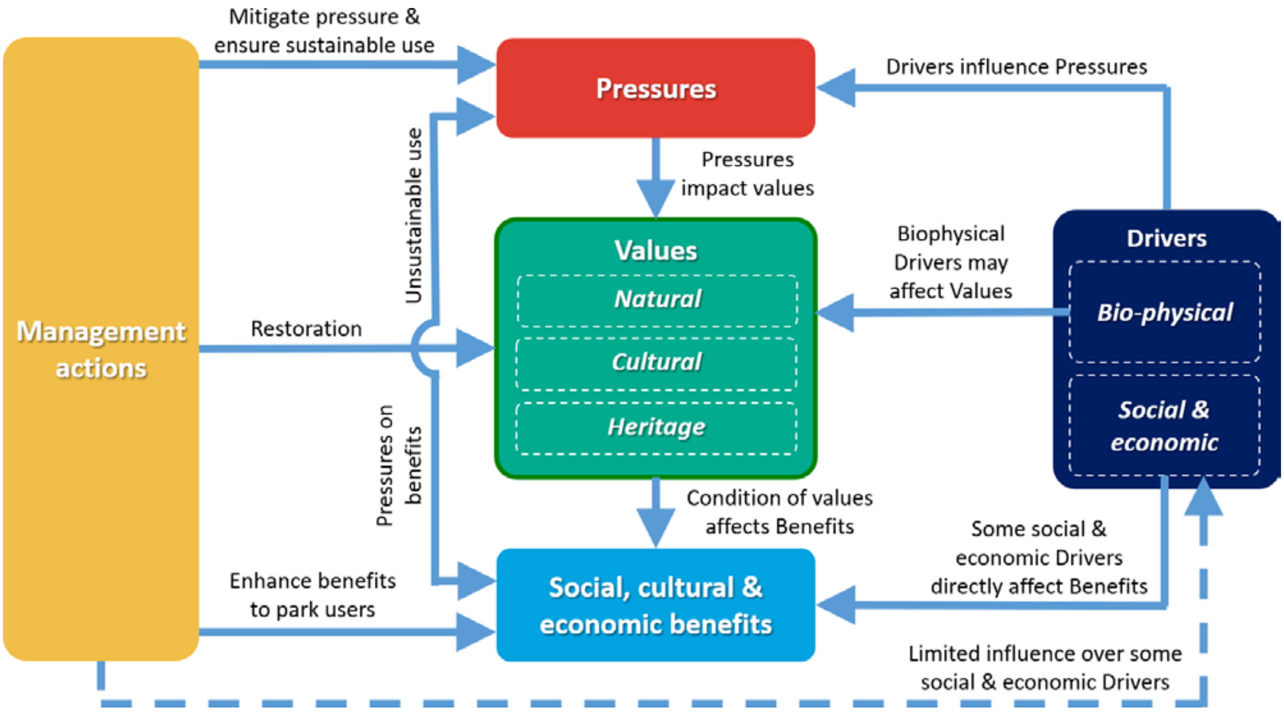

Figure 1.5: A conceptual model of a marine park system (with reference to Pocklington et al., 2012; Conservation Measures Partnership, 2013; Bradley and Yee, 2015; Bryars, et al., 2017a; 2017b; Dambacher and Anthony, 2019).

1.5 Project objectives

The SS2 and D7 projects were instigated by Parks Australia and the National Environmental Science Program (NESP) Marine Biodiversity Hub ("the hub") to support the design of the AMP MERI system, and more specifically, the AMP Science Plans. The SS2 project focused predominantly on the prerequisite "planning" steps required to inform the development of the MERI system. The D7 project focused on the development and implementation of a pilot approach to identifying monitoring priorities for the South-east Marine Parks Network (South-east Network). Each of the subsequent sections in this report are based on these prerequisites and design steps.

The primary objective of the SS2 project was to provide a spatially explicit analysis of the relative risks posed to marine conservation values, as defined by the AMP natural values common language (Section 2), by pressures that operate within Australia's Exclusive Economic Zone and state/territory waters. In completing this objective the project has drawn upon the outcomes of many preceding hub projects, most notably: (i) the geo-location of pressures in projects C1, C5, E2 and E4 (Dunstan, 2018; Peel et al., 2019; Erbe et al., 2021; Lynch et al., 2019); (ii) the collation of spatial products that identify the benthic habitats of the Australian shelf, coordinated by project D3 (Lucieer et al., 2019); and, (iii) the on-going baseline surveys conducted by the hub, under projects D3 and D4, and its predecessors.

The objectives of the D7 project were to provide the necessary scientific support and advice to complete the monitoring prioritisation for natural values and pressures. It is not practical or feasible for Parks Australia to monitor all the values, benefits, and pressures in the 58 marine parks across the entire AMP network. It has therefore been necessary to develop a process to identify the highest priorities for monitoring to support evidence-based management and make best use of available resources. The D7 project aimed to identify monitoring priorities in the SE network, using outputs from the SS2 project.

The SS2 and D7 projects included the following core components:

1. Developing a new model to identify continental shelf reefs (Section 2.2.2).
2. Working collaboratively with Parks Australia staff to develop and implement a process to identify and describe Key Natural Values.
3. Undertaking vulnerability and cumulative impact assessments.
4. Providing feedback on key components developed by Parks Australia:
5. Establishing a common language.
6. Developing a generic conceptual model of a marine park system.
7. Establishing Key Evaluation Questions (KEQs) and Specific Evaluation Questions (SEQs).
8. Contributing to the development and refinement of conservation goals, monitoring questions and indicators.
9. Providing input into the prioritisation of ecosystems for monitoring.

The overarching questions addressed as part of the SS2 and D7 projects, and associated outputs, are illustrated in Figure 1.6 together with the key questions and elements considered in the process of identifying monitoring priorities for the AMP Science Plans[4]. MERI pre-requisites were largely dealt with as part of the SS2 project, while the process for identifying monitoring priorities was largely dealt with as part of D7. Developing monitoring methods or standard operating procedures, and determining the most appropriate monitoring design, was beyond the scope of the SS2 and D7 projects. NESP Field Manuals developed as part of project D2 will be used as standard operating procedures for the AMP monitoring program and any other procedures that are required will be addressed as part of the AMP Marine Science Program. Monitoring design will also be determined on a case by case basis as part of the AMP Marine Science Program and will depend on the monitoring question(s).

1.6 South-east Marine Parks Network pilot

The SS2 and D7 projects are geographically focused on the South-east Network (formerly known as Commonwealth Marine Reserves Network; Figure 1.7). The South-east Network serves as a pilot for developing and refining a process for identifying monitoring priorities, which can then be implemented in other networks and the Coral Sea Marine Park. The South-east Network was chosen as the pilot network because it has the longest period of management and the highest level of knowledge and understanding.

[4] Conservation goals would normally be a MERI pre-requisite and form part of the "Plan" step in the adaptive management cycle, but they have been included as a core component of the SE Science Plan as they have currently only been developed for natural values identified as monitoring priorities (and it is anticipated they will help inform the evaluation process).

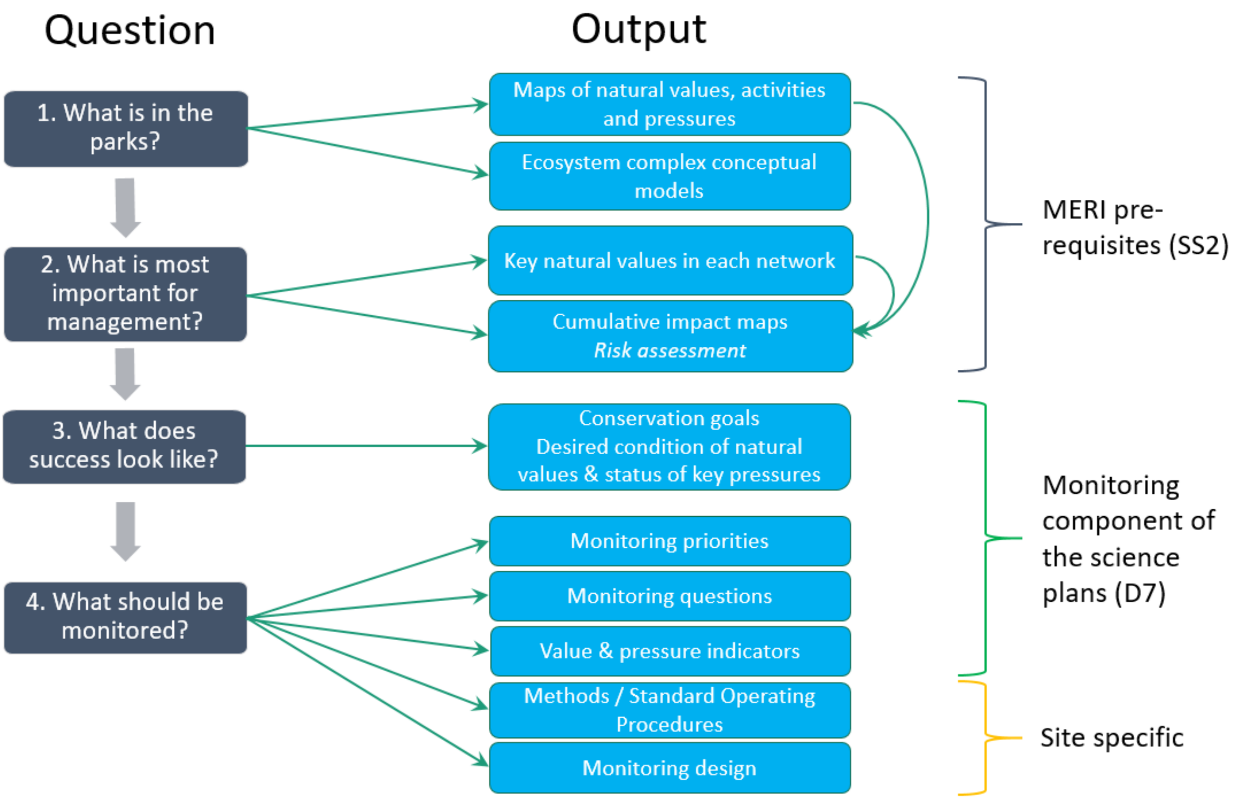

Figure 1.6: An overview of the key questions and elements considered in the process of identifying monitoring priorities for the AMP Science Plans.

The South-east Network is comprised of 14 marine parks off the coast of Victoria, South Australia, and Tasmania (including sub-Antarctic Macquarie Island). The marine parks in the South-east Network cover approximately 388,464 km^2 and include a broad range of temperate and sub-Antarctic environments across 11 provincial bioregions[5] and in depths from 40m on the continental shelf to more than 4,600m on the abyssal plain.

The South-east Network was proclaimed on 28 June 2007 and came into effect on 3 September 2007. Some pre-existing reserves were incorporated into the South-east Network including the Habitat Protection Zone of Huon Marine Park (formerly Tasmanian Seamount Marine Reserve) and Macquarie Island Marine Park proclaimed on 19 May and 27 October 1999 respectively. The Management Plan for the South-east Network (2013–2023) came into effect on 1 July 2013.

During the period between the SE parks being proclaimed in 2007 and the management plan coming into effect in 2013, there were a number of general approvals given to allow existing commercial activities and activities that involve the taking of native species (fishing), that were consistent with the IUCN categories of the zones of the reserves, to legally continue. There were also some activities that required an individual approval on an application basis. These interim arrangements can be found at Appendix 7. An understanding of the timing of management actions is important for determining when changes in natural values are expected to be seen in response to management and thus informing monitoring questions and setting of appropriate time frames for conservation goals.

[5] Large areas of ocean with broadly similar characteristics that are classified by scientists based on the distribution of fish species and ocean conditions. Australia's EEZ is divided into 41 provincial bioregions.

Each marine park in the South-east Network is divided into zones (see Figure 1.7). There are six different zone types within the South-east Network (listed from highest to lowest levels of protection): Sanctuary Zone (SZ); Marine National Park Zone (NPZ); Habitat Protection Zone (HPZ), Recreational Use Zone (RUZ); Special Purpose Zone and Multiple Use Zone (MUZ).

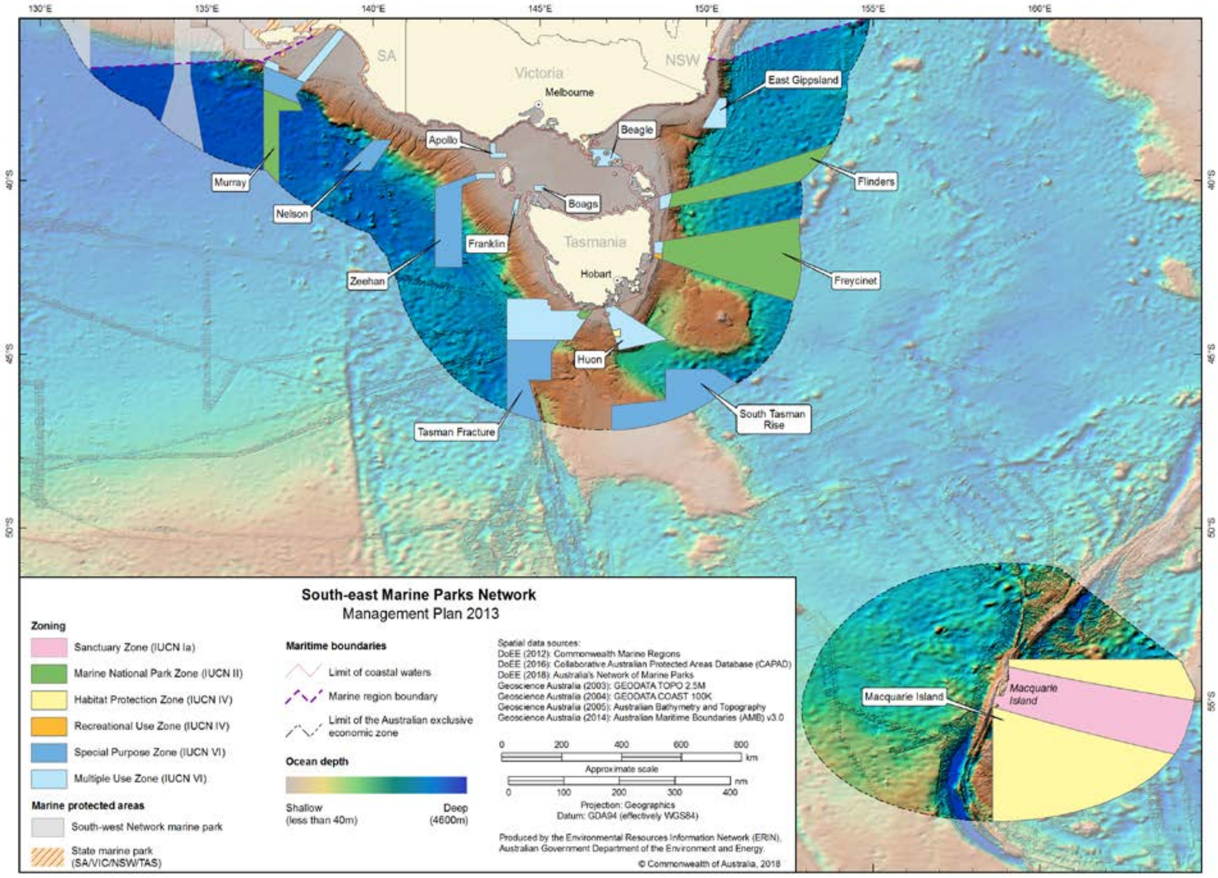

Figure 1.7: The 14 marine parks in the South-east Marine Parks Network showing zoning.

2 WHAT'S IN THE PARKS?

2.1 Controlled common language

The MERI 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 is hierarchical, and the structure has been deliberately chosen to provide a balance between sufficient detail to allow unambiguous interpretation, whilst being sufficiently succinct so that its role within the MERI system remains practical for management (Appendix B). The use of common language will allow Parks Australia to use the same terminology across all AMPs. It will also enable evaluation and reporting at different spatial scales, making it easier to scale or aggregate up from individual ecosystems or zones to a national scale as required. The following subsections of this report provide further details on the natural values and pressures that form the focus of the pilot project.

2.1.1 Ecosystems and ecosystem complexes

The natural values common language was developed to articulate what ecosystems, habitats, communities and species occur within the provincial bioregions that form part of the Integrated Marine and Coastal Regionalisation of Australia (IMCRA[6]). This greater level of detail about what occurs in the parks is critical for developing effective management and monitoring programs. The natural values common language was developed at a national scale based on broad national ecosystems (e.g. shelf reefs and sediments, upper-slope reefs and sediments) and ecosystem components (e.g. fish populations, mobile invertebrates, sessile invertebrates, macroalgal and seagrass communities) to: 1) ensure the full range of ocean depths and a broad range of biodiversity was covered, and 2) enable reporting to be done at various spatial scales.

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 (see Table 2.1 for example). Ecosystem components are functional or taxonomic groups of species from which ecological indicators and metrics are ultimately selected and measured. The common language identified a total of 26 different ecosystem components across all AMPs, each of which is allocated to at least one ecosystem, but in most cases, they occur within two or more ecosystems. The specific species, communities, or habitats within the ecosystem components (i.e. the lowest level in the hierarchical common language) will vary by location (e.g. bioregion).

The natural values common language also identifies 22 benthic ecosystems and 4 pelagic ecosystems in AMPs (Figure 2.1), each allocated to an ecosystem complex (there may be multiple ecosystems in each ecosystem complex). Ecosystems are delineated by habitat, depth, and other biological and/or spatial features, in a manner that ensures that their boundaries are identifiable. For example, the mesophotic rocky reef ecosystem is defined as "rocky reef formations on temperate continental shelf areas in the mesophotic zone: a reduced light zone between 30m and the maximum depth at which there is sufficient penetration of sunlight to support photosynthesis. The maximum depth is variable dependent

[6] IMCRA is a spatial framework for classifying Australia's marine environment into bioregions that make sense ecologically and are at a scale useful for regional planning. Provincial bioregions reflect broad patterns of biodiversity using fish populations and geomorphological features as proxies. See A guide to the Integrated Marine and Coastal Regionalisation of Australia – version 4.0 June 2006 (IMCRA v4.0) at: https://parksaustralia.gov.au/marine/management/resources/scientific-publications/guide-integrated-marine-and-coastal-regionalisation-australia-version-40-june-2006-imcra/

upon water clarity and may extend to 150m in the clearest of waters however, as a national average it is nominally defined as 70m". Defining ecosystems in this manner allows them to be mapped, thereby providing the basis for a whole-of-system, place-based approach to management. The ecosystems within the common language align closely with the marine components of the IUCN global ecosystem typology 2.0 (Keith et al., 2020).

Table 2.1: Example of the natural values common language including ecosystem complex, ecosystems and ecosystem components

Ecosystem complex:	**Deep shelf reefs (30m to shelf break [200m])**		
Ecosystems	**Mesophotic rocky reefs (30m to 70m)**	**Mesophotic coral reefs (30m to 70m)**	**Rariphotic shelf reefs (70m to 200m)**
Ecosystem components:	Benthic and cryptic fish Demersal fish Macroalgae Mobile macroinvertebrates Sessile invertebrates	Benthic and cryptic fish Demersal fish Macroalgae Mobile macroinvertebrates Sessile invertebrates	Benthic and cryptic fish Demersal fish Mobile macroinvertebrates Sessile invertebrates

Finally, the common language groups ecosystems into 11 ecosystem complexes, consisting of groups of broadly similar ecosystems with similar pressures and management approaches[7]. For example, the pelagic ecosystems defined by the language (Appendix B) are grouped into the water column ecosystem complex, whereas the shallow (<30m) coral and rocky reef ecosystems are grouped under the shallow reefs ecosystem complex. The ecosystem complexes provide a coarser categorisation of natural values that can be used in the MERI system as a fall-back option in the event that data on the location of ecosystems is unavailable, or the higher level of detail within the ecosystems is too onerous to implement.

2.1.2 Activities, sub-activities, and pressures

Anthropogenic activities in the common language are defined at two levels: 1) activities, and 2) sub-activities. This hierarchy and nomenclature is based on the AMP management plans. Anthropogenic pressures in the common language are linked to the activities and are also defined at two levels: 1) management plan pressures, and 2) specific pressures. This pressure hierarchy and nomenclature is based on the pressures identified in the AMP management plans, with specific pressures based on various other examples including the Conservation Action Planning approach used by Parks Victoria and that used in the NSW marine estate threat and risk assessment (NSW Department of Primary Industries 2017). The approach that has been adopted recognises that pressures (stressors in the NSW lexicon) that threaten environmental values (assets) arise through various anthropogenic activities.

Activities and sub-activities identify things that occur in the AMPs. The controlled language distinguishes 16 activities that are sub-divided into 58 activity–sub-activity combinations. For example, the sub-activities charter fishing tours, aviation tours, nature watching, scuba/snorkel tours and tourist vessel transiting are allocated to the activity commercial tourism.

[7] Detailed conceptual models were developed at the ecosystem complex level (Appendix 14)

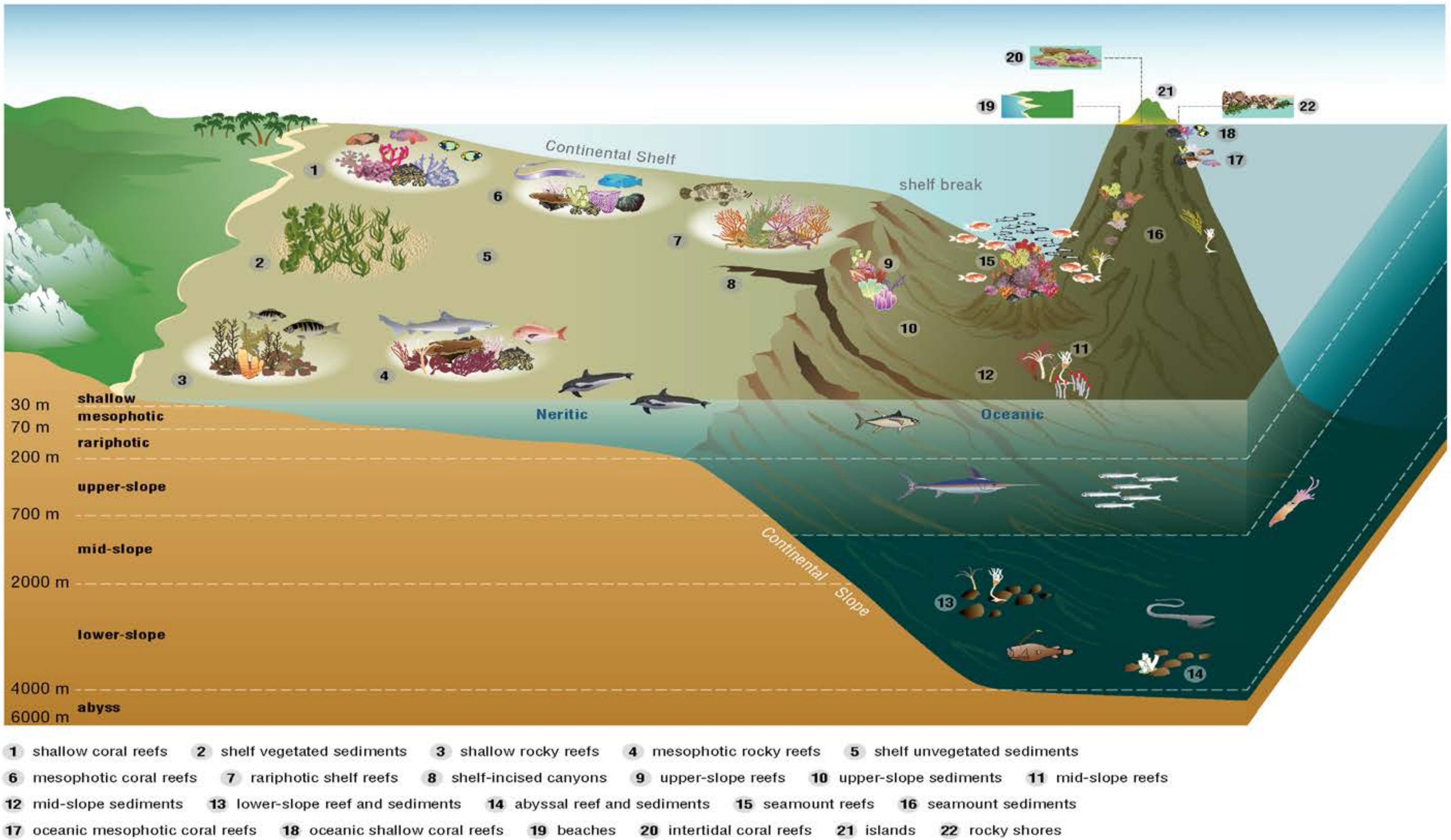

Figure 2.1: Ecosystems identified in the natural values common language.

The largest number of sub-activity categories occur within the commercial fishing activity. Together with vessel transiting, the language identifies 15 commercial fishing sub-activities, such as Danish seine, demersal trawl, hand collection, etc. To create a national picture of commercial fishing in the commonwealth marine area, the project aligned the (inconsistent) fishing gear names used in each of the state and commonwealth fisheries to the (consistent) commercial fishing sub-activity names. For example, trolling in the Torres Strait fishery, jigging in the small pelagic fishery and hand line in the southern shark hook fishery are (with other fisheries) assigned to the sub-activity "minor line" in the common language.

The common language identifies 24 specific pressures that arise through sub-activities. For example, the language distinguishes habitat modification due to physical disturbance and removal; changes in nutrients and organic matter; and suspended sediments and smothering. These three specific pressures are caused by a variety of different human sub-activities. For example, suspended sediments are created by vessel transiting, diffuse source run-off, dredging and mining, and stock grazing of riparian and marine vegetation (Norfolk Island). For the purposes of the common language and vulnerability assessments (see Section 3.2), climate change was treated as an activity with climate change "stressors" (e.g. increased sea surface temperature, sea level rise etc.) treated as sub-activities.

Parks Australia reviewed the management plan for the South-east Network and supporting authorisation instruments to categorise each sub-activity by their respective management category. Sub-activities that are more responsive to management were assigned into one of three categories: "Allowed", "Not allowed", or "Authorisation required". Those sub-activities (and their associated pressures) that were either not included in the management plan or are less responsive to management, were categorised as "NA". These categories are used in the monitoring prioritisation process, along with the cumulative impact scores, to filter the data depending on the question being asked.

2.2 Map creation

2.2.1 Ecosystems

By defining ecosystems via a combination of depth and characteristic habitat, the common language enables the creation of an Australian marine ecosystem map (Figure 2.2). Geoscience Australia's 2009, 250m resolution bathymetry https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/67703 serves as the basis for the map. From this a 16,411 row by 29,161 column raster of the commonwealth marine area (and adjacent state waters) was created, with 478,561,171 depth-labelled cells that were then used to geo-locate the depth boundaries between different ecosystems.

The map itself was created in a series of sequential applications of the common language definitions, that starts by assigning sediment-based ecosystems to their appropriate depth ranges. For example, all raster cells in the depth range 0 to 200m are initially identified as "shelf unvegetated sediments", and all cells in the depth range 200 to 700m assigned as "upper slope unvegetated sediments", and so forth. Reef, coral and vegetated ecosystems are then added to, and excised from, these regions. Vegetated shelf sediments (seagrass habitats), for example, are identified using the Coastal and Marine Resources Information System (CAMRIS) seagrass data set https://data.csiro.au/collections/collection/CIcsiro:12640v1. In this manner, ecosystem map layers were created for all the common language ecosystems except beaches, intertidal coral reefs, islands (including cays and islets) and rocky shores. The map generation process is described in full in Appendix C.

Information on the location of reefs/hard substrate was not available/located for either Norfolk or Macquarie Islands. The location of reefs is one of the key data needs to distinguish ecosystems within ecosystem complexes. Due to the lack of this data, the benthic marine area around Norfolk and Macquarie Islands were only mapped to the ecosystem complex level. As data on reefs in these areas becomes available then it will be possible to map the benthic area to the ecosystem level.

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 IMCRA bioregionalisation, 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. For example, the Australian ecosystem map identifies five shelf ecosystems in the South-east marine region: shelf unvegetated sediments, shelf vegetated sediments, shallow rocky reefs, mesophotic rocky reefs and rariphotic rocky reefs (Figure 2.2). The species that are present in each of the ecosystems will vary, however, between the different bioregions in the South-east identified by the IMCRA bioregionalisation (Figures 2.3 and 2.4).

2.2.2 Shelf reefs model

A significant proportion of the D7 project resources were directed towards developing a new predictive model of hard substrate (reef) on the Australian continental shelf to map the shallow rocky reef, mesophotic rocky reef and rariphotic reef ecosystems. This effort sought to build upon previous analysis of multibeam sonar data (Kloser, Penrose, and Butler 2010; Kloser and Keith 2013), previous collation of shelf reef data products (Lucieer et al., 2019) and the recent collation of Baited Remote Underwater Video (BRUV) data sets, from which habitat data could be discerned from the background of the cameras' field of view. The BRUV dataset is currently not publicly available as it is currently under a strict data-sharing agreement but is described in Harvey et al. (2021). Details on habitat annotation methods from the BRUV imagery can be found in Langlois et al. (2020).

The modelling effort is described in detail in Appendix D. The modelling produced a predicted probability of reef for all of Australia's continental shelf. Cross-validation of these predictions using the BRUV habitat data, however, indicates that the model has a limited ability to discriminate reef from non-reef sites in a hold-out data set. Hence to prevent over-prediction a conservatively high cut-off value of predicted probability of reef is used to delineate reef from not-reef in the final map products. Reef predicted sites were subsequently designated into one of the three shelf reef ecosystems in the common language based on the depth of the predicted reef location.

An external validation of the new model's predictions was also undertaken using the data products described in Lucieer et al. (2019). The poor results obtained in this validation, however, are ambiguous as they could mean that the previous predictions are poor (noting that some are themselves invalidated) or that the new ones are. The visual comparison did, however, highlight substantial differences in the prediction sets. Differences in the spatial resolution also makes it difficult for direct comparison because the Lucieer et al. (2019) data sets are patchy and at various resolutions (generally 5m) whereas the new model predictions are at a consistent 250m resolution across the entire continental shelf.

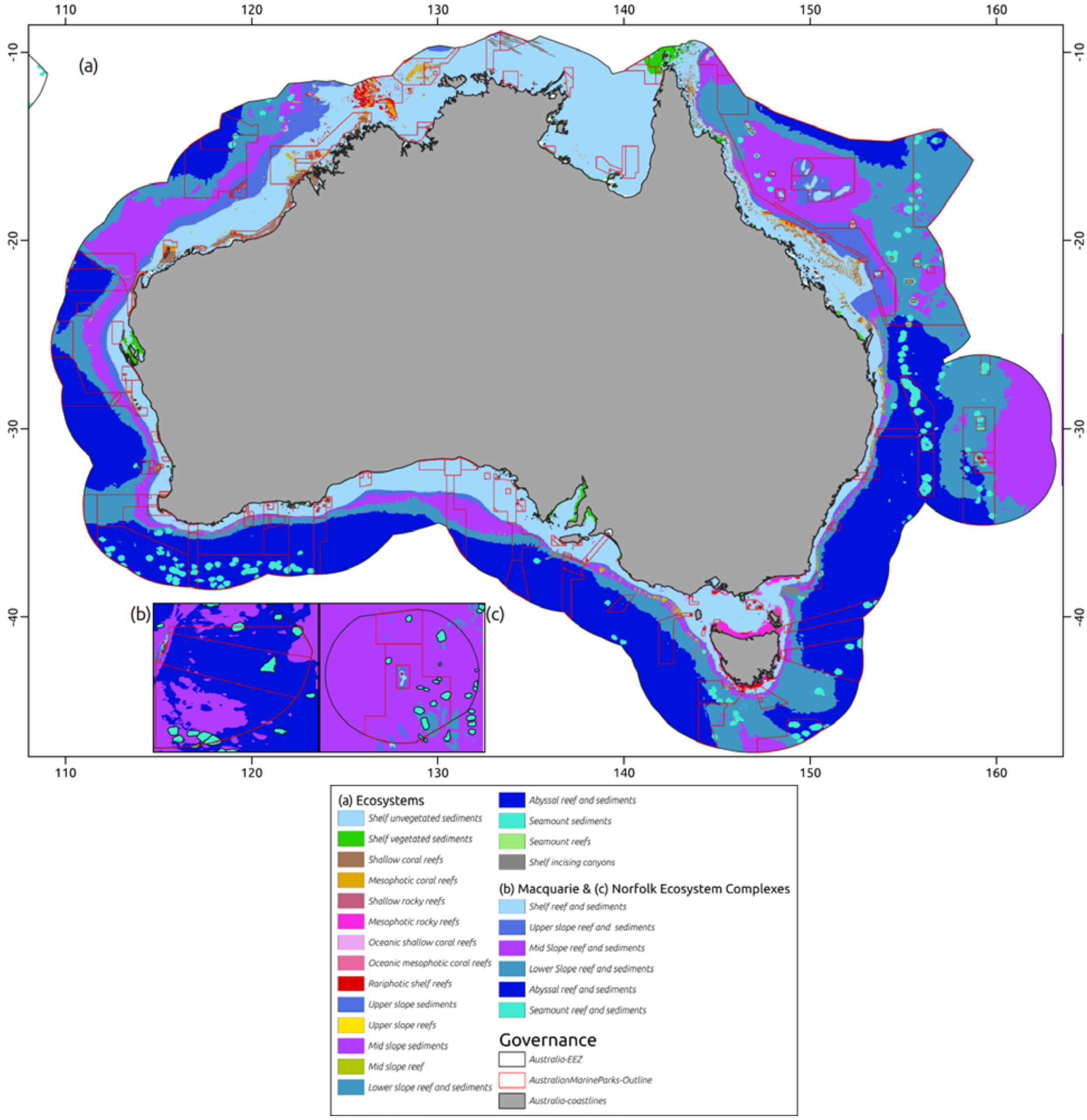

Figure 2.2: Australian ecosystem map developed for the AMPs (showing ecosystem complexes for Norfolk and Macquarie Island). This map is based on a large raster that identifies the depth in every 250m grid cell across the Australian commonwealth marine area. The raster was developed from Geoscience Australia's 2009 250m resolution bathymetry product. The map was then produced in a sequence of steps that geolocate the 18 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, Rocky shores and Islands (including cays and islets)

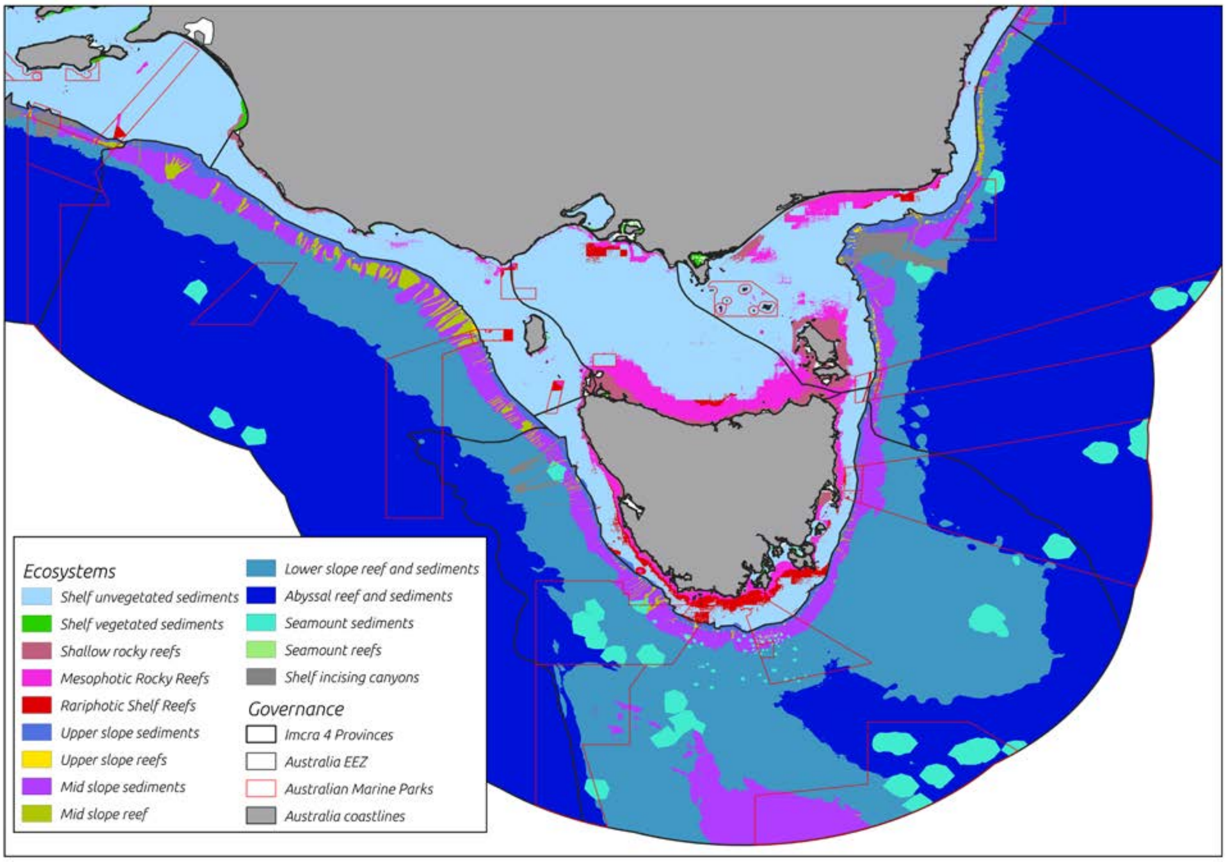

Figure 2.3: Ecosystem map for the South-east marine region showing the distribution of the ecosystems relative to the AMP boundaries in the South-east Network, and the IMCRA bioregional provinces. Four of the 18 mapped benthic ecosystems in the common language do not occur within the South-east marine region, namely shallow coral reefs, mesophotic coral reefs, oceanic coral reefs and oceanic mesophotic coral reefs. The 13 remaining mapped benthic ecosystems are shown here. The species that are present in the South-east marine region are expected to vary between these ecosystems but also within the same ecosystem between different IMCRA bioregions.

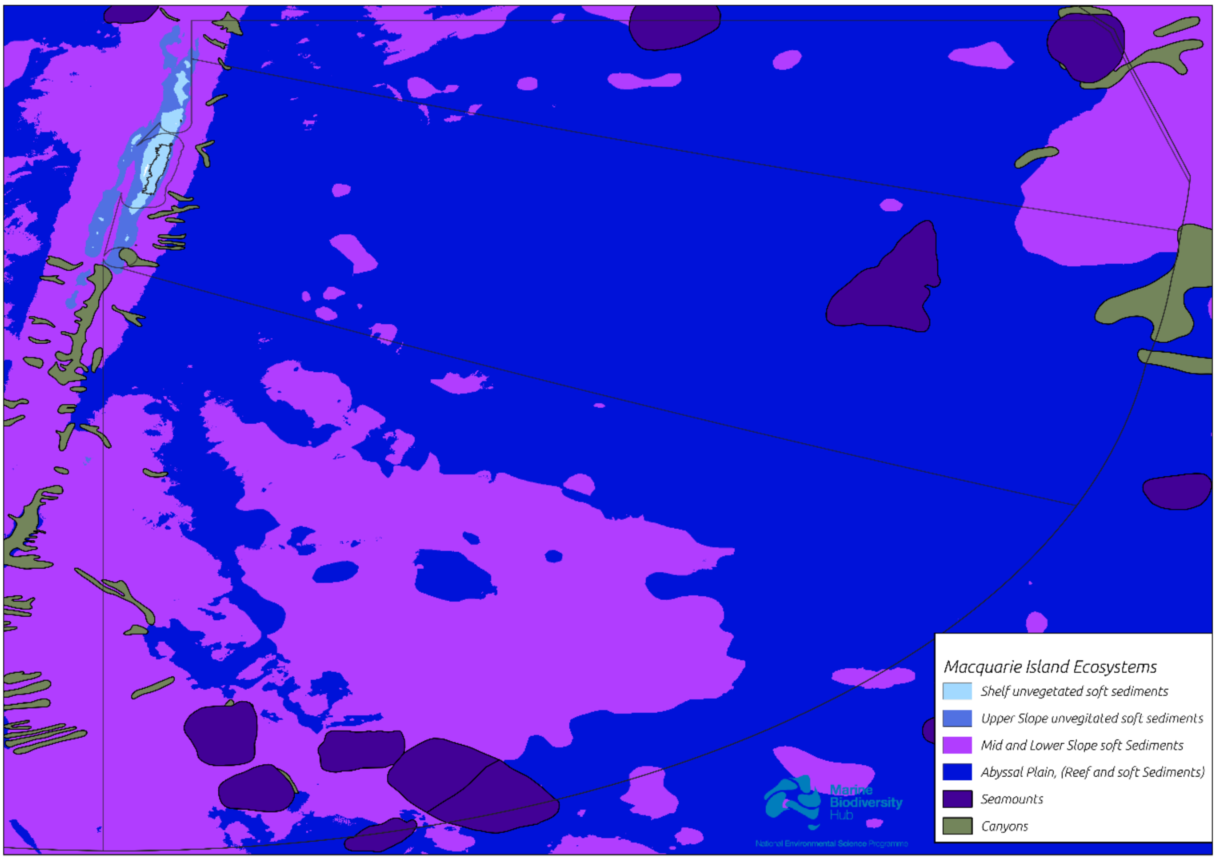

Figure 2.4: Ecosystem complexes map for the Macquarie Island Marine Park showing the distribution of the ecosystem complexes relative to the marine park boundaries. Six of the 18 mapped benthic ecosystems in the common language are thought to occur within the Macquarie Island Marine Park but their precise distribution is yet undetermined.

The new model appears to over-predict reef at certain locations such as the west and north coasts of Tasmania. Some of these apparent over-predictions (those within AMPs) were subsequently manually edited based on the results of more recent, but largely invalidated, fine-scale multibeam mapping. This over-prediction seems to reflect spatial bias in the BRUVs data set, and likely cannot be remedied until further observations of the seabed are made in the areas that are not currently captured in the BRUVs data, through additional BRUVs, towed video or drop-camera surveys, that can then be used to derive validated habitat maps. Nonetheless, from a management perspective, this national-scale product represents a significant improvement on previously available products and was deemed sufficient for the purposes of the pilot. Importantly it also now provides a basis for future development and improvement within the MERI system.

2.2.3 Sub-activities and pressures

The common language identifies 58 categories of anthropogenic activity/sub-activity combinations that exert 24 types of pressures on the marine environment. Taken together the hierarchy identities 199 unique activity/sub-activity–pressure combinations. By building on previous pressure mapping exercises conducted by CSIRO (Hayes et al., 2012), and the hub (Dunstan 2018), the MERI project collated existing, and generated new, data products that directly measure (45), or serve as proxies for (83) for these combinations, usually for the period 2011 to 2015 inclusive. A total of 14 activity/sub-activity–pressure combinations did not occur in the South-east marine region during this period, for example all pressures associated with commercial fishing/trawl-midwater. Data was also available for 18 pressures, that could not be attributed to an activity/sub-activity (see below) and no data was available for 39 combinations (Appendix E).

The project targeted data collation over the five-year period 2013 to 2018 – i.e. the five years immediately following the start of management activities in the South-east Network (1st July 2013). Some data sets were subsequently collated for this period (Appendix E). Data on commonwealth fisheries (the largest data set) was also successfully collated for this target period and permission was sought to display the data in this analysis. The project has yet to receive this permission from AFMA. For commonwealth fisheries the analysis therefore proceeded with data from the period 2011 to 2015 which had been previously cleared for publication and display.

A visual examination suggests that the pattern of fishing effort across the different commonwealth fisheries changes only slightly when the data is averaged over the years 2011 to 2015 compared to 2013 to 2018. We do not therefore anticipate that updating the data sets to the target period will have a substantial effect on the overall analysis. The analysis, however, also necessitates that fishing pressure is aligned by gear type. Hence the target period for state fishery data sets was also changed to 2011 to 2015 to allow the project to align fishing effort for the same gear, sourced from different agencies. At this stage we do not know what the effect on this analysis would be if the state-agency sourced fishing effort data was also changed to the original target period of 2013 to 2018.

Wherever possible (and permissible) each pressure data product was mapped to a 0.1 degree (approximately 10 kms^2) grid resolution raster, resulting in 309,870 cells across the commonwealth marine area. Each data product was then standardised to a maximum value of 1, averaged over the period of time that the data was available, identified as manageable (or not) under Parks Australia's current governance arrangements, and collated at the sub-activity level of the common language hierarchy. A description and map of each sub-activity data set, including the individual records that it comprises and its meta-data record, is provided in Appendix F.

For example, the commercial fishing sub-activity "Net-demersal" is represented by 10 individual pressure data products comprising commonwealth and state fishing data records. The records show annual kilometers trawled, mostly at a native resolution of 0.1 degrees, each year between 2011 to 2015 inclusive. All the data sets were standardised to a maximum value of 1, averaged over the reporting period, and then aggregated to provide a national picture of "Net demersal" fishing effort across Australia.

The common language identifies vessel transiting to be a sub-activity under five activities: commercial aquaculture, commercial fishing, commercial shipping, mining and recreational fishing. Data layers for each of these combinations were created by sub-setting the global automatic identification system (AIS) data set https://www.amsa.gov.au/safety-navigation/navigation-systems/about-automatic-identification-system. This data set had been processed previously by the hub's C5 project (Peel et al., 2019) to identify the total vessel distance traversed (kms) by moving vessels in 1km grid cells in the calendar years 2013 to 2016. The processed AIS data identifies nine vessel types, including "CT_FISH", used as the subset for the commercial fishing–vessel transiting layer, and "CT_CARGO" and "CT_TANK", used as the subset for the commercial shipping–vessel transiting layer. Vessel transiting layers for commercial aquaculture, mining and recreational fishing used the "CT_GENERAL", CT_WORKING" and "CT_REC" subsets respectively.

Where possible charter fishing tour vessels, authorised by Parks Australia to access the AMP network were identified in the processed AIS dataset using their IMO number or their Maritime Mobile Service Identify (MMSI) number. The commercial tourism–charter fishing tour pressure layer was created using the distance travelled by these authorised vessels, together with their authorised anchorages.

Four of the activity/sub-activities, including three types of commercial fishing (dropline, scallop dredge and midwater trawl) did not occur in the South-east region during the period 2011 to 2015. Geospatial data for a further 15 activity/sub-activities was not available at the time of writing. For the main part these missing data sets, such as cultural and traditional fishing, commercial media and stock grazing of riparian vegetation, are not considered to represent significant sources of pressure in the commonwealth marine area, except for recreational fishing. It is therefore important that better information on the location of recreational fishing effort and catch is collected in the future.

2.2.4 Cumulative pressures in Australia's EEZ

Having compiled a standardised set of sub-activity data sets it is possible to overlay these, summing across each data set within each cell of the pressure data raster, to provide an indicative picture of the intensity of anthropogenic activity and hence pressure in the commonwealth marine area. Figure 2.5 provides this analysis at a national level, while Figure 2.6 focuses on the South-east marine region.

It is important to recognise that this overall picture of anthropogenic stress depends on the resolution of the underlying data sets, the standardisation procedure and the assumptions and choices made when creating the standardised data layers. A two dimensional exponential decay function has been used to map point pollutant sources (such as point discharges associated with land use intensification and oil spills) into diffuse pressure layers. The exponential decay function is simply $exp(-r/n)$ where r is the distance from the point source and n is a constant used to scale the rate of decay over the entire data set.

The constant n was chosen based on the size of the pressure raster cell resolution. The function was applied via a faster Fourier transformation of Euclidean space (Rue and Held 2005) to speed up the decay calculation by eliminating the need to compute a large distance matrix over the pressure raster. In this approach the distance r is calculated using a block circulant matrix, projected as a torus. This assumes a stationary 2D decay function, which means that spatial decay from a point is even in all directions and at constant rate - i.e. the rate of spread and decay does not change with the magnitude of the point source pollutant (which would be a reasonably assumption for many pollutants).

In a few instances a number of similar or equally suitable data products were available to serve as measurements for activity–sub-activity pressures. The most notable example is climate-change induced increases in sea surface temperature. Global patterns of change in sea surface temperature (SST) have previously been reported using the linear trend component of time series models fitted independently to satellite observation of SST at a 4km grid scale (Dunstan et al., 2018). An alternative way to represent this pressure is through the marine heat wave index http://www.marineheatwaves.org/ which measures the number days where SST constantly exceeds the upper percentiles of historical satellite observations at the same 4km resolution. This index is supported by a large on-going body of analysis and research (Benthuysen et al., 2020) but is divided into 5 categories based on severity (Hobday et al., 2018). In this analysis we have used the standardised value of the severe category averaged over the years 2013 to 2018. Other choices of category, however, are possible, and this choice may warrant further discussion.

We have used two different pressure layers to represent climate-change induced changes in the frequency/intensity of severe weather events. The first is global observations of cyclone tracks acquired from the IBTRACS data base (Knapp et al., 2010). Wind speed was converted from a point record to a raster, with each cell representing the wind speed radius in km/h of a recorded cyclone track, using the spatial smoothing techniques described previously to provide a continuous layer. In this instance, however, we used a logistic decay kernel $1/[1 + exp\left(\frac{(r-\alpha)}{\beta}\right)]$ to approximate the decay of cyclones from the point source data, where r is the distance from the source and α, β are shape and slope parameters. Using the empirical cyclone track data, we calculated the mean radius in km across all tropical cyclones. The resulted in a mean value of approximately 140 km. We then used this value to represent the distance shape value (α); assuming that 14 cells at 0.1 degree resolution is approximately 140kms. We also assumed a relatively sharp decay of the logistic function with a decay slope value (β) value of 0.5.

The second layer is the p504 wave energy flux estimates provided by the Australian Energy Wave Atlas (Hemer et al., 2018), where again alternative choices of energy flux estimates are available. The use of these two data sets reflects the different sources of severe weather in the tropical (cyclones) and temperate (Southern Ocean storms) parts of the commonwealth marine area.

All vessel transiting layers used in this analysis are based on interpolated AIS data. All commercial vessels larger than 250 gross registered tonnes are represented in the data set but many smaller private vessels are not. The raw AIS data is sub-sampled to 5 minute intervals so there may be some inaccuracy at fine scale (sub 5km resolution) due to the linear interpolation. This will mainly be an issue for fast moving vessels that are not travelling in a straight path. Importantly, an updated pressure layer for the noise generated by these vessels has very recently been developed by the hub but has not been included in this analysis.

Finally, the cumulative activity/sub-activity maps presented here do not include marine pests (because no national scale distribution maps are currently available) or other marine pollution pressure layers that cannot be attributed to an individual sub-activity operation. Marine pests are identified as a pressure potentially exerted by 18 activity/sub-activities. In all cases, except for General use, access and waste management/Ballast-water discharge where data on actual discharge volumes and location was available, the standardised intensity of the activity/sub-activity is treated as proxy for marine pest pressure.

Pressure layers for oil and other noxious substance spills, light pollution and most significantly marine debris are available, but none the layers attribute the data to a unique sub-activity. A predicted marine debris data layer exists, this layer does not distinguish the source of the marine debris and as such it cannot be attributed. Marine debris in the Commonwealth marine area, for example, may originate from land-based sources or ship-based sources (Ryan et al., 2019). In the common language marine debris is attributed to 12 activity/sub-activities. The available data is potentially relevant to 7 of these but cannot be attributed to them (proxy code 2), data for 4 such as land-use intensification/point discharges, is currently unavailable, and one activity (camping) does not occur in the South-east marine parks network.

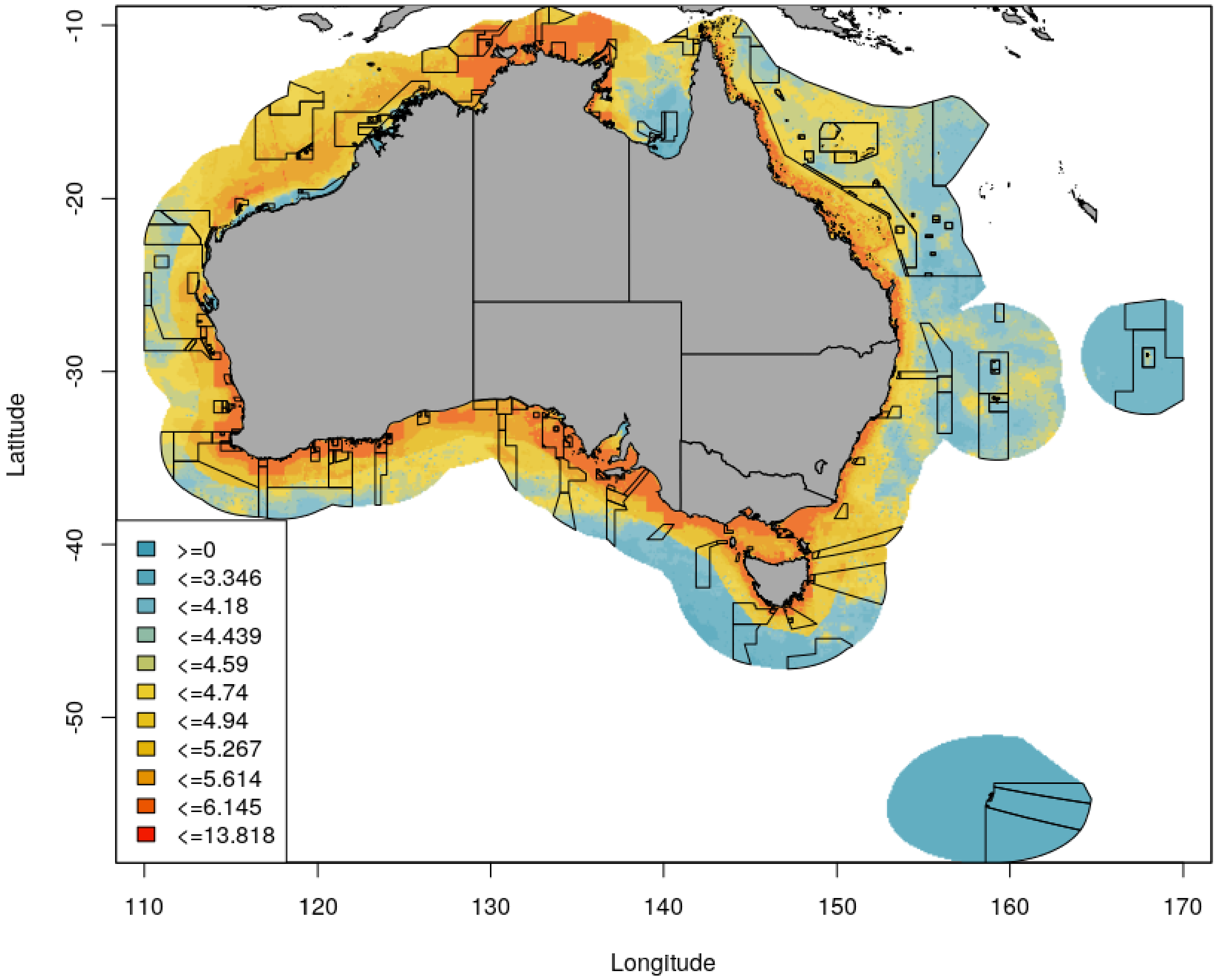

Figure 2.5: Sum of activity/sub-activity at a national scale. This figure shows the sum of 39 standardised activity–sub-activity layers, that were themselves developed from 109 standardised pressure layers, together with the zone boundaries of the Australian Marine Parks. Wherever possible pressure layers for the period 2011 to 2015 were collated, mapped to 0.1 degree raster, standardised to a 0 - 1 scale, by dividing the value in each raster cell by the maximum annual value from the entire raster, and then averaged over the (usually) five year period. These standardised pressure layers were then aggregated (where necessary) to produce a national map of each activity–sub-activity category for which geospatial pressure data was available. The cumulative sum of the standardised activity–sub-activity scores is calculated by overlaying and summing the values in each raster cell. The figure legend shows the 10th percentiles of this cumulative sum, that is the values that contain 10%, 20%, 30%…,80%, 90%, 100% of all the cumulative scores across the map. The map should be interpreted as showing the relative intensity of anthropogenic pressures in the Commonwealth marine area and state waters. The absolute values of the cumulative scores have no ecologically meaningful interpretation.

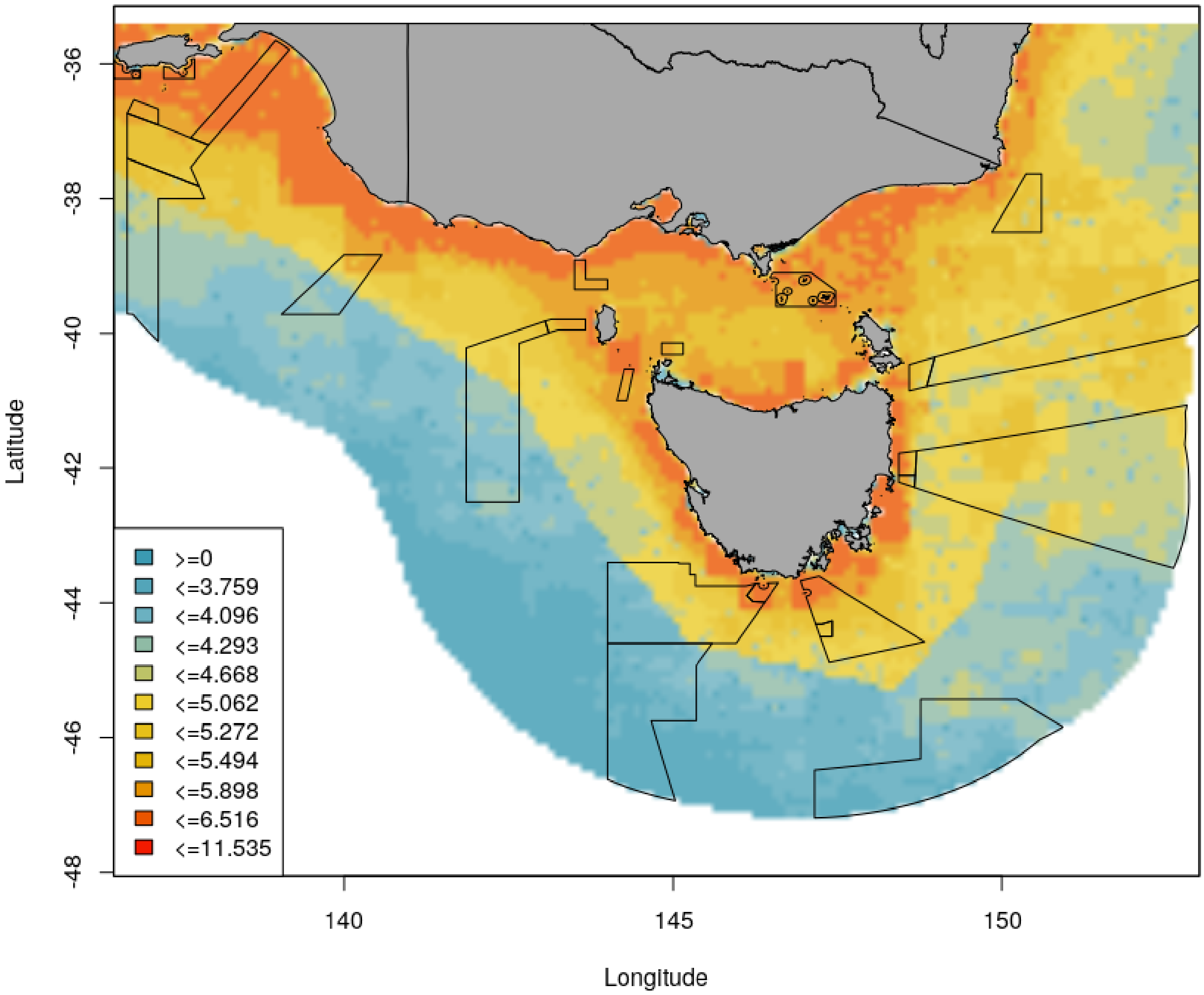

Figure 2.6: Sum of sub-activities/activities in the South-east marine region scale excluding Macquarie Island. The figure shows the cumulative sum of the standardised activity–sub-activity, clipped to the South-east marine region excluding Macquarie Island, together with the boundaries of the Australian Marine Parks in this region. The figure legend shows the 10th percentiles of the cumulative sum, when clipped to the South-east region, that is the values that contain 10%, 20%, 30%…,80%, 90%, 100% of all the cumulative scores across the map. The map should be interpreted as showing the relative intensity of anthropogenic pressures in the South-east marine region with the redder colours indicating higher anthropogenic pressures. The absolute values of the cumulative scores have no ecologically meaningful interpretation.

The lack of attribution creates difficulties during the vulnerability assessment and prioritisation process because the intensity of the different sources is not reflected in the currently available data layers, and the different sources include instances that originate inside and outside of Australia's jurisdiction, and hence are a mixture of pressures that are responsive to management and less responsive to management from Parks Australia's perspective.

Similarly, the common language attributes light pollution to the anchoring of commercial vessels, mining operations and moorings, but the data layer does not distinguish between these different sources of light some of which will be within, and some outside of, the commonwealth's jurisdiction.

3 WHAT IS MOST IMPORTANT FOR MANAGEMENT?

3.1 Key Natural Value criteria

The MERI system recognises the existence of Key Natural Values (KNVs) within the AMP network that warrant special consideration. 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[8]. 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.

The KNV criteria include additional considerations beyond the EBSA criteria, such as cultural significance and social and economic benefits, as described in the AMP management plans and the EPBC Act. 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.

The workshop process for identifying KNVs was based on the hub's experience with the criteria used for equivalent (or similar) concepts developed in various national and international fora. A comparison of the criteria used for these equivalent concepts shows a significant amount of commonality (Appendix G). The relative utility of these criteria were discussed with Parks Australia and following these discussions Park's Australia developed a set to identify KNVs (Table 3.1). Note that the culturally significant species, communities or habitats criterion was not used in the South-east pilot as it was not possible to engage Traditional Owners in the workshop, in part due to COVID-19 restrictions. It is intended that this criterion will be addressed in the South-east Network, and other networks and the Coal Sea Marine Park, through consultation with Traditional Owners.

3.1.1 Process to identify South-east KNVs

KNVs for the South-east network were identified in a workshop in Hobart on the 23rd of June 2020. Participation at this workshop was limited due to COVID-19 restrictions. Participants in the workshop were tasked with identifying habitats or species that met at least one of the KNV criteria (Table 3.1) and occurred in any one of the South-east AMPs. Participants were asked to draw rough boundaries on a map around the areas that met the criteria to show the KNV's approximate location. For each area identified, the KNVs within it were ranked (High/Medium/Low/NA) based on the understanding of how well they met the criteria. This information was entered into a template that gave a brief description of the area, and the rationale for each of the rankings.

The KNV boundaries were refined after the workshop using additional information that was not available at the workshop. This information was provided in the form of additional geospatial data layers that more accurately identified the locations of the KNV. Each KNV was also associated with one or more ecosystems, as defined by the common language. Each KNV was then subsequently mapped to the relevant ecosystem within the refined boundaries (Figure 3.1). KNVs were clipped to park boundaries and further work is required to map the full extent of all KNVs. This will be important for determining the proportion of the

[8] 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 KEFs and BIAs but are not intended to replace them.

KNV that overlaps with the park(s) (and the importance of the park for the KNV), as well as identifying possible locations for reference sites where a KNV has been identified as a monitoring priority (depending on the monitoring question).

A key part of the process to identify KNVs is the selection of expertise that is present to describe the areas. There was a noticeable lack of expertise on the ecosystems around Macquarie Island in the workshops that were held to develop the list of KNVs for the SE AMP network. As a result, the entire AMP around Macquarie was identified as potentially having KNVs (e.g. Seabirds, Cetaceans, other Marine Mammals) but there was insufficient expertise to describe these properly. This is an identified gap and will be filled later in collaboration with Parks Australia.

Table 3.1: Criteria used by Parks Australia to identify Key Natural Values in the South-east marine region

Criteria	Description
Unique or rare species, communities or habitats	Species, communities and habitats that are: unique (the only one of its kind), rare (occurs only in a few locations), endemic to the network or park or threatened
Functionally important species	Keystone species, apex predators, ecosystem engineers (e.g. parrotfish) etc.
Important habitat forming species	Species whose biogenic structure creates habitats for other species (e.g. corals form coral reefs; sponges form sponge gardens) and that support a broad array of ecosystem processes.
Vulnerable, fragile, sensitive or susceptible species, communities and habitats	Those that are highly susceptible to degradation or depletion by human activity or by natural events or are slow to recover from disturbance.
Biota associated with biologically productive areas	Particularly abundant populations or communities associated with areas of comparatively higher natural biological productivity (e.g. biota associated with upwellings or deep-sea vents).
Biological diversity	Area contains comparatively higher diversity of ecosystems, habitats, communities, or species, or has higher genetic diversity.
Bio-geographic importance	Species, communities or habitats associated with an area that either has rare biogeographic qualities or contains unique or distinctive biological characteristics resulting from unusual chemical, physical, or geological features.
Culturally significant species, communities or habitats	Species, communities or habitats that are important to indigenous communities (e.g. dugongs).
Provide important social and economic benefits	Species, communities and/or habitats that provide important recreational and commercial services (provisioning services), and other services such as coastal protection, climate regulation etc.
Iconic species, communities or habitats	Species, communities and/or habitats of considerable community interest.

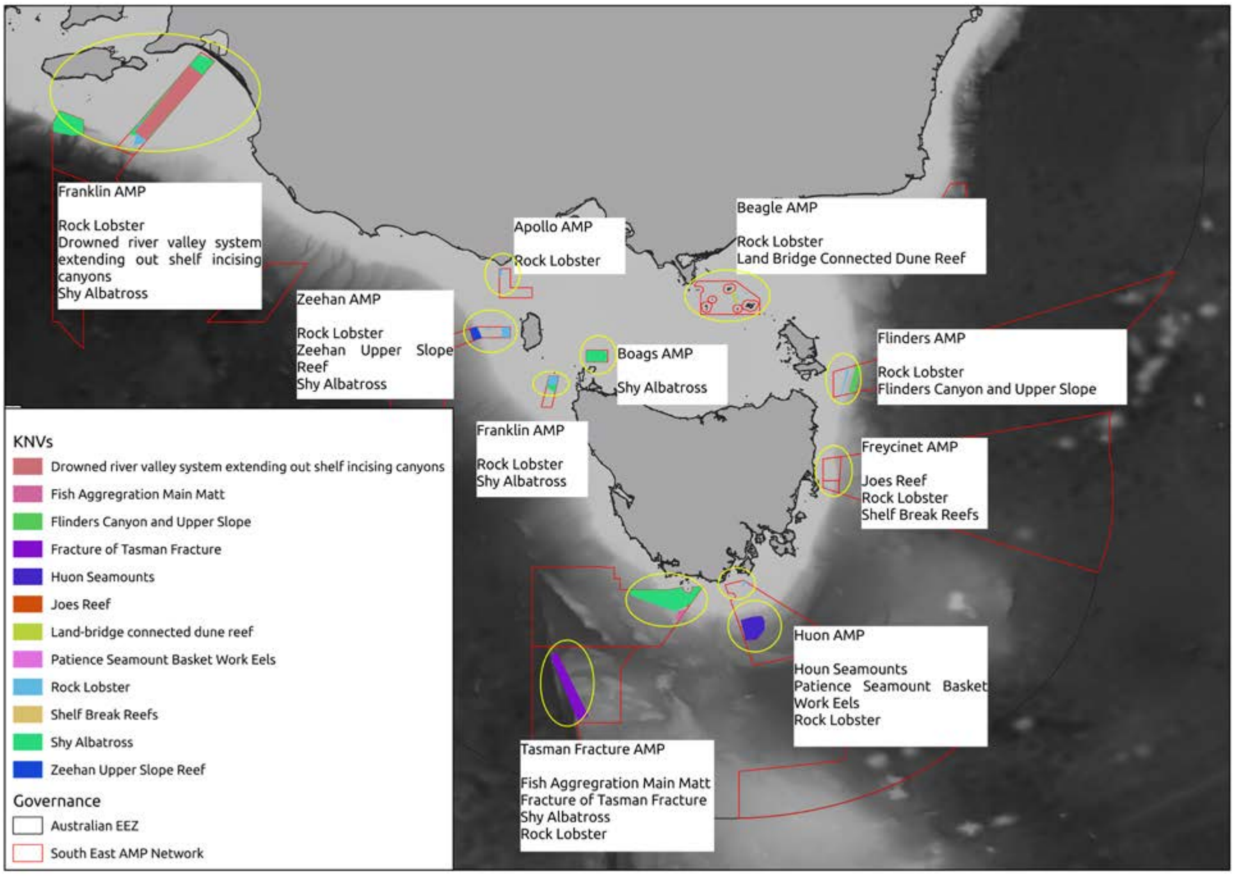

Figure 3.1: Key Natural Values in the South-east Network. The KNVs were identified by subject matter experts using a set of criteria developed from the criteria used to identify equivalent or similar concepts in other national and international contexts. Each KNV is allocated to an ecosystem within the common language and thereby mapped. KNVs for Macquarie Island will be described at a later date.

3.2 Risk assessment

3.2.1 Cumulative risk and impact assessment

The last of the MERI pre-requisite steps is the completion of a vulnerability and cumulative impact assessment that accounts for the cumulative impacts of anthropogenic sub-activities on natural values (Figure 1.6). The objective of this step is to identify and prioritise locations within the South-east marine region 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. This step therefore aims to provide a relative assessment of the cumulative impacts across the South-east marine region. It does not aim to predict or quantify the effects of the cumulative pressures acting on the ecosystems at any location.

Korpinen and Andersen (2016) review a variety of methods for conducting cumulative pressure and impact assessments, and conclude that all assessments have in general three essential components: (i) spatial data on the intensity of pressures; (ii) spatial data on the occurrence of ecosystems and their components; and (iii) a set of factors or models for estimating impacts. The main difference between the various methods proposed in the literature occurs in this last component.

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 raster:

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

where I_c is the impact score for raster cell c, D_i is the (sometimes log-transformed) standardised intensity of anthropogenic pressure i at the raster cell location, E_j is indicator variable scored 1 if ecosystem j is present at the raster cell location and 0 otherwise, and μ_{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. Synergistic or antagonistic effects, or other forms of non-linear response, cannot be represented in this manner.

The impact weights μ_{ij} reflect the vulnerability of ecosystem j to anthropogenic pressure i, and almost always assessed through expert elicitation. In one of the earlier examples of this approach, Halpern et al. (2007) identified five vulnerability factors, scored on scales that varied between 0 and 6, that were subsequently averaged (and weighted with a certainty score) to estimate the overall vulnerability weight. This approach, however, creates a considerable elicitation load, because each of these factors must be calculated for every ecosystem/pressure combination in the analysis. Halpern et al. (2007)'s analysis, for example, considered 874 ecosystem/pressure combinations, thereby requiring 5,244 expert responses to obtain a single complete assessment of the vulnerability weights.

In a more sophisticated analysis using the same criteria, however, Teck et al. (2010) were able to demonstrate that two criteria - the trophic impact score and the percent change score - together explained 89% of their overall vulnerability weights. Their analysis indicates that very similar outcomes can be achieved with one-third of the elicitation load, and consequently the vulnerability weights in this project were assessed using only the tropic impact score and percent change score.

3.2.2 Interaction matrix

The common language identifies 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. 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

The vulnerability assessment began by identifying at least one expert in each of the 18 mapped benthic and pelagic ecosystems that occur in the AMPs in the South-east marine region (artificial reefs, cables and pipelines were excluded from vulnerability assessment). Expert's scores on the two most important vulnerability criteria – trophic impact and percentage change - were then elicited via in-person interviews with a project staff member. The elicitation was initially attempted remotely but this was abandoned due to a poor response and misinterpretation of the assessment's goals and scope.

Experts were asked to score trophic impact, defined as the primary level of marine life affected per interaction with a sub-activity, on a scale of 0 to 4, where 0 is defined as no impact; 1 is species (single or multiple); 2 is a single trophic level; 3 is more than one trophic level; and 4 is the entire community, including associated habitat structure. This score was elicited for every sub-activity identified by the interaction matrix as having the potential to impact the ecosystem in question.

Experts were provided with the following examples drawn from Teck et al. (2010) to assist them in this regard: A sub-activity that directly impacts only one or several species - such as ship strikes on whales - would score 1. A sub-activity that may directly impact all or most of the species within the same trophic level but without cascading effects to the rest of the ecosystem would score 2. A sub-activity that may remove species from many trophic levels - hook and line fishing - but leave the habitat structure otherwise intact would score 3. A sub-activity that may impact the underlying habitat upon which the entire community depends - such as the effect of climate change acidification on coral reefs - would score 4.

Experts were then asked to score percent changes, defined as the degree to which the species, trophic levels or entire ecosystem's "natural" state is impacted per interaction with the sub-activity. In other words, the average tendency of the selected trophic component to change due to the given sub-activity, where 0% indicates no effect on abundance, 100% indicates that all the species, trophic level or underlying habitat is damaged or removed. This score was also elicited for each impactful sub-activity identified in the interaction matrix.

Definitions of each ecosystem together with their components, as defined by the common language, were provided to each of the experts during the elicitation (Appendix B). When providing their scores the experts were asked to consider the vulnerability of the ecosystem to the sub-activities in the context of the condition of the ecosystem in the South-east marine region in the period 2013 to 2018 on average – that is on average over space and time without factoring in any effects that a marine park zone may have. Experts were also asked to assume that all operators display typical rates of compliance with all relevant laws and regulations regarding disposal of waste, sewage, catch limits, maintenance schedules, etc.

The experts were reminded to provide scores on a "per interaction" basis rather than an "accumulated impact over time" basis. For example, for a fishing gear this would be per (typical) deployment of that gear in that ecosystem. For infrastructure such as aquaculture facilities, moorings, etc. this would be per single (typical) facility over the course of a year. For commercial and recreational vessel traffic it would be per individual vessel moving through or over the ecosystem with typical velocity and direction changes.

This aspect of the elicitation had been previously misinterpreted by the experts when the elicitation was attempted remotely, hence the in-person interviews sought to remove ambiguity surrounding the meaning of "on a per interaction basis". For the main part this was successful except for climate change associated sub-activities where the interaction is continuous and difficult to define in terms of discrete events. For these sub-activities experts were therefore asked to consider the scores in the context of the impacts on the ecosystem over the last 5 to 10 years.

The elicitation was performed for all sub-activities identified as potentially having an impact on the ecosystems in the South-east marine region but without reference to the overall magnitude of the activity/sub-activity in the South-east region because the elicitation is performed on a "per interaction" basis. This means that if the activity/sub-activity is not present or no longer present in the South-east region, then the results of the elicitation will not be applicable to this region. They will, however, be applicable in any subsequent national-scale analysis. The elicitation also does not account for any specific management rules in the South-east (e.g. Danish seine and trawl are prohibited in South-east marine parks) because the mitigative effects of management are considered separately during the prioritisation process (Section 5.1).

Figure 3.2 summarises the results of the vulnerability assessment for sub-activities identified by Parks Australia as manageable. Figure 3.3 summarises the results for sub-activities identified as unmanageable. The vulnerability score for each activity/sub-activity–ecosystem combination is obtained by multiplying the trophic impact score, on a scale 0 to 4, by the percent change score, from 0 to 100%. Hence the vulnerability score lies ranges from 0 to 4, where 0means that the ecosystem is not affected at all by interactions with the sub-activity, and 4 means that all of the underlying habitat, and the communities that this supports, that interacts with the sub-activity is damaged or removed.

The results suggest that shelf vegetated sediments (seagrass beds) are the most vulnerable ecosystem in the South-east marine region, to both manageable and unmanageable sub-activities, but as far as we are aware this ecosystem is not found within any of the south east marine parks, but as far as we are aware this ecosystem is not found within any of the south east marine parks. The results also indicate a general pattern of decreasing vulnerability with depth, in terms of the number of different sub-activities that are potentially harmful, and the magnitude of the ecosystem's vulnerability. This pattern can be seen, for example, moving along a depth gradient from mesophotic rocky reefs to rariphotic shelf reefs to mid-slope reefs and lower-slope reefs.

The most harmful manageable sub-activities vary by ecosystem, but prominent candidates include Danish seine, demersal trawl and mining operations in mesophotic rocky reefs (and to a similar extent in rariphotic shelf and mid-slope reefs); and anchoring, fish aggregating devices and moorings in shelf vegetated sediments. The most harmful unmanageable sub-activities include climate-change induced changes to ocean currents, the frequency and intensity of severe weather (cyclones and storm waves) and sea surface temperature in shelf vegetated sediments (and to a similar extent in unvegetated shelf sediments); and agricultural diffuse source run-off to rariphotic shelf reefs.

It is important to emphasise, however, that these results represent the opinions of a single expert (per ecosystem) and may therefore be idiosyncratic. Ideally this elicitation would be repeated in a workshop setting, and the results averaged across the contributions of multiple experts in each ecosystem. Travel restrictions prevented this from happening during this pilot study, but this is something that should be rectified into the future.

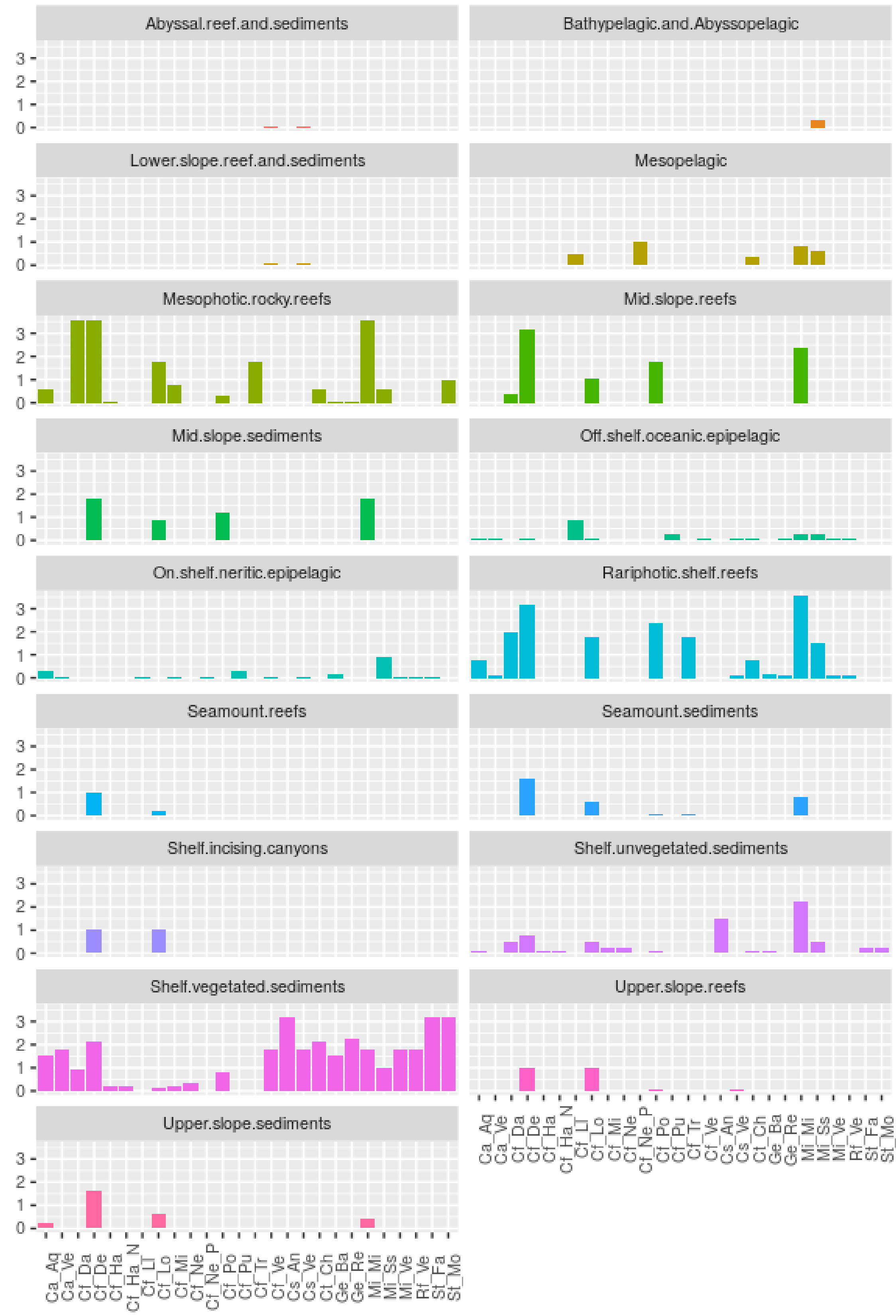

Figure 3.2: Summary of the vulnerability assessment for managed activity–sub-activity combinations. Figure shows the overall vulnerability score for the 13 benthic and 4 pelagic mapped ecosystems in the South-east AMP network, on a scale of 0 to 4, to the activity–sub-activities identified by Parks Australia as manageable. Identification codes for the sub-activities are described in Table 3.2.

Figure 3.3: Summary of the vulnerability assessment for unmanaged activity–sub-activity combinations. Figure shows the overall vulnerability score for the 13 benthic and 4 pelagic mapped ecosystems in the South-east AMP network, on a scale of 0 to 4, to the activity–sub-activities identified by Parks Australia as unmanageable. Identification codes for the sub-activities are described in Table 3.3

Table 3.2: Identification codes for activity/sub-activities identified by Parks Australia as manageable

Activity/sub-activity	**id**
Commercial_aquaculture_Aquaculture_including_commercial_pearling	Ca_Aq
Commercial_aquaculture_Vessel_transiting	Ca_Ve
Commercial_fishing_Danish_Seine	Cf_Da
Commercial_fishing_Demersal_trawl	Cf_De
Commercial_fishing_Longline_demersal_auto-longline	Cf_Lo
Commercial_fishing_Longline_pelagic	Cf_Ll
Commercial_fishing_Minor_line	Cf_Mi
Commercial_fishing_Net_demersal	Cf_Ne
Commercial_fishing_Purse_Seine	Cf_Pu
Commercial_fishing_Hand_collection	Cf_Ha
Commercial_fishing_Hand_net	Cf_Ha_N
Commercial_fishing_Pot_and_trap	Cf_Po
Commercial_fishing_Net_pelagic	Cf_Ne_P
Commercial_fishing_Purse_seine	Cf_Pu
Commercial_fishing_Trotline	Cf_Tr
Commercial_fishing_Vessel_transiting	Cf_Ve
Commercial_shipping_Anchoring	Cs_An
Commercial_shipping_Vessel_transiting	Cs_Ve
Commercial_tourism_Charter_fishing_tours	Ct_Ch
General_use_access_and_waste_management_Ballast_water_discharge_and_exchange	Ge_Ba
General_use_access_and_waste_management_Recreational_use_boating_including_vessel_transiting	Ge_Re
Mining_Mining_operations_including_exploration	Mi_Mi
Mining_Mining_seismic_survey	Mi_Ss
Mining_Vessel_transiting	Mi_Ve
Recreational_fishing_Vessel_transiting	Rf_Ve
Structures_and_works_Fish_aggregating_devices	St_Fa
Structures_and_works_Moorings	St_Mo

Table 3.3: Identification codes for activity/sub-activities identified by Parks Australia as unmanageable

Activity/sub-activity	**id**
Climate_change_Altered_ocean_currents	Cl_Al
Climate_change_Increased_frequency_and_intensity_of_severe_weather_events	Cl_In_cy
Climate_change_Increased_frequency_and_intensity_of_severe_weather_events	Cl_In_wa
Climate_change_Increased_Sea_Surface_Temperature_SST	Cl_In_mhw
Climate_change_Ocean_acidification	Cl_Oc_oa
Climate_change_Sea_level_rise	Cl_Se
Land-use_intensification_Agricultural_diffuse_source_runoff	La_Ag
Land-use_intensification_Point_discharges	La_Po
Marine_pollution_Light_pollution	Ma_Li
Marine_pollution_Marine_debris_including_microplastics	Ma_Md
Marine_pollution_Noxious_substances_including_chemicals_and_heavy_metals	Ma_No
Marine_pollution_Oil_fuel_spill_or_leak	Ma_Oi
Renewable_energy_Wave_tidal_and_wind	Re_Wa

3.2.4 Cumulative impact scores

The cumulative impact scores for the benthic ecosystems and pelagic ecosystems are shown in Figures 3.4 and 3.5 respectively. For benthic ecosystems, each raster 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.

Six of the 19 mapped benthic ecosystems do not occur within the AMPs in the South-east marine region - that is all of the coral reef ecosystems (shallow, mesophotic, oceanic mesophotic and intertidal), shallow rocky reefs less than 30m deep and islands including cays and islets. Cumulative impact scores for the remaining 13 mapped benthic ecosystems (Figure 3.4) reflect the general pattern of decreasing impact with depth evident in the vulnerability assessment (Figures 3.2 and 3.3) and the cumulative pressures (Figure 2.6). Other prominent patterns include relatively high impacts around seamounts, and slightly higher impacts across the continental shelf to the southeast, southwest and west of Tasmania, as compared to equivalent habitats to the northeast.

The pelagic ecosystem cumulative impacts show a similar depth pattern, with relatively higher impacts in shallower waters, although this also reflects the score averaging that occurs for the three offshore pelagic ecosystems.

3.2.5 Shiny app

The cumulative pressure scores (and ecosystem maps) have been made available in a web-accessible, user-modifiable, RShiny application https://shiny.it.csiro.au/SkipWoolley/parkspressureprofiles_v0.3/. The application is currently password protected and was designed to allow Parks Australia to visualise each of the individual ecosystem maps, the standardised pressure layers, and any combination of these pressure layers. Maintenance of this feature, however, is contingent on further discussion with Parks Australia regarding its utility and their ability to replicate its functionality within their own in-house systems.

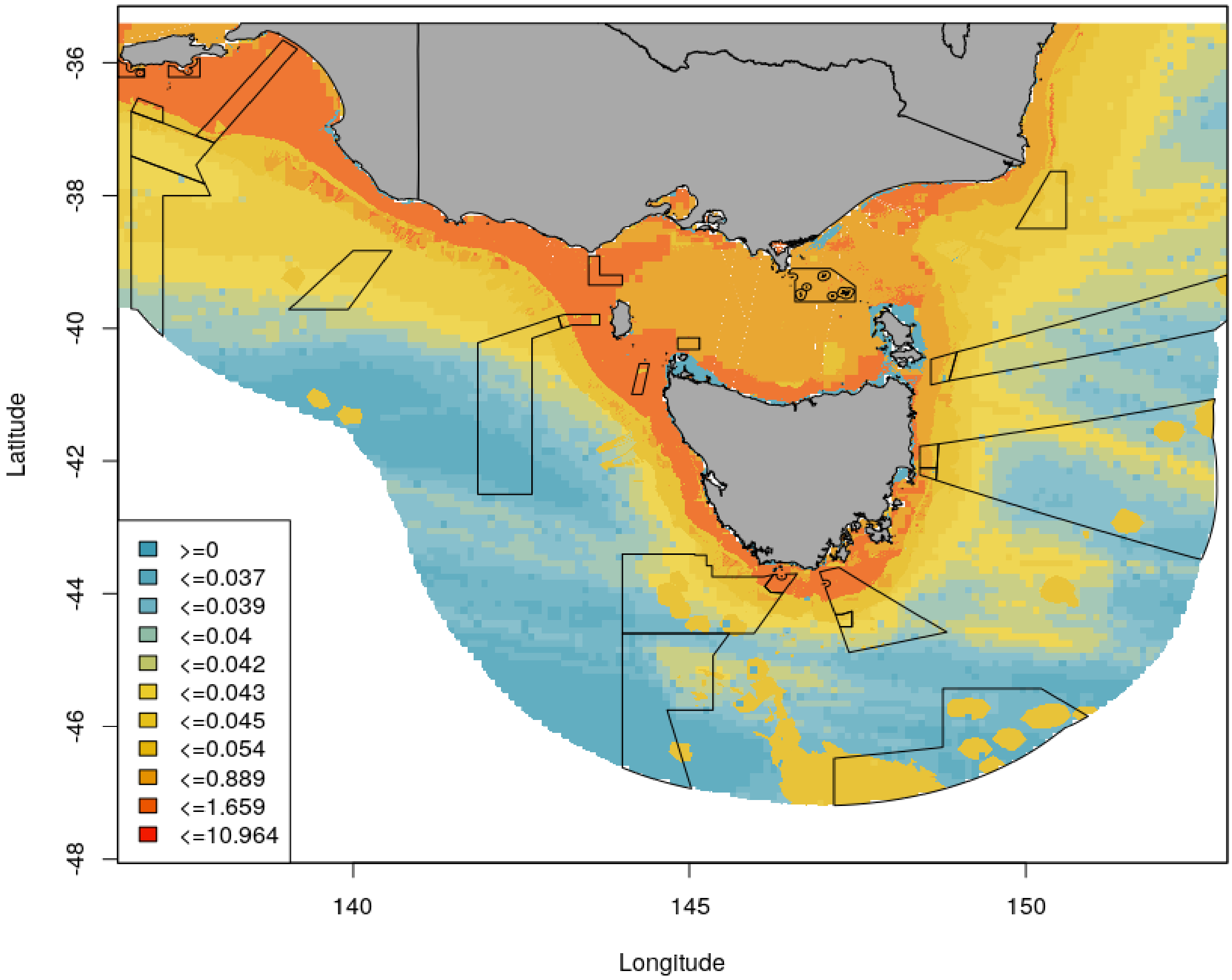

Figure 3.4: Cumulative impact map for benthic ecosystems in the South-east marine region, excluding Macquarie island. This figure shows the cumulative impact scores across the 13 mapped benthic ecosystems that occur in the AMPs in the South-east marine region. The cumulative impact score is calculated 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 map should be interpreted as showing the relative intensity of cumulative impacts in the South-east marine area. The absolute values of the scores have no ecologically meaningful interpretation. Scores for Macquarie island will be completed at a later date once the ecosystems in this region have been defined.

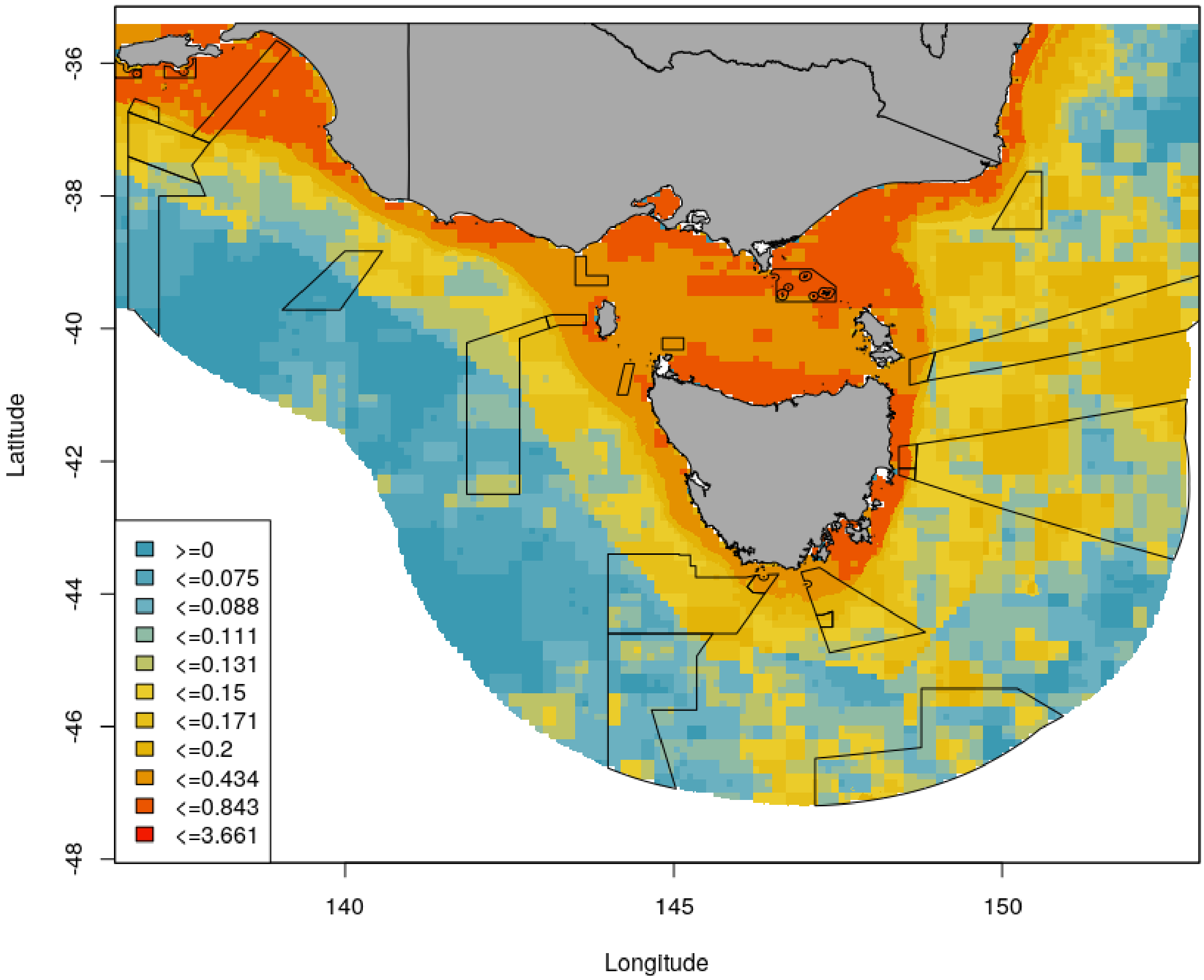

Figure 3.5: Cumulative impact map for pelagic ecosystems in the South-east marine region, excluding Macquarie island. This figure shows the cumulative impact scores across the 4 mapped pelagic ecosystems identified in the common language, together with the boundaries of AMPs in the South-east marine region. 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 map should be interpreted as showing the relative intensity of cumulative impacts in the South-east marine area. The absolute values of the scores have no ecologically meaningful interpretation. Scores for Macquarie island will be completed at a later date once the ecosystems in this region have been defined.

4 WHAT DOES SUCCESS LOOK LIKE?

4.1 Conservation goals

Conservation goals were developed for natural values identified as monitoring priorities for the SE Network, specifically for an ecosystem associated with a particular park zone. These goals and associated information (see Table 4.1 below) are intended to be SMART (Specific, Measurable, Achievable, Results-oriented, and Time-limited) (Conservation Measures Partnership, 2013) and clearly articulate what management is seeking to achieve for these values. These goals are intended to be specific to the natural values identified as monitoring priorities in each network and sit under the relevant national cross-cutting long-term outcome (10 years) in the AMP program logic, “The condition and trend of priority natural habitat, species and communities in AMPs has been maintained or improved”. Conservation goals, along with monitoring questions and evaluation questions will help frame the evaluation of management effectiveness.

Time frames associated with conservation goals are based on the following approaches:

1. Where the goal indicates that condition of the natural value will improve as a result of management, the time frame is intended to be ecologically meaningful. For example, sessile invertebrates damaged by demersal trawl may take decades to recover so an ecologically meaningful time frame might be 30 years.
2. Where the goal indicates that condition of the natural value will be maintained as a result of management, the default time frame is until the end of the management planning cycle. In the case of the SE Network, the current management planning cycle is coming to an end (i.e., 2023) so for this network the default time frame is until the end of the next 10-year management planning cycle (i.e., 2033).

Table 4.1: Example conservation goal and associated information for one of the monitoring priorities in the South-east network (mesophotic rocky reefs in the Flinders Multiple Use Zone).

Conservation goal: *Maintain or improve the condition of species and communities associated with mesophotic rocky reefs ecosystems in the South-east Marine Parks Network.*					
Park	Zone	Current condition	Goal	Time-frame	Ecosystem components
Flinders	MUZ	To be informed by the SE evaluation	Improve (following the end of demersal trawling in 2007)	2037	Low profile reef species[9]: • Benthic and cryptic fish • Demersal fish • Macroalgae • Sessile invertebrates • Mobile macroinvertebrates
			Maintain	2033	• Demersal fish (commercially targeted minor line species) • Mobile macroinvertebrates (rock lobster)

[9] Trawling is only likely to occur on low profile areas of mesophotic rocky reef

5 WHAT SHOULD WE MONITOR?

5.1 Prioritising locations for monitoring

5.1.1 Prioritisation process overview

The monitoring program for natural values and pressures in the marine parks is largely driven by management priorities and the need for Parks Australia to assess management effectiveness. The steps outlined to this point in the report, particularly identifying "what is the most important for management" covered in Section 3, helps marine park managers narrow down where monitoring efforts should be focused. The outputs from these steps have helped to identify the following:

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 historic impacts).
2. Pressures or biophysical drivers that are less responsive to management that are expected to influence and be important considerations when assessing management effectiveness (e.g. climate change).
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).[10]

An additional process for further refining monitoring priorities was broken down into four levels (Figure 5.1). Each level of prioritisation further refined the list of monitoring locations until a very targeted list was achieved.

1. 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.
2. Level 2 was focused on ensuring there was adequate representation of key features or areas in the priority list of monitoring sites.[11] 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.
3. Level 4 was an optional step which 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.

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

[10] Monitoring design is beyond the scope of the SS2 and D7 projects. This will be determined separately as part of the AMP Science Program and will depend on conservation goals and monitoring questions.

[11] Once science plans have been developed for the other networks and the Coral Sea Marine Park, this step may be undertaken at a national level to ensure characteristic values or features are represented as far as possible.

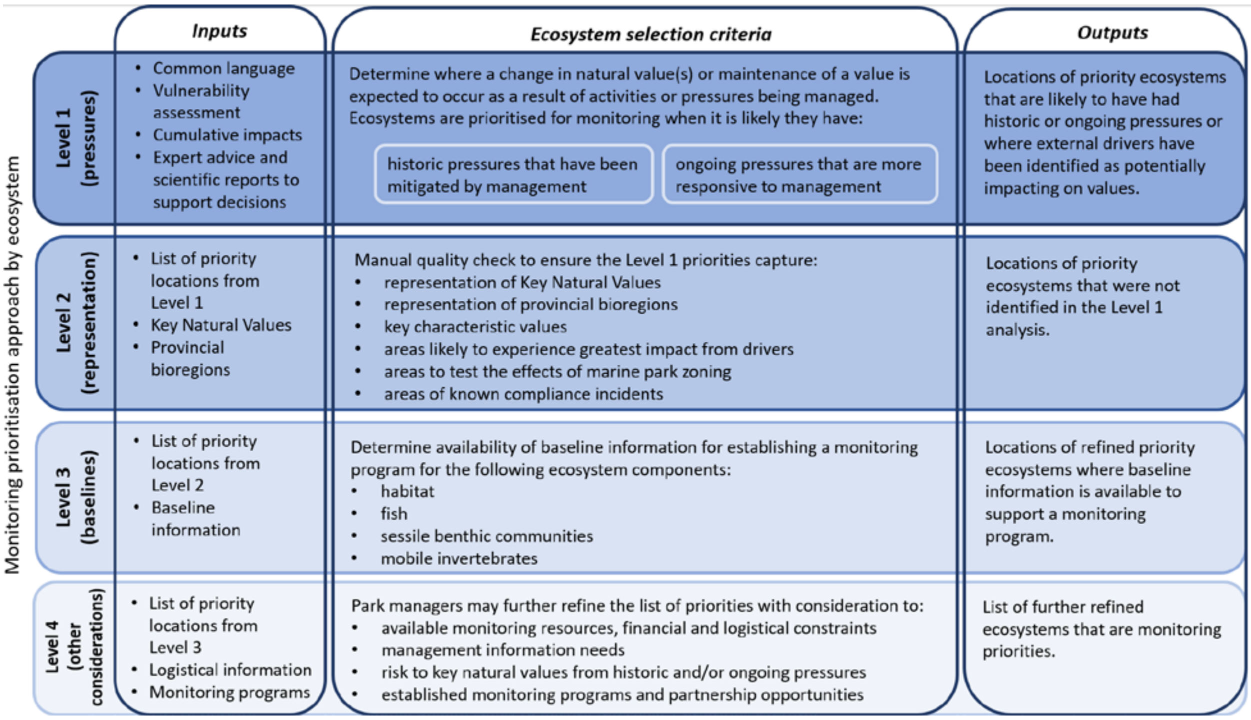

Figure 5.1: Monitoring prioritisation process for natural values and pressures. This figure shows the inputs, selection criteria and resulting outputs from running each level of the process.

5.1.2 Level 1 prioritisation (pressures)

The first step in the prioritisation focused on identifying where there were historic or ongoing pressures for individual ecosystems. This involved collating a list of all individual ecosystems present in the South-east network by marine park and zone (e.g. multiple use, habitat protection, recreational use zones etc.), of which there are 187 combinations. A value of 1-3 (see value category descriptions below) was then assigned to each of these ecosystem/zone combinations against two criteria (Table 5.1).

The criteria highlight where we predict a response to management, and locations where ongoing pressures are occurring and monitoring is necessary to ensure that the zone's objectives are being met (this also helps to inform the development of conservation goals, which should be consistent with zone objectives).

The methodology for determining a value against each of the criteria is dependent on the period of data used in the cumulative impact (CI) assessment and the history of management arrangements within the marine park. Ideally the CI assessment would cover periods immediately prior to and post management coming into effect to account for both ongoing and historic pressures. In the case of the South-east pilot, most of the available data used in the CI assessment is from 2011-2015. As this covers the period after the parks were declared and management arrangements were in effect, the CI assessment identifies likely ongoing pressures (criteria B), or those occurring following implementation of activity rules in the South-east network.

Table 5.1: Ecosystems by zone were assessed against two criteria: A) where there was historic pressure that has been mitigated by a change in management arrangements, and B) where there are ongoing pressures form activities that are permitted, but which are responsive to management. Each of these criteria was assessed against three assessment categories.

Level 1 ecosystem/zone selection criteria
Criteria A: Historical pressure that was acting on the ecosystem has been mitigated by management Criteria B: Current pressures (that are responsive to management)
Criteria assessment categories
(1) No: no pressure existed or exists; pressure is less responsive to management (e.g. climate change); status of pressure remained the same after marine park declared (criteria A only); not identified in the cumulative impact (ci) assessment (criteria B only); or ciMean <0.01 (criteria B only). (2) Possibly: information suggests some pressure existed or exists (resolution of data unable to determine with certainty); pressures somewhat responsive to management. (3) Likely: highly likely that pressure existed or exists; cumulative impact assessment identified high relative pressure (criteria B only); pressures responsive to management (criteria B only).

5.1.3 Assigning values to criteria A

Determining a value for criteria A against each ecosystem/zone combination, in the absence of a cumulative impact assessment for the period prior to park proclamation, the project team considered historic activities that are no longer allowed in the parks. Expert advice and scientific reports were used to identify where those activities had been occurring.

In the South-east network, commercial fishing and mining were identified as the main activities likely to have been impacted by the proclamation of the parks in 2007 (see Appendix A). There were three commercial fishing gear types that were no longer allowed to be used within the South-east network, including demersal trawl, Danish seine and scallop dredge. A qualitative analysis was undertaken using historical fishing information from 2001-2006, the period immediately prior to the South-east marine parks being proclaimed in 2007. Mining was prohibited in IUCN II and Ia marine park zones in 2007 and based on limited available information, much of the activity occurred in zones where it continues to be allowed (subject to authorisation) and therefore is not considered a historic pressure. It's possible that historical mining activities may have been undertaken in some marine parks where they are no longer allowed (e.g. Murray Marine Park multiple use and national park zones). Further analysis is required for any future pressure analysis.

5.1.4 Assigning values to criteria B

The cumulative impact scores for activities/sub-activities most responsive to management (those categorised as 'Allowed' or 'Authorisation required') were used to inform a value for criteria B. Each ecosystem/zone combination were assigned a value of 1 ('No') if the sub-activity ciMean score was low, 2 ('Possibly') if it was medium, and 3 ('Likely') if it was high where low, medium and high scores were identified by using the tertiles of the scores across the South-east Network. The values were adjusted up or down to account for expert knowledge or finer scale data not available to the ciMean calculations.

When applying this process to the remaining AMP networks, it's anticipated that criteria A will be answered using the CI assessment which uses historic data from before the majority of parks were managed in 2018. The data can be filtered to show those activities categorised as ‘Not allowed’ which will give an insight into where we are likely to see a change. The CI assessment can also be used to inform scoring of criteria B by filtering the data to show activities that are ‘Allowed’ or ‘Authorisation required’, although a literature review will help to validate current pressures under the current management arrangements.

A quality check was conducted after the initial scoring against both criteria where issues and knowledge gaps were flagged for further investigation. This allowed review of technical reports that provided finer scale information on pressures and where necessary, original values were adjusted with justification recorded. When this process is undertaken for the remaining networks and the Coral Sea Marine Park, it is anticipated that a literature review will be completed in the MERI pre-requisite stage before undertaking the prioritisation process. This will help to identify information sources that can inform pressure identification and feed into the cumulative impact assessment process.

5.1.5 Issues with the data

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.

Occasionally the ciMean score for a manageable activity/pressure did not align with expert knowledge (further supported by scientific reports) or finer-scale data not included in the analysis. Where further and/or finer-scale information existed, the value assigned to the ecosystem/zone reflected this knowledge and the reason for the value was recorded. For example, the broad pressure data for lobster fishing (broader than underlying raster for privacy reasons) used in the analysis, indicated that this fishing activity occurred in rariphotic reefs in the Freycinet MP. Alternatively, fine-scale lobster fishery data obtained from Institute of Marine and Antarctic Studies indicated no pot and trap fishing in this ecosystem. In this instance, the value for criteria B was decreased to reflect this knowledge. Similarly, where a pressure was thought to exist but did not appear in the CI assessment, it was flagged for further investigation and values adjusted accordingly once confirmed.

5.1.6 Level 1 results for the South-east Network

A total of 34 zone/ecosystem combinations across the South-east Network were identified as high priority monitoring locations. 18 of these locations are zone/ecosystem combinations where change is expected as a result of management (criteria A). 19 of these locations are where high pressure is expected to continue under the current management arrangements (criteria B). Three of these locations are where both historic and ongoing pressures are likely to exist.

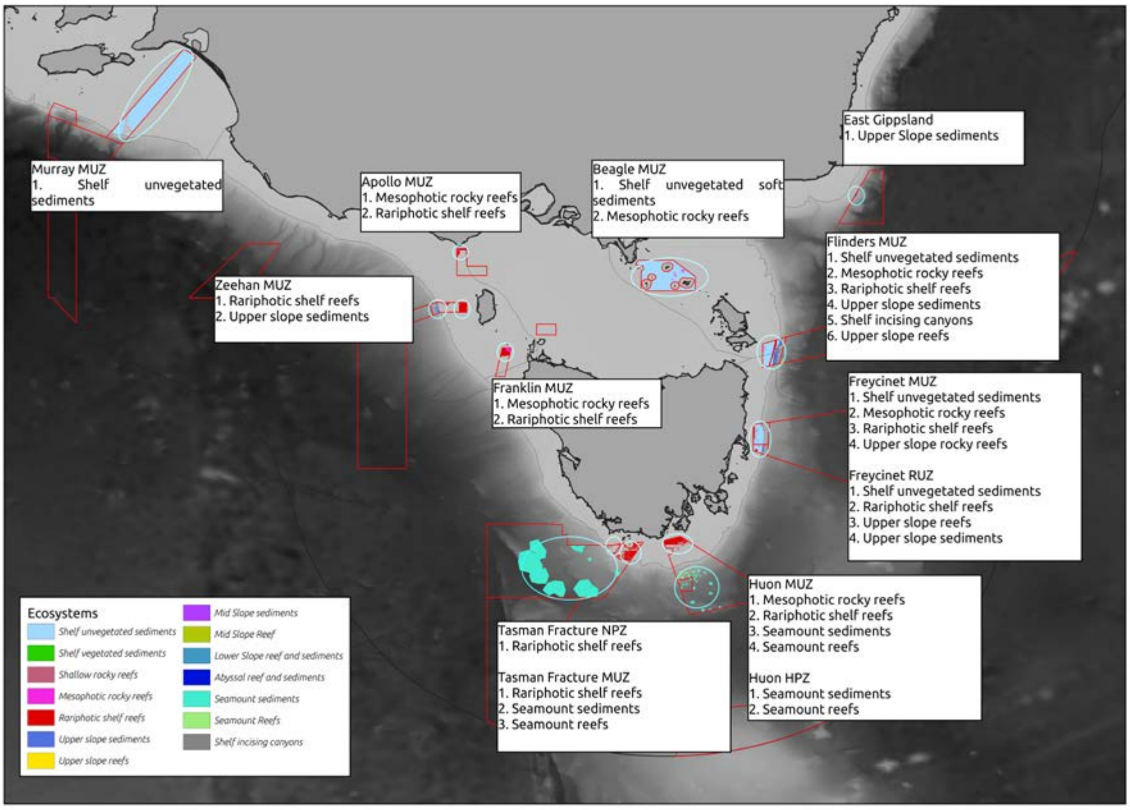

Figure 5.2: Zone and ecosystem monitoring priorities in the South-east marine parks. The figure shows the zones and ecosystems identified as the highest priority for monitoring following a two-stage prioritisation process. The first stage scored all zone/ecosystem combinations in the South-east against the questions: (a) do we expect to see a change as a result of management; (b) are there current manageable high level pressures; and (c) are unmanaged pressures impacting our ability to assess management effectiveness or meet objectives. Locations ranked as a high priority following this stage were further ranked based on the presence of KNVs, logistical considerations and the availability of baseline data.

5.1.7 Level 2 prioritisation (representation)

Following the Level 1 analysis, all those ecosystem/zone combinations that were assigned a value of 3 ("Likely") against either criteria were collated into a single list of priorities for monitoring. The Level 2 prioritisation manually checked this short-list of monitoring priorities to ensure the priorities capture:

1. Representation of Key Natural Values.
2. Representation of provincial bioregions.
3. Key characteristic values.[12]
4. Areas likely to experience greatest impact from drivers.[13]
5. Areas to test the effects of marine park zoning.

[12] Key characteristic values are those ecosystem components that represent a large component of the area within marine parks of each network. For example, shelf unvegetated soft sediments are a large component of the marine parks in the SE Network.

[13] For those locations identified as monitoring priorities in Level 1, the CI scores were reviewed to determine whether external drivers have the potential to impact for those locations identified as monitoring priorities and therefore our ability to assess management effectiveness (e.g. climate change).

6. Areas with known history of ongoing (rather than one-off) compliance incidents (to monitor the effects of non-compliance on park values).

Including a manual step like Level 2 this in the process allows Parks Australia to use a criteria-based approach (informed by MERI pre-requisites and other information) to address other key considerations when refine monitoring priorities, which were not considered as part of level 1 (largely informed by the cumulative impact assessment). Analysis of the Level 1 outputs in the South-east Network identified that these requirements had been met and no manual adjustments were required.

5.1.8 Level 3 prioritisation (baselines)

The Level 3 prioritisation involved assessing the availability of adequate[14] baseline information for areas identified through the Level 2 prioritisation, to form the basis of a long-term monitoring program. To determine monitoring priorities for AMPs, the Level 3 prioritisation identifies those ecosystems (identified following level 2 prioritisation) where adequate baselines are available for the specific ecosystem component (see example at Table 5.2).

Table 5.2: 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.

Ecosystem	Park	Zone	Pressure	Ecosystem component impacted	Baseline			
					H	F	BC	MI
Mesophotic rocky reefs	Flinders	Multiple Use Zone	Historic & 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 = adequate15, IA= inadequate16.								

The foundation and minimum requirements for a monitoring program are:

1. Habitat mapping to validate the presence of ecosystems from modelled data (i.e. national reef model). This also provides further clarity on the ecosystem components likely to exist (see common language).
2. An initial ecological (inventory) survey such as baited remote underwater video (BRUV), visual census, autonomous underwater vehicle (AUV) surveys to provide additional information about ecosystem components and to help inform monitoring design (e.g. inform a survey design).

For priority ecosystems where baselines are inadequate for one or more ecosystem components, that ecosystem component may still be included as a monitoring priority, but these priorities will also feed into the research prioritisation process with an aim of building a foundational understanding prior to establishment of an ongoing monitoring program.

[14] Defined as sufficient habitat mapping and inventory surveys to characterise the specific ecosystem component
[15] Adequate: sufficient habitat mapping and inventory surveys to characterise the specific ecosystem component
[16] Inadequate: insufficient habitat mapping or inventory surveys to characterise the specific ecosystem component

There was a total of 21 zone/ecosystem combinations across the South-east network identified as having adequate baselines to form the basis of a long-term monitoring program (Figure 5.3).

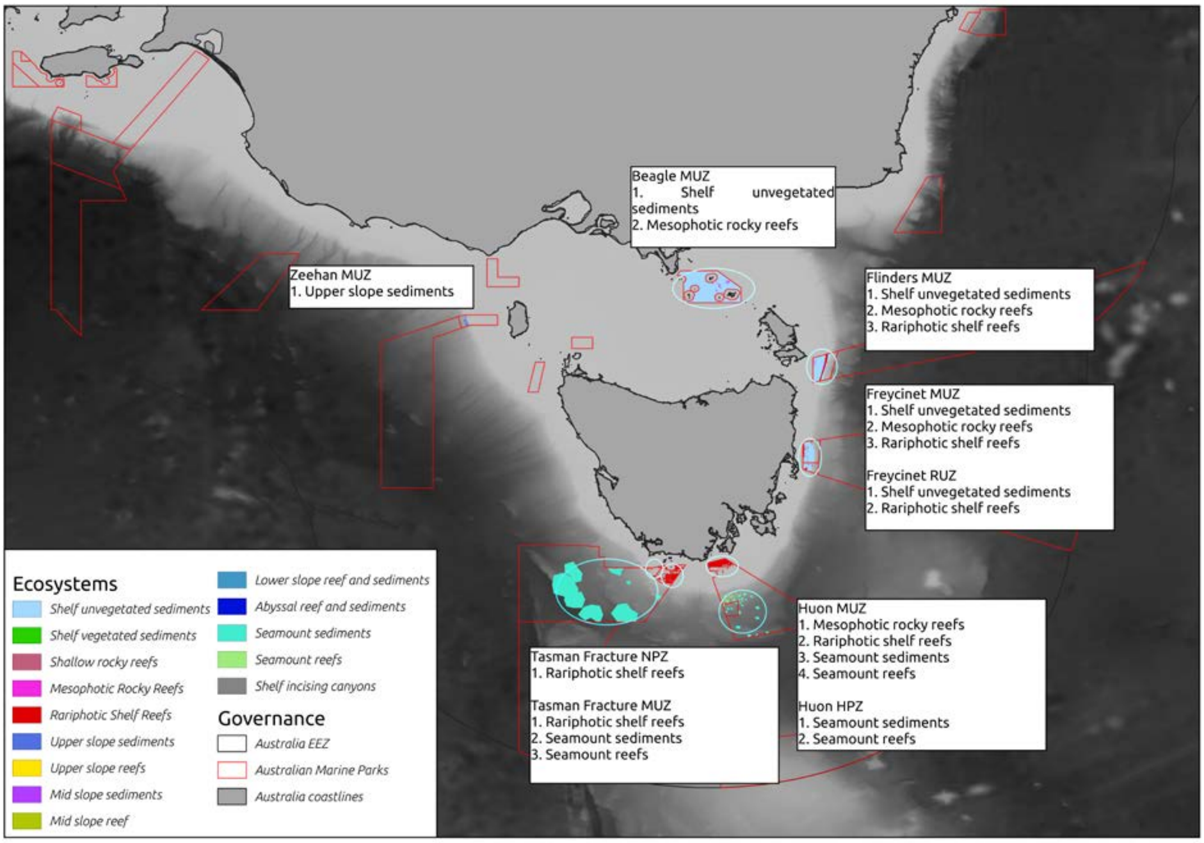

Figure 5.3: Zone and ecosystem monitoring priorities with adequate baselines in the South-east Network. The figure shows the highest priority monitoring locations with adequate baselines following the Level 3 prioritisation (baselines) process.

5.1.9 Level 4 prioritisation (other considerations)

The final level of prioritisation is optional and dependent on how feasible it is to monitor the resulting list of priorities from the Level 3 prioritisation process. If the list of priorities from Level 3 are able to be monitored over the life of the management plan, this step may not be required. Level 4 is a subjective process best undertaken in close consultation with park managers who have a good understanding of any ongoing research/monitoring programs, logistical constraints of operating in marine parks and partnership opportunities. Consideration should also be given to prioritising monitoring sites where it is possible to test the effects of marine park zoning and where key natural values are likely to have been impacted by historic pressures or likely to be impacted by ongoing pressures.

Logistical efficiencies can be gained when monitoring multiple locations using similar methodologies within the network. For example, if mesophotic rocky reef mobile invertebrate communities appear as a priority in Huon and Tasman Fracture Marine Parks, then cost efficiencies could be gained by combining these surveys together in a single voyage. Further logistical considerations are outlined in Table 5.3.

Selection of ecosystems in this level of prioritisation also considers maintaining representation of ecosystems across provincial bioregions as with the Level 1 prioritisation. Consideration should also be given to monitoring sites likely to experience the greatest impact from drivers as a way of determining the impact on Parks Australia's ability to meet marine park objectives. Figure 5.4 represents an example of the Level 4 outputs for the South-east Network and illustrates the refined priority ecosystems that are feasible to monitor in the South-east Network. These will be finalised and documented in the South-east Marine Parks Science Plan currently in development by Parks Australia.

Table 5.3: Further logistical considerations when identifying monitoring priorities.

Logistical considerations	Details
Accessibility of vessels	Site access possible using easily accessible vessels or vessel availability subject to (i) application process; and (ii) vessel schedule for partner organisations
Travel time to site	Survey location with regards to distance from port and speed of vessel typically used to access site.
Vessel and crew costs	Costs ranging from $4,000-$25,000+ per day
Weather conditions	Limited, moderate or good weather windows

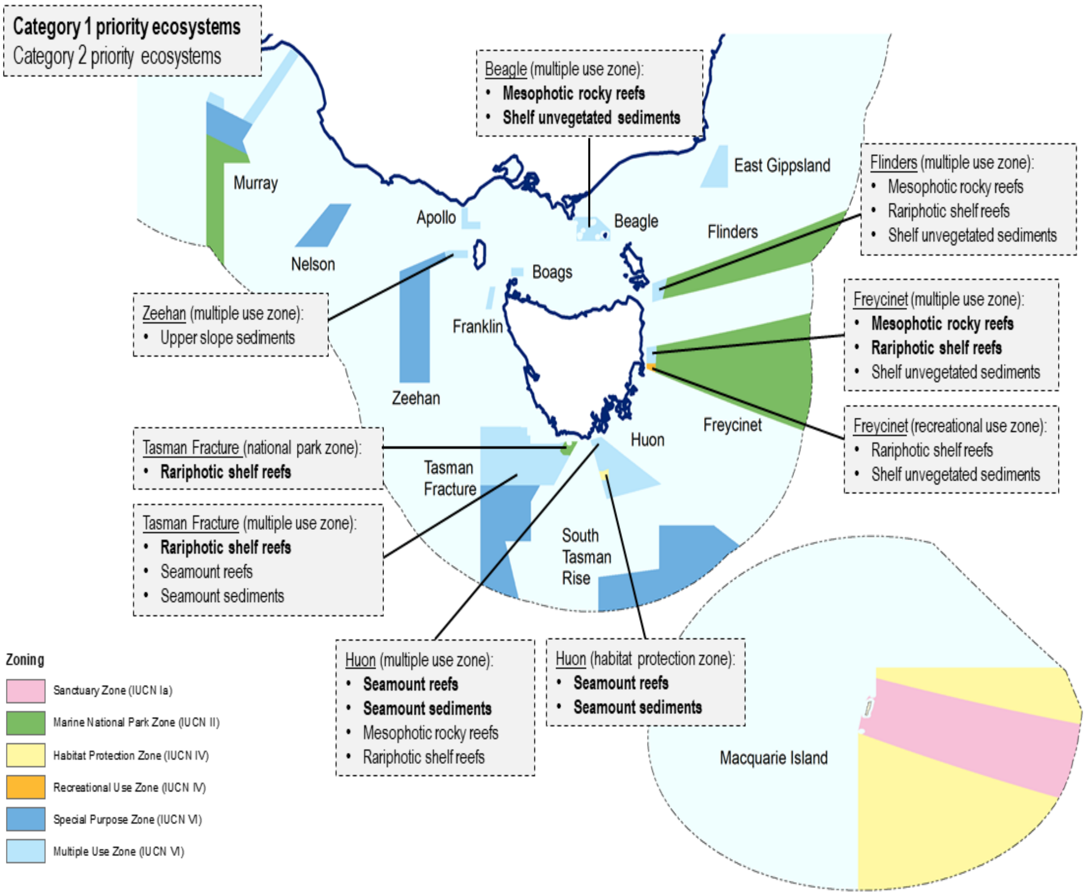

Figure 5.4: Example output from the Level 4 prioritisation (other considerations) process for the South-east Network. The figure shows the draft list of priority locations that will be a focus for monitoring. The South-east Marine Parks Science Plan is currently in development by Parks Australia and will include a final list. There are currently 10 Category 1 (primary) priority ecosystems (bold text) and 11 Category 2 (secondary) priority ecosystems (regular font).

5.2 Monitoring questions

Evaluating the effectiveness of marine park management will draw on the information collected through monitoring. Parks Australia has developed evaluation questions to help focus the monitoring in AMPs (see Table 1.1). The Key Evaluation Questions (KEQs) (and associated Specific Evaluation Questions) and conservation goals provide the basis for establishing monitoring questions as they identify what needs to be monitored to inform the evaluation of management arrangements (Table 5.4).

Monitoring questions were developed for ecosystems identified as priorities and their relevant ecosystem components that were subject to impact from pressures responsive to management. Monitoring questions help to focus monitoring efforts on those ecosystem components most likely to result in a change (positive or negative) as a result of management as informed by the cumulative impact assessment, and also help to inform monitoring design (beyond the scope of SS2 and D7).

5.3 Indicator identification

Potential high-level indicators were identified for each of the monitoring priorities in the SE Network (see Table 5.5). Indicators have been identified for natural values to help assess condition, as well as for pressures or relevant biophysical drivers to help assess status of pressures and their impacts on natural values. In many cases these may overlap with general condition indicators (see Table 5.6).

Where it isn't possible to monitor pressures or biophysical drivers directly, then only indicators to assess impact on affected or targeted natural values were identified. For example, it may be possible to directly monitor invasive species as a pressure (indicators may include abundance, population distribution etc.), while it may not be possible to directly monitor anchoring (in which case we may monitor anchor damage, which may include indicators such as number and/or area of anchor "scars").

High-level potential indicators were informed by ecosystem conceptual models developed by Parks Australia and a review of approaches used for MPAs in other jurisdictions, and checked for consistency with Global Ocean Observing System (GOOS) framework for global observation, and Essential Biodiversity Variables developed by the Group on Earth Observations Biodiversity Observation Network (GEOBON). Indicators were also broadly considered against a set of indicator selection criteria based on a review of national approaches (Table 5.7, informed by Hayes et al., 2015). More detailed measures and metrics will be considered as part of the delivery of the AMP Marine Science Program, and will be based on previous research and monitoring in the AMPs, other jurisdictions etc., and it is anticipated that these will be assessed more rigorously against the indicator criteria mentioned above.

Table 5.4: Template for developing monitoring questions based on Key Evaluation Questions (KEQs).

Natural values monitoring questions **Key Evaluation Questions:** **To what extent was the condition and trend of natural values in AMPs in a desirable state in relation to zone objectives?** **How did park management influence the condition of natural values?**		
	Template text	South-east monitoring question examples
Historic pressures	Has the condition of [ECOSYSTEM] [ECOSYSTEM COMPONENT/S] communities in [MARINE PARK NAME AND ZONE] improved by [YEAR] following the end of [ACTIVITY] in [NETWORK] marine parks, having regard to impacts from drivers, in particular climate change?	Has the condition of mesophotic rocky reef sessile invertebrate and macroalgal communities in Flinders MP MUZ improved by 2037 following the end of demersal trawling in SE marine parks, having regard to impacts from drivers, in particular climate change?
	Where the ecosystem appears in multiple zones and has been identified as a priority in both zones: Does the rate of recovery of [ECOSYSTEM] [ECOSYSTEM COMPONENT/S] communities in [MARINE PARK NAME AND ZONE] differ between [X and Y] zones?	Does the rate of recovery of seamount reefs demersal fish and mobile invertebrate communities in Huon MP differ between the multiple use and habitat protection zones?
Ongoing pressures	Is the condition of [ECOSYSTEM] [ECOSYSTEM COMPONENT/S] communities in [MARINE PARK NAME] maintained, consistent with [ZONE OBJECTIVE] over time?	Is the condition of mesophotic rocky reef fish and mobile invertebrate communities in Flinders MP maintained, consistent with ecological sustainable use[17] over time?
	Where the ecosystem appears in multiple zones and has been identified as a priority in both zones: Does the condition of [ECOSYSTEM] [ECOSYSTEM COMPONENT/S] communities in [MARINE PARK NAME] differ between [X and Y] zones?	Does the condition of upper-slope rocky reef fish and mobile invertebrate communities in Freycinet MP differ between the multiple use and recreational use zones?
Pressures and drivers monitoring questions **Key Evaluation Question:** **To what extent were pressures and/or their impacts on AMP values minimised or maintained at acceptable levels?**		
Historic pressures	To what extent is [NON-COMPLIANT ACTIVITY] affecting our ability to protect and conserve natural values in [MARINE PARK NAME AND ZONE] [ECOSYSTEM]?	N/A for South-east Network – monitoring questions only required where there is a known high occurrence of illegal activity (e.g. illegal recreational or commercial fishing).
Ongoing pressures	What is the trend in [PRESSURE] in [MARINE PARK NAME AND ZONE] [ECOSYSTEM] over time?	What is the trend in commercial fishing catch and effort in Flinders MP MUZ mesophotic rocky reefs over time?
	Where drivers identified as likely to impact ability to assess management effectiveness: To what extent is [DRIVER] affecting our ability to protect and conserve natural values in [MARINE PARK NAME AND ZONE] [ECOSYSTEM]?	To what extent is climate change affecting our ability to protect and conserve natural values in Flinders MP MUZ mesophotic rocky reefs?

[17] Use of the natural resources within their capacity to sustain natural processes while maintaining the life-support systems of nature and ensuring that the benefit of the use to the present generation does not diminish the potential to meet the needs and aspirations of future generations (EPBC Act).

Table 5.5: Natural value indicators.

SEQ	Category	Potential indicators
2.1 To what extent was the condition and trend of key natural values in AMPs in a desirable state in relation to zone objectives?	Fish assemblages	Biomass (kg)
	Fish assemblages	Abundance (# individuals)
	Fish assemblages	Size (length)
	Fish assemblages	Diversity (# species)
	Fish assemblages	Areal extent of population (m2)
	Mobile invertebrate assemblages	Biomass (kg)
	Mobile invertebrate assemblages	Abundance (# individuals)
	Mobile invertebrate assemblages	Size (length)
	Mobile invertebrate assemblages	Diversity (# species)
	Mobile invertebrate assemblages	Areal extent of population (m2)
	Habitat forming species	Abundance (# individuals)
	Habitat forming species	Diversity (# species)
	Habitat forming species	Cover (% total area)
	Habitat forming species	Areal extent of population (m2)
	Marine megafauna (excl. fish and invertebrates)	Biomass (kg)
	Marine megafauna (excl. fish and invertebrates)	Abundance (# individuals)
	Marine megafauna (excl. fish and invertebrates)	Size (length)
	Marine megafauna (excl. fish and invertebrates)	Diversity (# species)
	Marine megafauna (excl. fish and invertebrates)	Areal extent of population (m2)

Table 5.6: Potential pressure indicators for SEQs.

SEQ	Category	Potential indicators
5.1 To what extent were pressures and/or their impacts on AMP values minimised or maintained at acceptable levels?	Climate change	Ocean acidity (pH)
	Climate change	Sea level (cm)
	Climate change	Sea surface temperature (°C)
	Climate change	Air temperature (°C)
	Climate change	Salinity (g/kg)
	Climate change	Frequency and intensity of severe weather events (e.g. wave height)
	Climate change	Ocean currents (chlorophyll A)
	Changes in hydrology	Turbidity
	Changes in hydrology	Nutrient levels (TN, TP, nitrate)
	Changes in hydrology	Ballast exchange (volume)
	Extraction of resources	Annual trends in commercial fishing activity in AMPs (volume of catch; hours of effort; catch per unit effort)
	Extraction of resources	Annual trends in charter fishing activity in AMPs (# active authorised operators; # trips; # visitors)
	Extraction of resources	Annual trends in recreational fishing activity in AMPs (# active authorised operators (TE only))
	Extraction of resources	Compliance incidents (# incidents reported; # investigations; # administrative actions; # successful prosecutions and litigations)
	Habitat modification	New infrastructure (# and areal extent)
	Habitat modification	Presence of habitat 'scars' (# and size - from propellers, anchors etc.)
	Human presence	Visitation rates (# operators, #trips, # visitors to sensitive areas, such as CSMP islands and cays)
	Human presence	Vessel noise (kHz)
	Invasive species	Presence of marine pest species (density, abundance)
	Invasive species	Presence of pathogens / disease
	Marine pollution	Frequency and extent of pollution incidents (e.g. oil spills)

Table 5.7: Selection criteria used to inform selection of potential indictors.

Key indicator needs
1. There are clear links to management (conservation) outcomes.
1a Relevance / application to AMP system issues (national).
1b Relevance to regional / network / local issues.
2. Feasible, cost effective, information benefits outweigh data collection and analysis costs.
3. Strong scientific and conceptual basis, based on well-defined / validated links.
4. Ecologically significant, reflects on a fundamental process or highly valued aspect of the ecosystem.
5. Sensitive to changes and pressures within policy / management relevant time frames.
6. Known / predictable responses to pressures, discriminatory, able to disentangle the effect of other factors.
7. Predicts changes that can be averted by management action.
8. Responsive, provides quick and reliable feedback on the effects of management intervention.
9. Easy to measure repeatedly / established protocols are available.
10. Has good statistical properties that allow unambiguous interpretation, low variability in response.
11. Compatible with indicators developed and used in other Australian Marine Parks, State Marine Parks and State of the Environment Reporting where possible.

6 DISCUSSION AND RECOMMENDATIONS

6.1 MERI system

Modern environmental management regimes are moving towards frameworks that are adaptive, integrated and place-based, in response to the mounting pressures imposed on environmental systems by multi-sector activities and climate change. These modern frameworks require several key pieces of information

- where do different habitats and ecosystems occur, and what species do they contain?
- where do anthropogenic activities occur and what is the cumulative effect of these activities on the ecosystems in which they operate?
- how effective are our management activities on protecting these ecosystems and ensuring the sustainability of the services they provide?

The MERI system described here represents a significant enabling-step towards such a regime. 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. The completion of this project, and the development of Standard Operating Procedures (SOPs) for environmental monitoring, developed previously by the hub https://marine-sampling-field-manual.github.io/, provides Parks Australia with all the pieces of information necessary to start this process in the South-east marine regime.

6.2 Learnings from the South-east pilot

The SS2 and D7 projects were conducted on a pilot scale in the South-east Network in order to trial the processes developed for prioritising monitoring, and provide an opportunity for reflection and learning, before rolling the process out nationally. During the course of the SS2 and D7 projects a number of issues were encountered around the availability of habitat mapping products, the availability and resolution of activity/sub-activity pressure data, some (relatively) minor aspects of the common language and the location of KNVs. Recommendations for addressing each of these specific issues are provided here and in the next section.

Two of the most critical data gaps encountered during the South-east Network pilot were recreational fishing effort and the location and extent of all three types of shelf reefs (shallow, mesophotic and rariphotic). Significant effort should be put into both. Accurately located ecosystems, particularly functionally important hard substrates, is an important pillar of the monitoring prioritisation process. A standard to analyse and integrate ecosystem information, building off the existing work described in Section 9, could be developed and incorporated into the iterative improvement of the MERI system. Further recommendations in this context are provided in the next section.

The remote vulnerability assessments proved to be one of the most significant difficulties encountered during the South-east Network pilot. As noted previously this was ultimately abandoned in favour of individual interviews with local experts. These individual interviews were more successful but were time consuming and because of COVID-related travel restrictions resulted in only a single expert response for each of the ecosystems in the South-east Network.

As part of the reflection process we also assessed the cumulative impact assessment, and the other steps in the monitoring prioritisation process, against the checklist described in the "Guidelines for Cumulative Impact Assessment" (Dunstan et al., 2019). This identifies a number of points in cumulative impact assessment process where improvements could be made. In particular, the current approach does not allow for non-linear or indirect impacts. Methods currently exist to develop informative prior estimates of cumulative impact that do allow for these types of interactions, and these could be further explored with Parks Australia. Importantly these informative priors can be coherently updated using the outputs of a monitoring program, and hence provide an explicit link between the monitoring program and the iterative improvement of the impact assessment within the MERI system. Again, further recommendations in this regard are provided below.

6.3 Recommendations

Before completing the MERI-prerequisites and monitoring prioritisation steps for the remaining marine regions outside the South-east, we recommend that Parks Australia and the D7/SS2 project teams consider the following recommendations:

6.3.1 Common language

- Parks Australia should modify the common language to separate construction from operation of pipelines/cables. Pipeline/cable construction causes much more significant environmental impacts than operation. Keeping both aspects coupled within the same sub-activity will likely lead to significant over-estimates of the impacts associated with existing pipelines. This occurred in the South-east pilot and for this reason this sub-activity was removed from the cumulative impacts analysis. Parks Australia should also consider whether it is necessary to maintain artificial reefs, pipelines and cables as a separate ecosystem in the common language.

6.3.2 Natural values and KNVs

- Any future national MERI project will need to create map layers for the following ecosystems: beaches, intertidal coral reefs, islands (including cays and islets) and rocky shores. These ecosystems do not occur within the south-east marine region hence the absence of these layers has no effect on the analysis completed to date. These ecosystems do, however, occur in the other marine regions and will need to be developed as a matter of priority.

- Gather additional habitat observations and increase the testing and validation of new and existing habitat models to improve their reliability, and where possible allow expressions of uncertainty, especially where there is doubt around presence/extent of ecosystems and KNVs. For example, rock lobster are listed as a KNV in the Beagle AMP but were not observed in a recent survey of the park.

- Options to encourage future surveys in AMPs to provide information on the location and extent of shelf reefs should also be explored.

- To ensure that the most comprehensive assessment of KNVs in a network is obtained, there should be an attempt to ensure that experts on all the ecosystems in the AMPs in a network are consulted and given the opportunity to identify KNVs. The KNVs should be linked to one or more ecosystems.

- There is a clear link between the ecosystems described in common language and the IMCRA bioregions, as described above. The ecosystems describe the functional parts of the AMP networks but do not describe the biodiversity. Considerations should be given to updating IMCRA to ensure it reflects the new information developed through this project and new biodiversity information collected since version IV was published (O'Hara, 2020).

6.3.3 Pressures

- The pressure layers used in this project (Appendix E) should be maintained and updated. Current layers mainly cover the time period from 2011 to 2015. Layers should be updated with more recent information covering the period 2016 to 2020, with on-going data collection. This would allow for the estimation of their status and trend. For most parks (excluding the pre-existing ones) in the other networks the most sensible target period would be from July 2013-June 2018 (i.e. the 5 year period immediately prior to management plans coming into effect). This would also enable alignment with mid cycle reviews (if done at 5 years rather than 4,4,2) and end of management plans (10 years). Ideally, additional data for the period post management plans coming into effect to inform "ongoing" pressures should also be gathered.

- The pressure common language should be checked against the available pressure data to ensure that the most appropriate data layers are being used. Where proxies have been used within this project, alternatives that directly measure the pressure should be explored.

- Obtain information on recreational fishing pressure. Recreational fishing effort is not reflected in the analysis completed for the South-east marine region. This, together with noise and marine plastics, are the most significant sub-activities that are not directly (rather than through proxies) reflected in the analysis to date. Recreational fishing effort can be estimated remotely (Keramidas et al., 2018; Dutterer et al., 2020) but information on catch location and composition will likely continue to be available only from individual interviews. Australian states and territories conduct regular recreational fishing surveys, but these surveys do not currently gather all of the necessary information. The NESP Marine biodiversity Hub report on "Social and economic benchmarks of the Australian Marine Parks" (Navarro et al., 2020) describes a national random utility model (RUM) that if implemented may provide reasonable measures of line-based recreational fishing effort across Australia with uncertainties. These estimates could be improved in terms of accuracy and updated to capture changes in recreational effort over time.

- Try to obtain fishery pressure data at a consistent, spatially-fine, scale for all commercial fishing sub-activities (including both commonwealth and state managed fisheries). Where possible arrangements with fisheries management agencies should be sought to allow Parks Australia to use data at its (fine-scale) native resolution, including for fisheries covered by the 5 boat rule etc, ensuring non-identifiability in the pre-reporting stage, rather than pre-analysis stage, of the monitoring prioritisation process. Options to streamline this process should be explored with fisheries managers, through engagement with the Australian Fisheries Management Forum.

- Consider methods for improving the identification of commercial aquaculture vessels in AIS data sets. In this analysis the AIS vessel type "CT_general" was used to represent the vessel transits by commercial aquaculture vessels. It is possible, however, that these vessels are represented in other AIS categories such as "CT_fish" or "CT_working".

6.3.4 Vulnerability assessment

- Consideration of the consequences of the differing spatial scales of natural values, KNVs and pressures and the confidence with which these are mapped should be considered when mapping the outputs of the vulnerability assessment. In some cases, significant mismatch between pressures and values may lead to bias in the estimation of impact. This was noted in the South east where regional expertise identified artificial overlap caused by the five boat rule or OCS arrangements.

- Consider alternative approaches to the vulnerability assessment, such as scoring scenarios rather than vulnerability criteria, ideally in a workshop setting with methods that can reflect the uncertainty in experts' responses. A number of alternative elicitation methods are available for the vulnerability assessment (Kuhnert, Martin, and Griffiths 2010). Direct methods, such as those employed in this analysis, elicit responses for model parameters (such as the vulnerability criteria). Indirect methods elicit responses against outcomes (typically for a set of scenarios) and from this infer model parameters, whilst allowing for non-linear responses (Hosack, Hayes, and Barry 2017). In either case, it is important to try and obtain multiple responses to the assessment, rather than the opinions of just a single scientist, to avoid idiosyncratic responses having an undue effect on the overall results of the analysis.

6.3.5 Data management

- Data management protocols should be established for all the steps in the MERI system to ensure that a record of the data used, and analytical approaches are clear. These protocols should include a delivery pathway to ensure that data products can be accessed in a timely way by Parks Australia and other stakeholders.

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7 APPENDIX A SE NETWORK MANAGEMENT

Table 7.1: Interim management arrangements for activities in the SE network 2007 - 2013

Activity	Multiple use zone IUCN.VI.	Special purpose zone IUCN.VI.	Recreational use zone IUCN.II.	Benthic sanctuary zone IUCN Ia.	Sanctuary zone IUCN Ia.
Commercial fishing – demersal trawl, Danish seine, gillnetting (below 183m) & scallop dredging	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed
Commercial fishing – pelagic fishing	Allowed	Not allowed	Not allowed	Allowed	Not allowed
Commercial fishing – other (those not listed above)	Allowed	Not allowed	Not allowed	Not allowed	Not allowed
Recreational fishing	Allowed	Allowed	Allowed	Allowed (pelagic only)	Not allowed
Research	Authorisation required	Authorisation required	Authorisation required	Authorisation required	Authorisation required
Commercial shipping	Allowed	Allowed	Allowed	Allowed	Allowed
Commercial tourism	Authorisation required	Authorisation required	Authorisation required	Authorisation required	Authorisation required
Charter fishing	Authorisation required	Authorisation required	Authorisation required	Authorisation required (pelagic only)	Not allowed
Mining – seismic survey and transit	Allowed	Allowed	Not allowed	Not allowed	Not allowed
Mining – all other	Authorisation required	Authorisation required	Not allowed	Not allowed	Not allowed

8 APPENDIX B COMMON LANGUAGE

8.1 Natural values

Table 8.1: Natural values common language

Ecosystem complexes	Ecosystems	Ecosystem components
Deep shelf reefs	Mesophotic coral reefs	Benthic and cryptic fish
		Demersal fish
		Macroalgae
		Marine reptiles
		Mobile macroinvertebrates
		Sessile invertebrates
	Mesophotic rocky reefs	Benthic and cryptic fish
		Demersal fish
		Macroalgae
		Mobile macroinvertebrates
		Sessile invertebrates
	Rariphotic shelf reefs	Benthic and cryptic fish
		Demersal fish
		Mobile macroinvertebrates
		Sessile invertebrates
Intertidal areas	Beaches	Infauna
		Shorebirds and waterbirds
	Intertidal coral reefs	Benthic and cryptic fish
		Macroalgae
		Mobile macroinvertebrates
		Sessile invertebrates
	Rocky shores	Benthic and cryptic fish
		Macroalgae
		Mobile macroinvertebrates
		Sessile invertebrates
Islands (including cays and islets)	Islands (including cays and islets)	Forest
		Grassland
		Herb field
		Marine reptiles
		Seabirds
		Shorebirds and waterbirds
		Shrubland
Lower-slope and abyssal reef and sediments	Abyssal reef and sediments	Benthic and cryptic fish
		Demersal fish
		Infauna
		Mobile macroinvertebrates
		Sessile invertebrates
	Lower-slope reef and sediments	Benthic and cryptic fish
		Demersal fish
		Infauna
		Mobile macroinvertebrates
		Sessile invertebrates

Ecosystem complexes	Ecosystems	Ecosystem components
Oceanic coral reefs	Oceanic mesophotic coral reefs	Benthic and cryptic fish
		Demersal fish
		Macroalgae
		Mobile macroinvertebrates
		Sessile invertebrates
	Oceanic shallow coral reefs	Benthic and cryptic fish
		Demersal fish
		Macroalgae
		Mobile macroinvertebrates
		Seagrass
		Sessile invertebrates
Seamounts (including guyots)	Seamount reefs	Benthic and cryptic fish
		Demersal fish
		Mobile macroinvertebrates
		Sessile invertebrates
	Seamount sediments	Benthic and cryptic fish
		Demersal fish
		Infauna
		Mobile macroinvertebrates
		Sessile invertebrates
Shallow reefs	Shallow coral reefs	Benthic and cryptic fish
		Demersal fish
		Macroalgae
		Mobile macroinvertebrates
		Seagrass
		Sessile invertebrates
	Shallow rocky reefs	Benthic and cryptic fish
		Demersal fish
		Macroalgae
		Mobile macroinvertebrates
		Seagrass
		Sessile invertebrates
Shelf vegetated sediments	Shelf vegetated sediments	Benthic and cryptic fish
		Demersal fish
		Infauna
		Macroalgae
		Mobile macroinvertebrates
		Seagrass
Shelf, upper and mid-slope unvegetated sediments	Mid-slope sediments	Benthic and cryptic fish
		Demersal fish
		Infauna
		Mobile macroinvertebrates
		Sessile invertebrates
	Shelf unvegetated sediments	Benthic and cryptic fish
		Demersal fish
		Infauna
		Mobile macroinvertebrates
		Sessile invertebrates
	Upper-slope sediments	Benthic and cryptic fish
		Demersal fish
		Infauna
		Mobile macroinvertebrates
		Sessile invertebrates

Ecosystem complexes	Ecosystems	Ecosystem components
Upper and mid-slope reefs (including canyons)	Mid-slope reefs	Benthic and cryptic fish
		Demersal fish
		Mobile macroinvertebrates
		Sessile invertebrates
	Shelf-incising canyons	Benthic and cryptic fish
		Demersal fish
		Mobile macroinvertebrates
		Sessile invertebrates
	Upper-slope reefs	Benthic and cryptic fish
		Demersal fish
		Mobile macroinvertebrates
		Sessile invertebrates
Water column	Bathypelagic & Abyssopelagic	Abyssopelagic fauna
		Bathypelagic fauna
	Mesopelagic	Mesopelagic fish
		Mesopelagic micronekton
		Pelagic mobile invertebrates
		Pelagic sharks and rays
		Plankton
	Off-shelf (oceanic) epipelagic	Marine mammals
		Marine reptiles
		Oceanic epipelagic fish
		Pelagic mobile invertebrates
		Pelagic sharks and rays
		Plankton
		Seabirds
	On-shelf (neritic) epipelagic	Coastal epipelagic fish
		Marine mammals
		Marine reptiles
		Pelagic mobile invertebrates
		Pelagic sharks and rays
		Plankton
		Seabirds

Common language definitions

Ecosystem A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.

Ecosystem complexes A collection of ecosystems with similar characteristics, functions, and drivers that shape their ecological character. The ecosystems in an ecosystem complex also have similar types of pressures and management needs.

Ecosystem component Natural values that are core elements of an ecosystem – these are mostly species assemblages or communities but may also include habitat features.

Ecosystem complexes

Deep shelf reefs Rocky and/or coral reef formations found on the continental shelf from 30m to the shelf break (nominally 200m).

Intertidal areas – the area between the highest and lowest tides.

Islands (including cays and islets) Island - Relatively small body of land surrounded by water; Cay – a low bank or reef of coral or sand; Islet – a little island.

Lower slope and abyssal reef and sediments Reef and sediment habitats deeper than 2000m on the lower continental slope (including the continental rise) and in the abyssal zone.

Oceanic coral reefs Coral reefs occurring seaward of the continental shelf break.

Seamounts (including guyots) Large, steep underwater mountains rising hundreds to thousands of metres from the surrounding seafloor but not reaching the water's surface. They are often extinct volcanoes; Guyots - an isolated underwater volcanic mountain with a flat-top more than 200 metres below the sea surface

Shallow reefs Rocky and/or coral formations occurring in continental shelf areas shallower than 30m.

Shelf, upper and mid slope unvegetated sediments Sediment habitats on the continental shelf that lack marine macroalgae or seagrass and sediment habitats on the upper (200m - 700m) and mid (700m - 2000m) continental slope.

Shelf vegetated sediments Sediment habitats on the continental shelf that support marine macroalgae or seagrass. Typically, these occur in depths of less than 30m but can extend beyond this in areas with very clear waters.

Upper and mid slope reefs (including canyons) Reef habitats on the upper section of the continental slope between 200m (shelf break) and 2000m.

Water column The entire water body between the surface of the ocean and the seafloor.

Ecosystems

Abyssal reef and sediments Reef and sediment habitats in the abyssal zone, between 4000m and 6000m.

Bathypelagic and Abyssopelagic The layers of the ocean between 1000m and 4000m (bathypelagic) and 4000m and 6000m (abyssopelagic), not influenced by the seafloor.

Beaches Gently sloping zone of sand and/or gravel sized rock and/or biological fragments along the shore, extending from the highest high-tide point to the lowest low-tide point.

Intertidal coral reefs Coral reefs found in the intertidal zone (i.e. between the highest and lowest tides)

Islands (including cays and islets) Island - Relatively small body of land surrounded by water; Cay – a low bank or reef of coral or sand; Islet – a little island.

Lower slope reef and sediments Rocky reef and sediment habitats on the lower continental slope and continental rise (i.e. between 2000m and nominally 4000m).

Mesopelagic The layer of the ocean between 200m and 1000m, not influenced by the seafloor.

Mesophotic coral reefs Coral reef formations on tropical continental shelf areas in the mesophotic zone: a reduced light zone between 30m and the maximum depth at which there is sufficient penetration of sunlight to support photosynthesis. The maximum depth is variable dependent upon water clarity and may extend to 150m in the clearest of waters however, as a national average it is nominally defined as 70m.

Mesophotic rocky reefs Rocky reef formations on temperate continental shelf areas in the mesophotic zone: a reduced light zone between 30m and the maximum depth at which there is sufficient penetration of sunlight to support photosynthesis. The maximum depth is variable dependent upon water clarity and may extend to 150m in the clearest of waters however, as a national average it is nominally defined as 70m.

Mid-slope reefs Reef habitats on the mid-continental slope between 700m and 2000m.

Mid-slope sediments Sediment habitats on the mid continental slope (700-2000m).

Oceanic shallow coral reefs Coral reefs occurring seaward of the continental shelf break in depths shallower than 30m.

Oceanic mesophotic coral reefs Coral reefs occurring seaward of the continental shelf break in in the mesophotic zone: a reduced light zone between 30m and the maximum depth at which there is sufficient penetration of sunlight to support photosynthesis. The maximum depth is variable dependent upon water clarity and may extend to 150m in the clearest of waters however, as a national average it is nominally defined as 70m.

Off-shelf (oceanic) epipelagic The uppermost layer of the ocean extending from the surface to 200m, that occurs seaward of the continental shelf break.

On-shelf (neritic) epipelagic The uppermost layer of the ocean extending from the surface to 200m, that occurs above the continental shelf.

Rariphotic shelf reefs Rocky reef formations found on the continental shelf below the mesophotic zone where light is so scarce it is not enough to support photosynthesis.

Nominally rariphotic shelf reefs occur between 70m and 200m (the nominal depth of the shelf break).

Rocky shores An intertidal area composed of rock platforms, boulders or cobbles.

Seamount reefs Rocky and deep-sea cold-water coral formations occurring on seamounts.

Seamount sediments Sediment habitats occurring on seamounts.

Shallow coral reefs Coral reefs occurring in continental shelf areas shallower than 30m.

Shallow rocky reefs Rocky reefs occurring in continental shelf areas shallower than 30m.

Shelf-incised canyons Steep sided valleys in the seabed that extend onto the continental shelf at least 500m shoreward of the shelf break.

Shelf unvegetated sediments Sediment habitats on the continental shelf (0-200 metres) that lack marine macroalgae or seagrass.

Shelf vegetated sediments Sediment habitats on the continental shelf that support marine macroalgae or seagrass. Typically, these occur in depths of less than 30m but can extend beyond this in areas with very clear waters.

Upper-slope reefs Reef habitats on the upper section of the continental slope between shelf break (nominally 200m) and 2000m.

Upper-slope sediments Sediment habitats on the upper continental slope (200m-700m).

8.2 Anthropogenic pressures

Table 8.2: Pressures common language

Activity	Sub-activity	Management plan pressure	Specific pressure
Climate change[18]	Altered ocean currents	Climate change	Altered ocean currents
	Increased frequency and intensity of severe weather events		Increased frequency and intensity of severe weather events
	Increased SST		Increased sea surface temperature
	Ocean acidification		Ocean acidification
	Sea level rise		Sea level rise
Climate change adaptation	Carbon storage and sequestration	Habitat modification	Habitat modification (physical disturbance and removal)
Commercial aquaculture	Aquaculture (including commercial pearling)	Habitat modification	Habitat modification (due to changes in nutrients and organic matter)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Marine pollution	Marine debris (incl. microplastics and litter on islands)
		Marine pollution	Noise pollution
	Vessel transiting	Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Marine pests
		Marine pollution	Noise pollution
Commercial fishing	Danish Seine	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
	Demersal trawl	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Marine pollution	Noise pollution
	Dropline	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)

[18] Climate change is defined as a pressure in the Australian Marine Park management plans, with specific pressures or stressors that sit below this (e.g. altered ocean currents, sea level rise etc.). For the purposes of the NESP project (i.e. cumulative impact assessment), climate change and associated specific pressures were also treated as 'activities' and 'sub-activities' respectively.

Activity	Sub-activity	Management plan pressure	Specific pressure
Commercial fishing	Hand collection	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
	Hand net	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
	Longline (demersal, auto-longline)	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
	Longline (pelagic)	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
	Minor line	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
	Net - demersal	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
	Net - pelagic	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
	Pot and Trap	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
	Purse Seine	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)

Activity	Sub-activity	Management plan pressure	Specific pressure
Commercial fishing	Scallop dredge	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Marine pollution	Noise pollution
	Trawl - midwater	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
	Trotline	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
	Vessel transiting	Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Marine pests
		Marine pollution	Marine debris (including microplastics and litter on islands)
Commercial shipping	Anchoring	Habitat modification	Habitat modification (physical disturbance and removal)
		Invasive species	Marine pests
		Marine pollution	Light pollution
	Vessel transiting	Habitat modification	Habitat modification (due to suspended sediments - including smothering)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Invasive species	Overabundant native species
		Marine pollution	Marine debris (including microplastics and litter on islands)
		Marine pollution	Noise pollution
		Marine pollution	Oil/fuel spill or leak

Activity	Sub-activity	Management plan pressure	Specific pressure
Commercial tourism	Charter fishing tours	Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Marine pollution	Marine debris (incl. microplastics and litter on islands)
		Marine pollution	Noise pollution
	Commercial aviation tours (up to 3000 m above sea level)	Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Marine pollution	Noise pollution
	Non-fishing related tourism - nature watching	Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Marine pests
		Marine pollution	Marine debris (including microplastics and litter on islands)
		Marine pollution	Noise pollution
	Non-fishing related tourism - scuba/snorkel tour	Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
	Non-fishing related tourism - vessel transiting	Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Marine pests
Commercial media	Commercial media	Human presence	Human presence (disturbance of mobile fauna communities or populations)
General use, access & waste management	Ballast water discharge and exchange	Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
	Camping	Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Terrestrial pest plants and animals
		Marine pollution	Marine debris (including microplastics and litter on islands)

Activity	Sub-activity	Management plan pressure	Specific pressure
General use, access & waste management	Disposal of waste from normal operations of vessels	Marine pollution	Sewage waste
	Non-commercial remote piloted aircraft	Marine pollution	Noise pollution
	Recreational use – boating (including vessel transiting)	Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Marine pollution	Marine debris (incl. microplastics and litter on islands)
	Recreational use - nature watching (above and below water)	Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Marine pollution	Marine debris (including microplastics and litter on islands)
Hunting and fishing	Cultural fishing	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Habitat modification	Habitat modification (physical disturbance and removal)
	Traditional hunting	Extraction of living resources	Extraction of megafauna (excluding fish)
Land-use intensification	Agricultural diffuse source runoff	Changes in hydrology	Changes in nutrients and organic matter
		Changes in hydrology	Suspended sediments (including smothering)
		Habitat modification	Habitat modification (due to suspended sediments - including smothering)
		Invasive species	Introduced pathogens/disease
		Marine pollution	Marine debris (including microplastics and litter on islands)
		Marine pollution	Noxious substances (including chemicals & heavy metals)
	Point discharges	Marine pollution	Marine debris (including microplastics and litter on islands)
		Marine pollution	Noxious substances (including chemicals & heavy metals)
		Marine pollution	Sewage waste
	Stock grazing of riparian and marine vegetation	Changes in hydrology	Changes in nutrients and organic matter
		Habitat modification	Habitat modification (due to suspended sediments - including smothering)
		Changes in hydrology	Suspended sediments (including smothering)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Invasive species	Terrestrial pest plants and animals

Activity	Sub-activity	Management plan pressure	Specific pressure
Mining	Construction and operation of pipelines	Habitat modification	Habitat modification (physical disturbance and removal)
	Mining - seismic survey	Marine pollution	Noise pollution
	Mining operations including exploration	Habitat modification	Habitat modification (due to suspended sediments - including smothering)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Marine pollution	Light pollution
		Marine pollution	Noise pollution
		Marine pollution	Noxious substances (including chemicals & heavy metals)
		Marine pollution	Oil/fuel spill or leak
	Vessel transiting	Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Marine pests
National security and emergency response	Actions by or under direction of the Commonwealth and Commonwealth agencies - defence, border protection, law enforcement and emergency response	N/A	#N/A
Recreational fishing	Anchoring	Habitat modification	Habitat modification (physical disturbance and removal)
	Recreational fishing (including spearfishing)	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Invasive species	Overabundant native species
		Marine pollution	Marine debris (incl. microplastics and litter on islands)
	Vessel transiting	Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Marine pests

Activity	Sub-activity	Management plan pressure	Specific pressure
Renewable energy	Wave, tidal and wind	Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Marine pests
Research and monitoring	Research, collecting, tagging	Extraction of living resources	Extraction of benthic mobile invertebrates
		Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Extraction of living resources	Extraction of terrestrial biota
		Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Marine pollution	Marine debris (incl. microplastics and litter on islands)
Structures and works	Artificial reefs	Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Habitat modification	Habitat modification (physical disturbance and removal)
	Dredging or disposal of dredged material	Habitat modification	Habitat modification (due to suspended sediments - including smothering)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Marine pollution	Noise pollution
		Marine pollution	Noxious substances (incl. chemicals & heavy metals)
	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Habitat modification	Habitat modification (due to suspended sediments - including smothering)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Marine pollution	Noise pollution
		Marine pollution	Noxious substances (incl. chemicals & heavy metals)
		Marine pollution	Oil/fuel spill or leak
	Fish aggregating devices	Extraction of living resources	Extraction of fish and free-swimming invertebrates
		Extraction of living resources	Extraction of megafauna (excluding fish)
		Human presence	Human presence (disturbance of mobile fauna communities or populations)
	Moorings	Extraction of living resources	Extraction of megafauna (excluding fish)
		Habitat modification	Habitat modification (physical disturbance and removal)
		Invasive species	Introduced pathogens/disease
		Invasive species	Marine pests
		Marine pollution	Light pollution

9 APPENDIX C ECOSYSTEMS

9.1 Creation of the Australian ecosystem map

Table 9.1: Steps used to develop Ecosystem Map for benthic ecosystems

Step	Ecosystem	Processing	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 9.2: 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 9.3: 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 9.4: 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.

9.2 Ecosystem maps

9.2.1 Shelf unvegetated sediments

Sediment habitats on the continental shelf (0-200 metres) that lack marine macroalgae or seagrass.

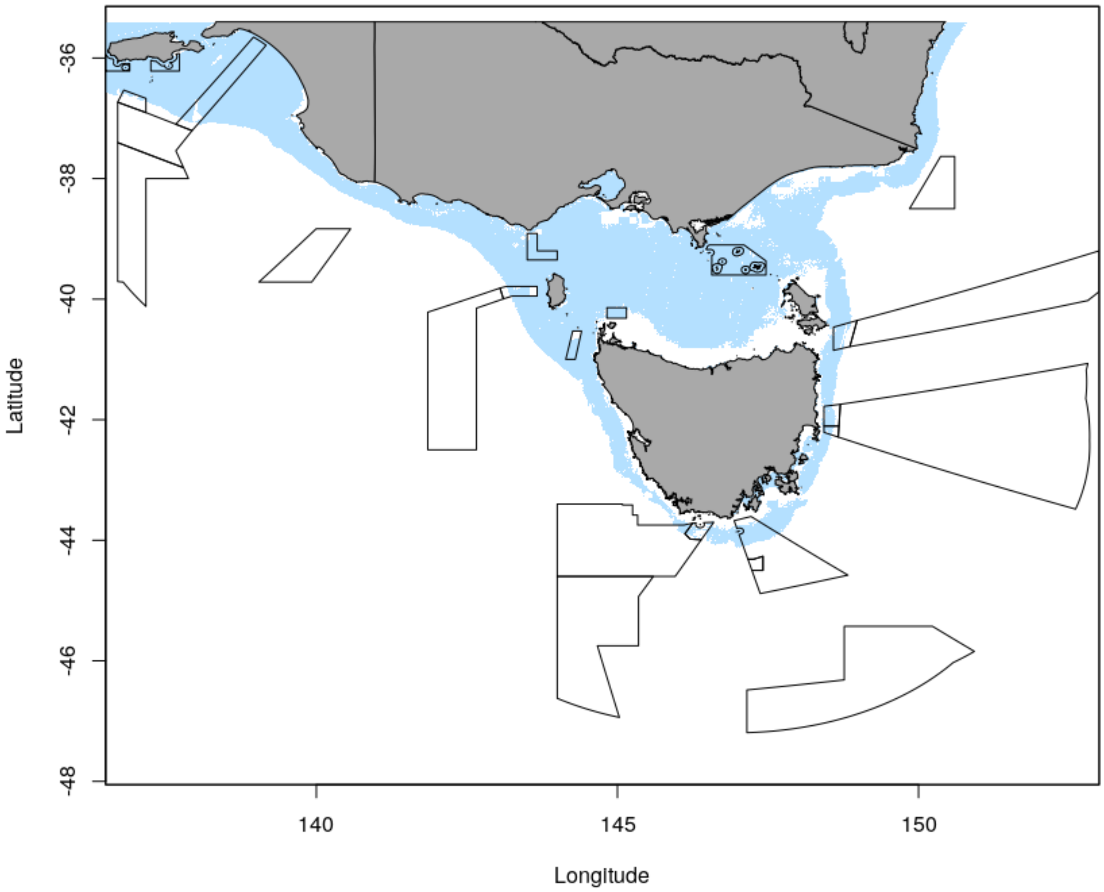

Figure 9.1: Shelf unvegetated sediments

9.2.2 Upper-slope sediments

Sediment habitats on the upper continental slope (200m -700m).

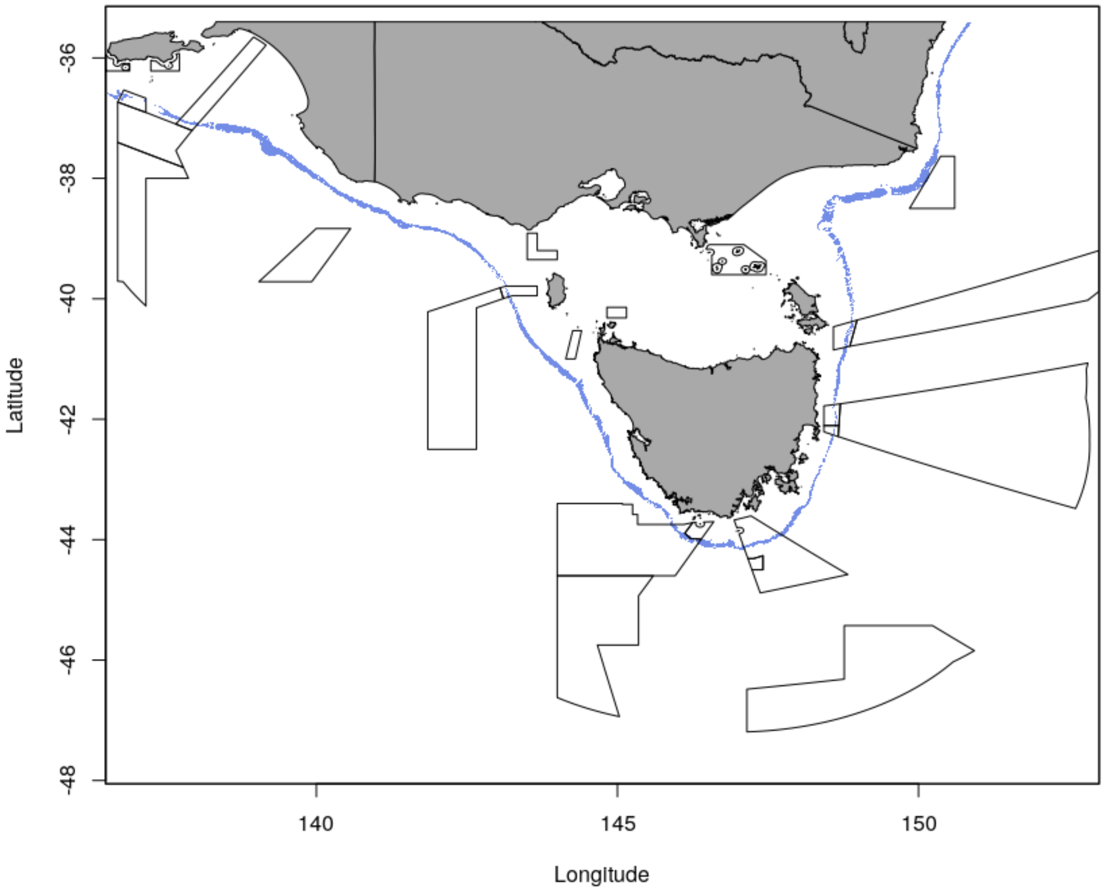

Figure 9.2: Upper-slope sediments

9.2.3 Mid-slope sediments

Sediment habitats on the mid continental slope (700-2000m).

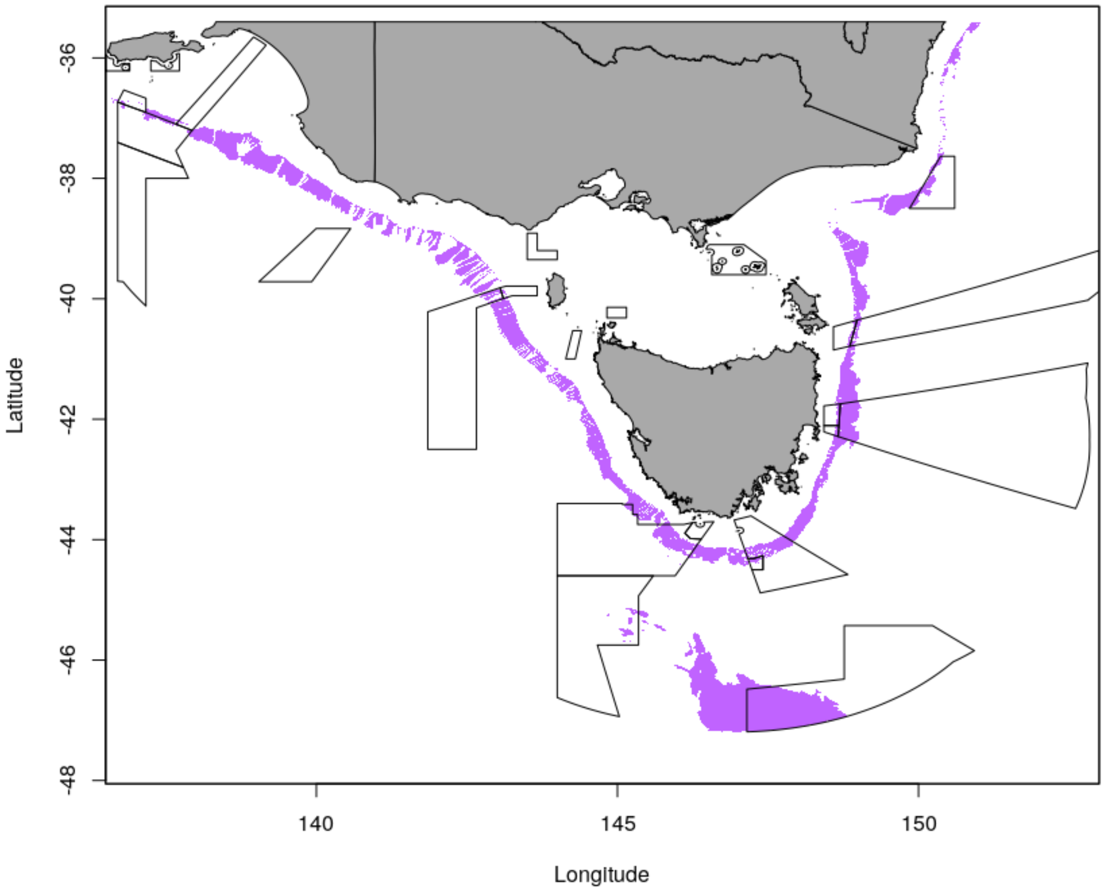

Figure 9.3: Mid-slope sediments

9.2.4 Lower slope reef and sediments

Rocky reef and sediment habitats on the lower continental slope and continental rise (i.e. between 2000m and nominally 4000m).

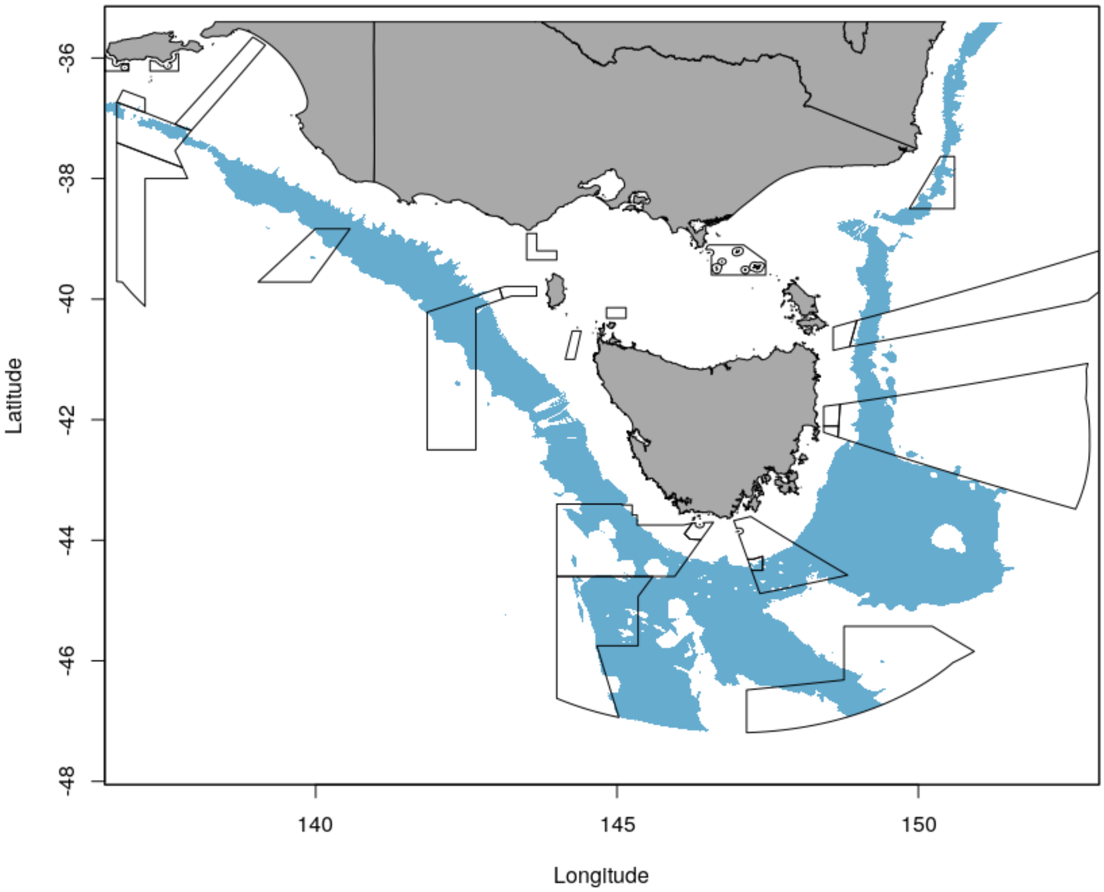

Figure 9.4: Lower slope reef and sediments

9.2.5 Abyssal reef and sediments

Reef and sediment habitats in the abyssal zone, between 4000m and 6000m.

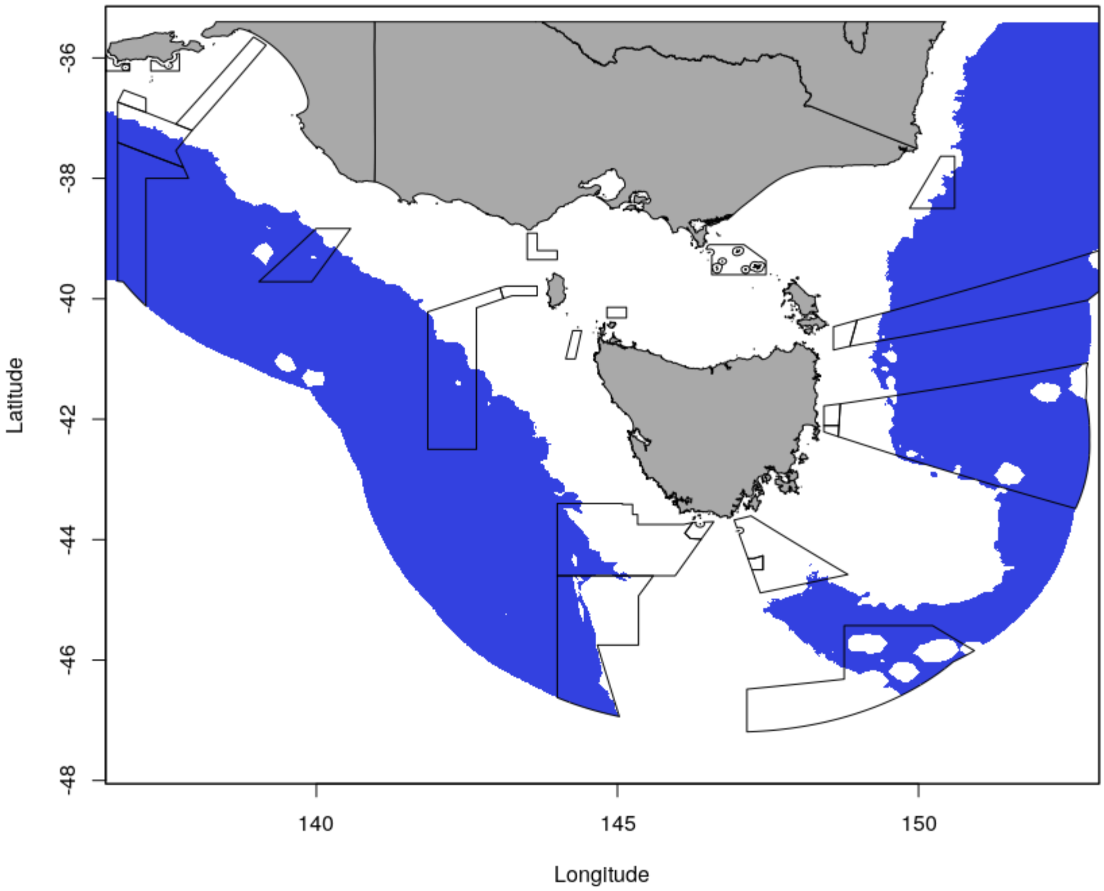

Figure 9.5: Abyssal reef and sediments

9.2.6 Seamount sediments

Sediment habitats occurring on seamounts.

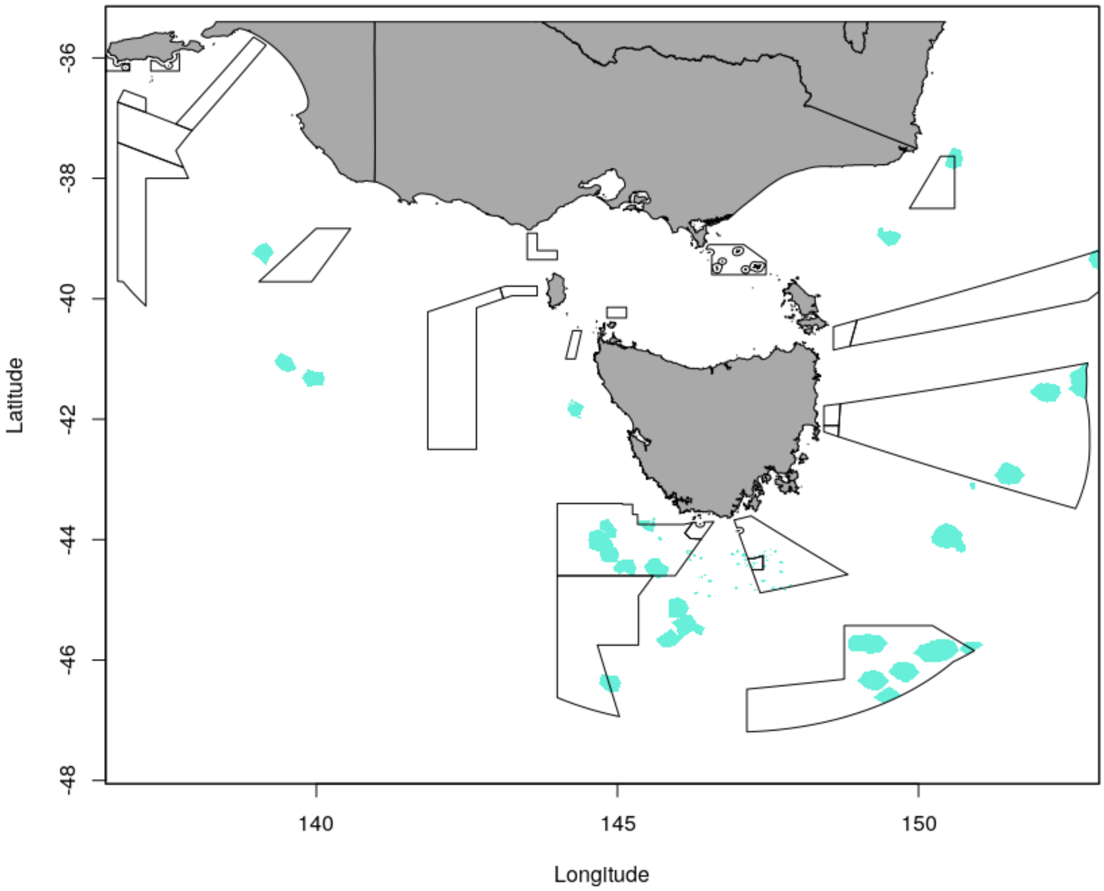

Figure 9.6: Seamount sediments

9.2.7 Seamount reefs

Rocky and deep-sea cold-water coral formations occurring on seamounts.

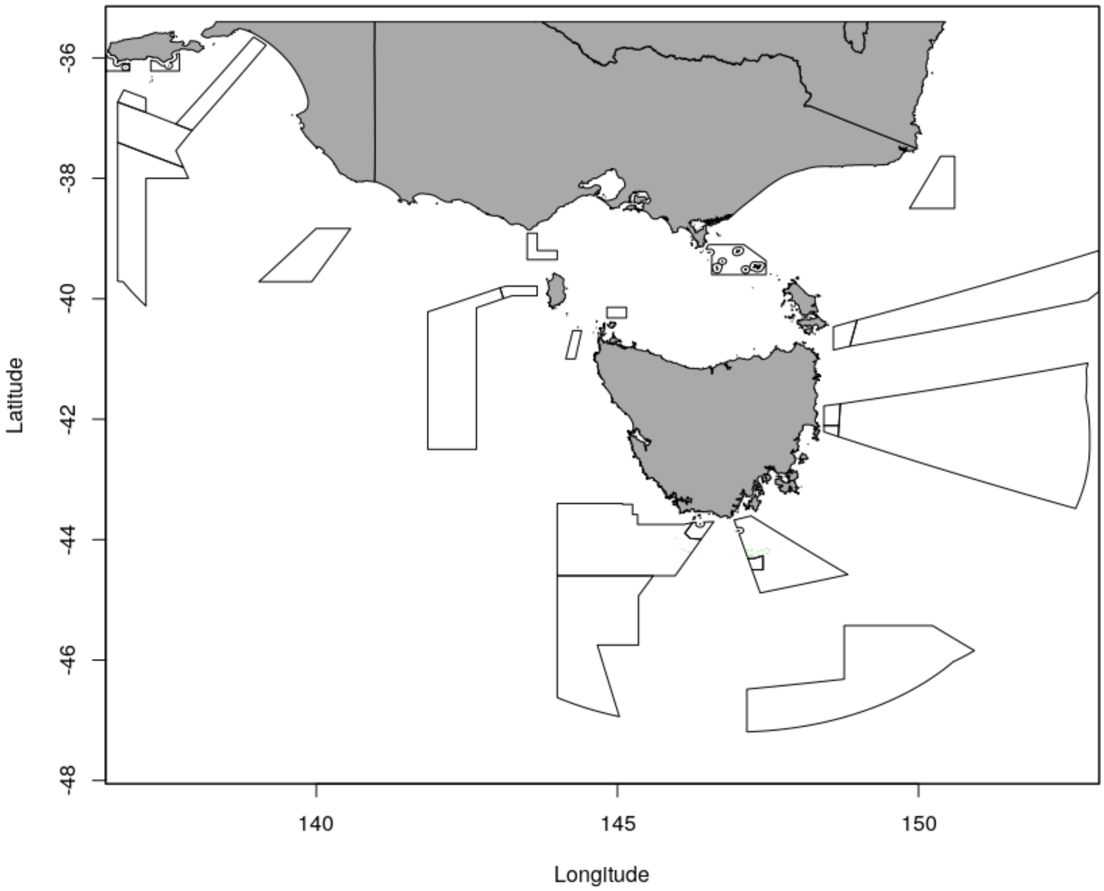

Figure 9.7: Seamount reefs

9.2.8 Shelf-incising canyons

Steep sided valleys in the seabed that extend onto the continental shelf at least 500m shoreward of the shelf break.

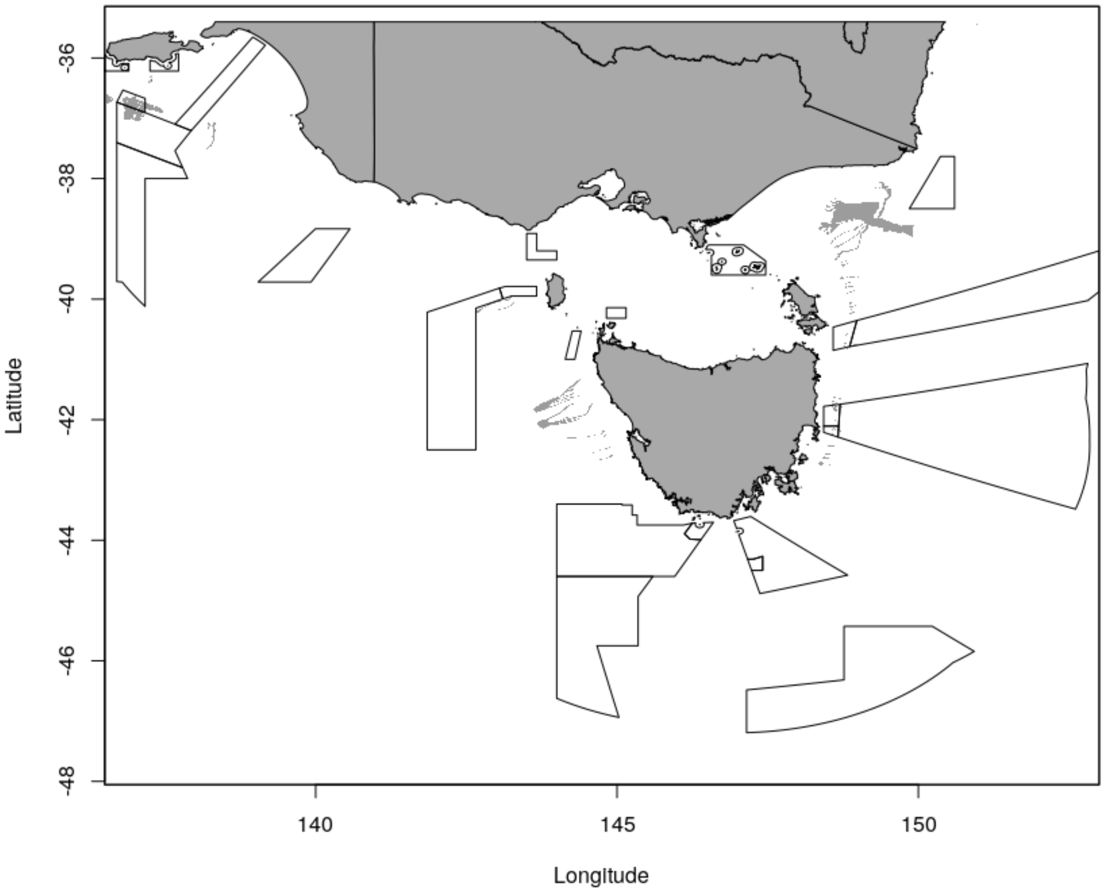

Figure 9.8: Shelf-incising canyons

9.2.9 Shelf vegetated sediments

Sediment habitats on the continental shelf that support marine macroalgae or seagrass. Typically, these occur in depths of less than 30m but can extend beyond this in areas with very clear waters.

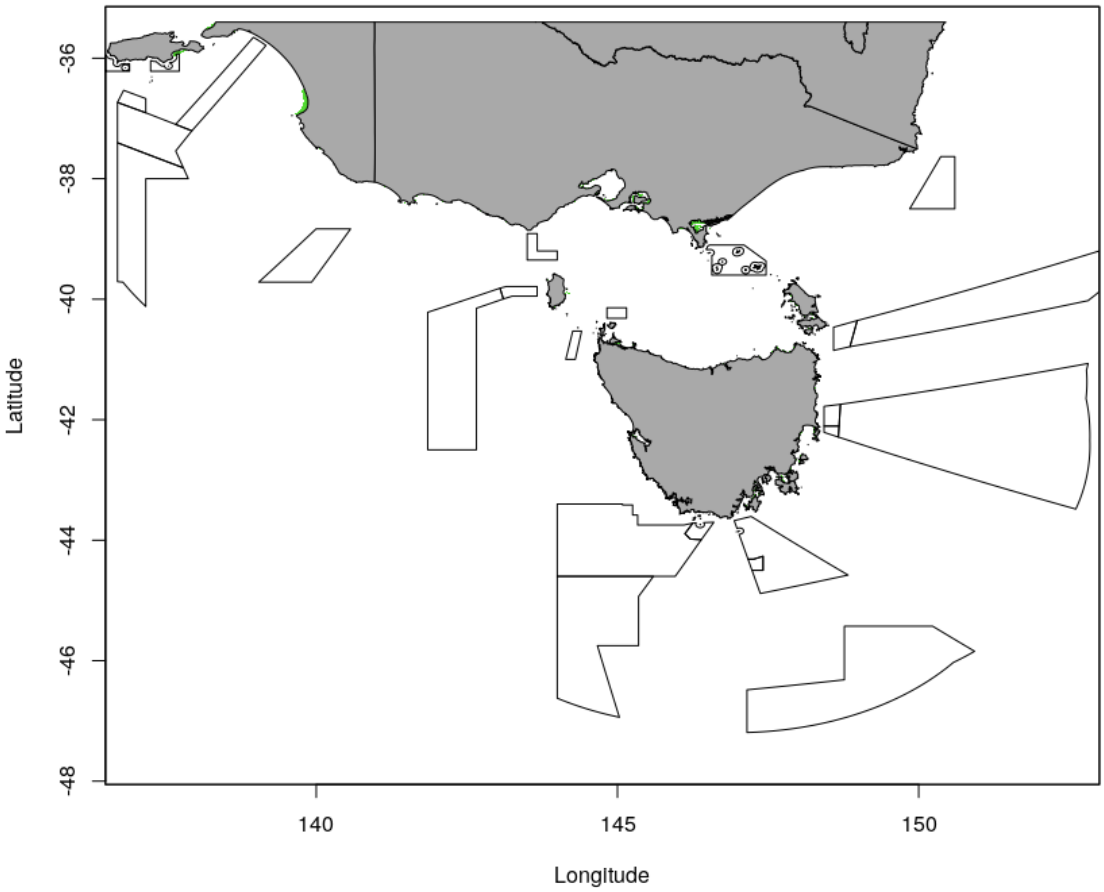

Figure 9.9: Shelf vegetated sediments

9.2.10 Shallow rocky reefs

Rocky reefs occurring in continental shelf areas shallower than 30m.

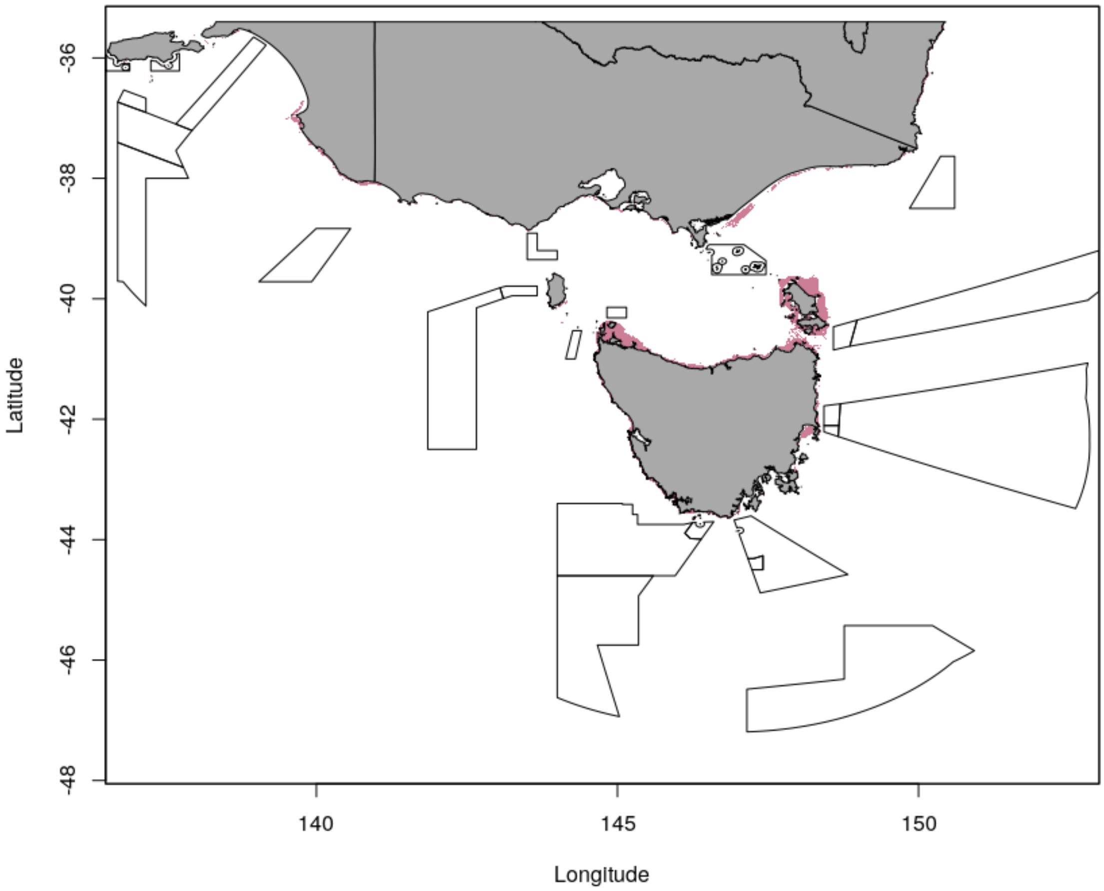

Figure 9.10: Shallow rocky reefs

9.2.11 Mesophotic rocky reefs

Rocky reef formations on temperate continental shelf areas in the mesophotic zone: a reduced light zone between 30m and the maximum depth at which there is sufficient penetration of sunlight to support photosynthesis. The maximum depth is variable dependent upon water clarity and may extend to 150m in the clearest of waters however, as a national average it is nominally defined as 70m

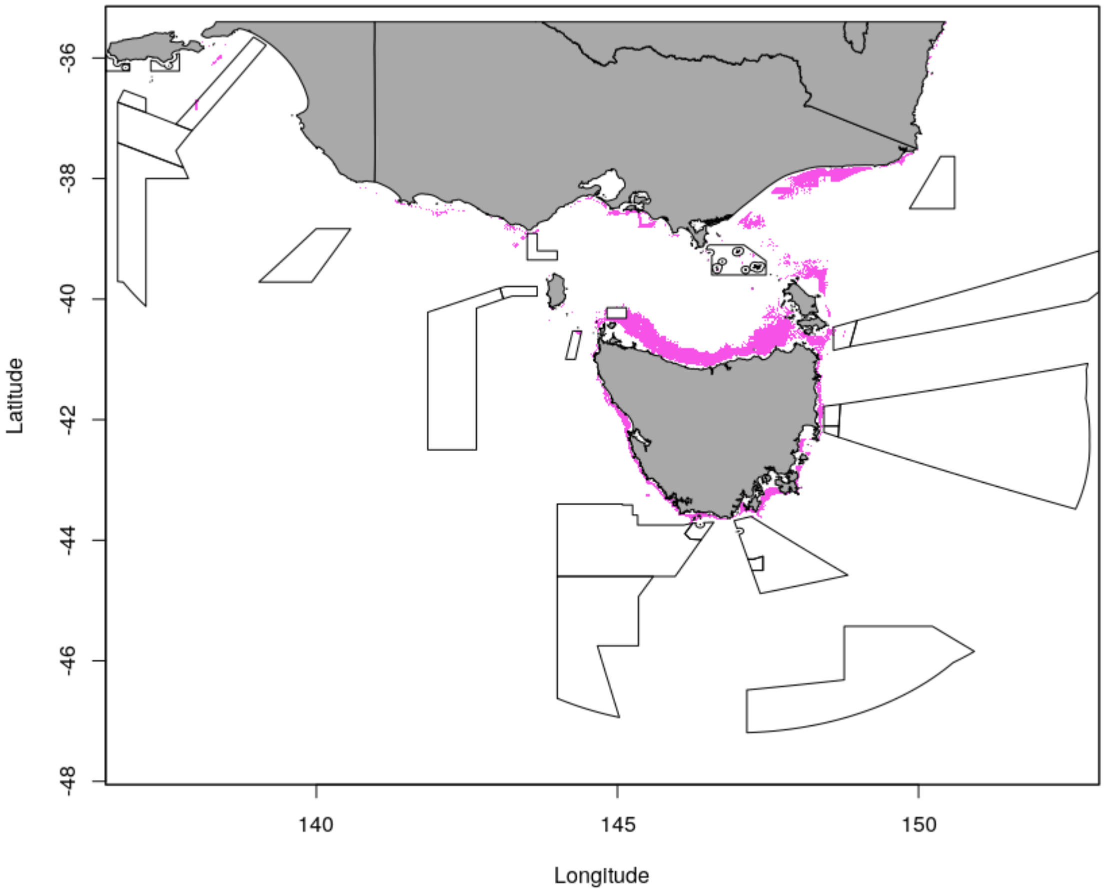

Figure 9.11: Mesophotic rocky reefs

9.2.12 Rariphotic shelf reefs

Rocky reef formations found on the continental shelf below the mesophotic zone where light is so scarce it is not enough to support photosynthesis. Nominally rariphotic shelf reefs occur between 70m and 200m (the nominal depth of the shelf break).

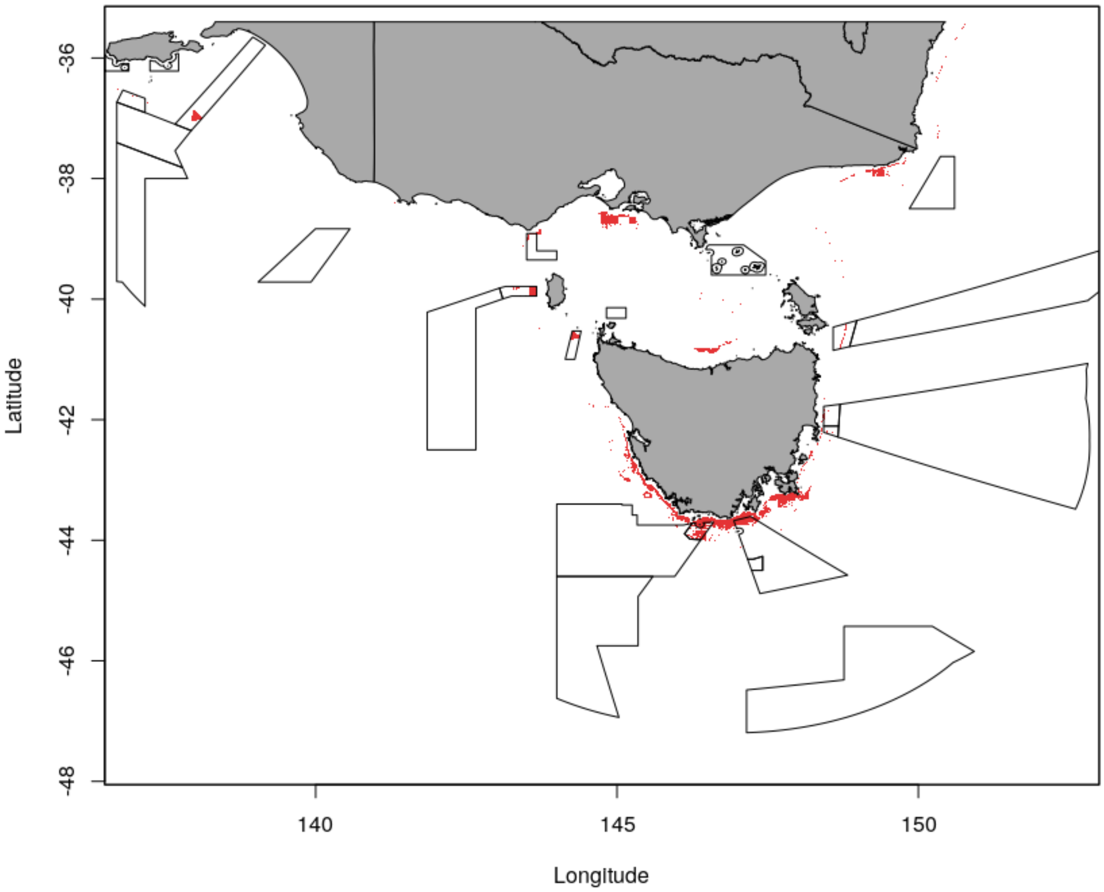

Figure 9.12: Rariphotic shelf reefs

9.2.13 Upper slope reefs

Reef habitats on the upper section of the continental slope between shelf break (nominally 200m) and 2000m.

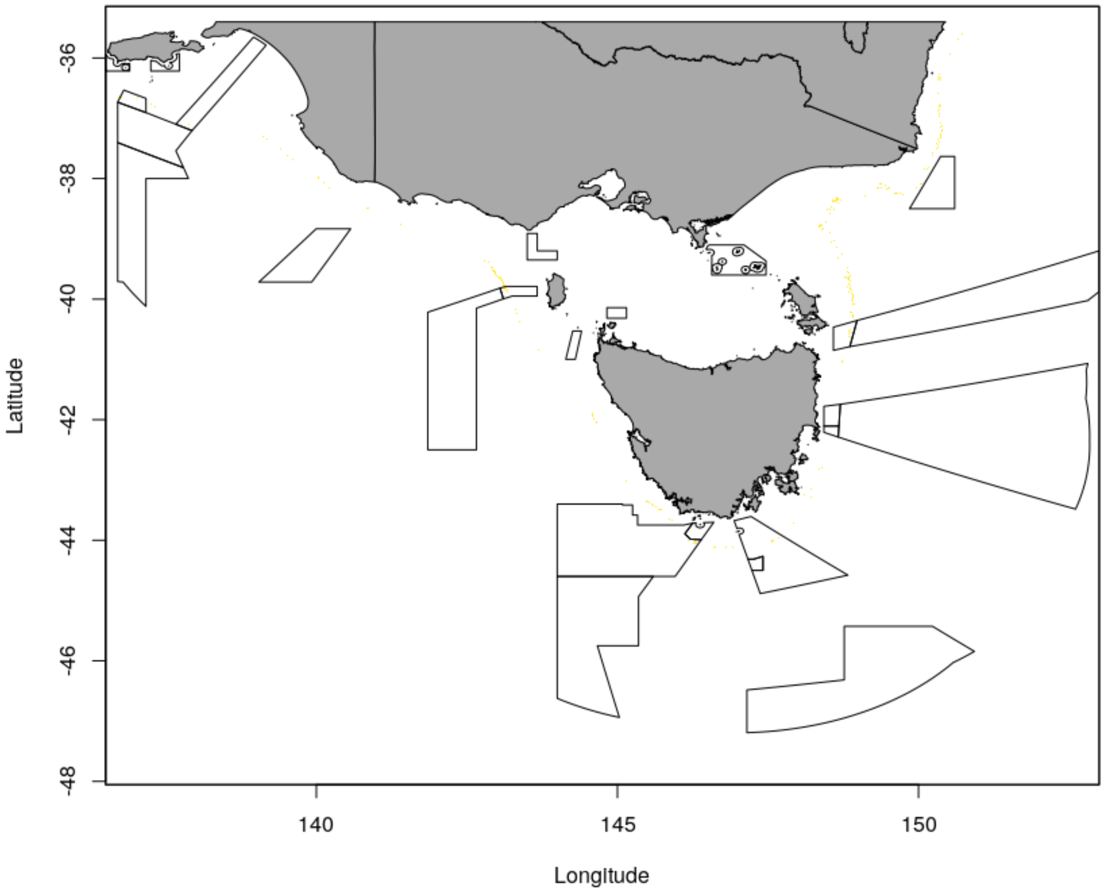

Figure 9.13: Upper slope reefs

9.2.14 Mid-slope reefs

Reef habitats on the mid-continental slope between 700m and 2000m.

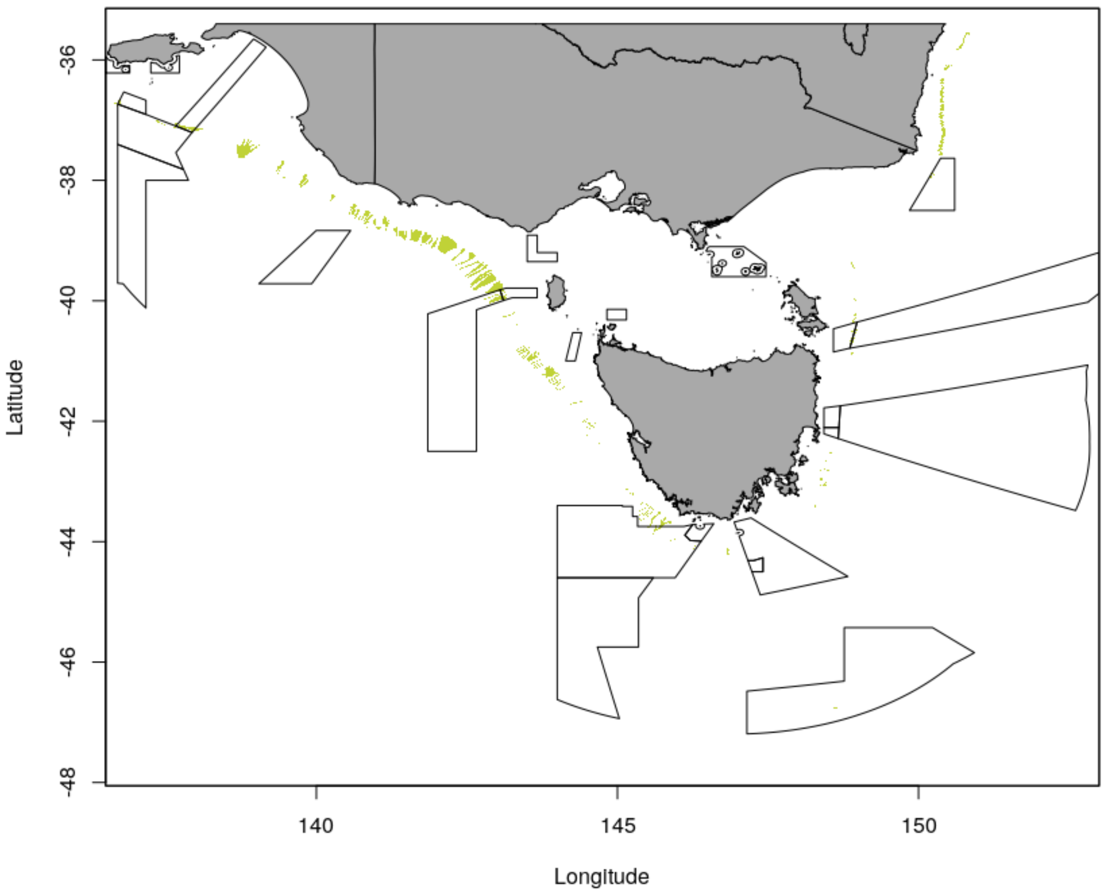

Figure 9.14: Mid-slope reefs

9.2.15 Artificial reefs, pipelines and cables

A structure or formation placed on the seabed for: (a) the purpose of increasing or concentrating populations of marine plants and animals; or (b) the purpose of being used in human recreational activities. This ecosystem has been removed from the common language.

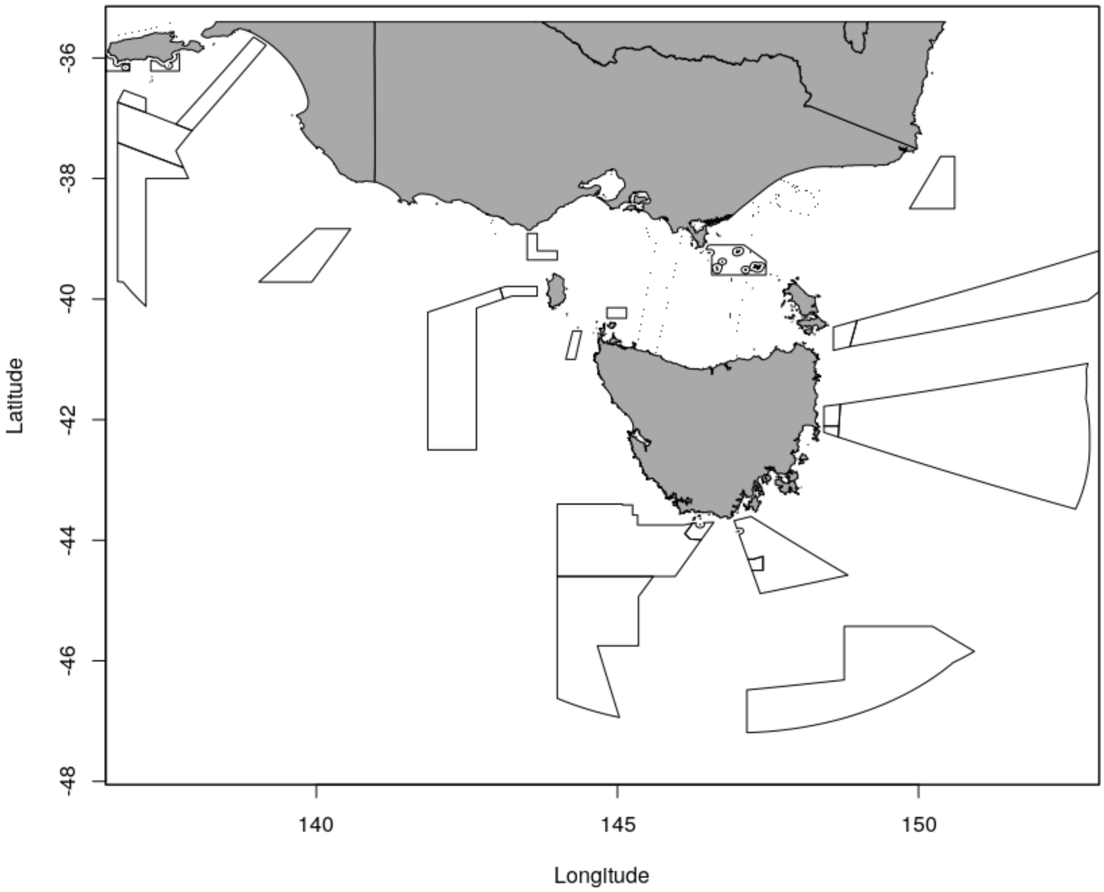

Figure 9.15: Artificial reefs, pipelines, and cables

9.2.16 Shallow coral reefs

Coral reefs occurring in continental shelf areas shallower than 30m.

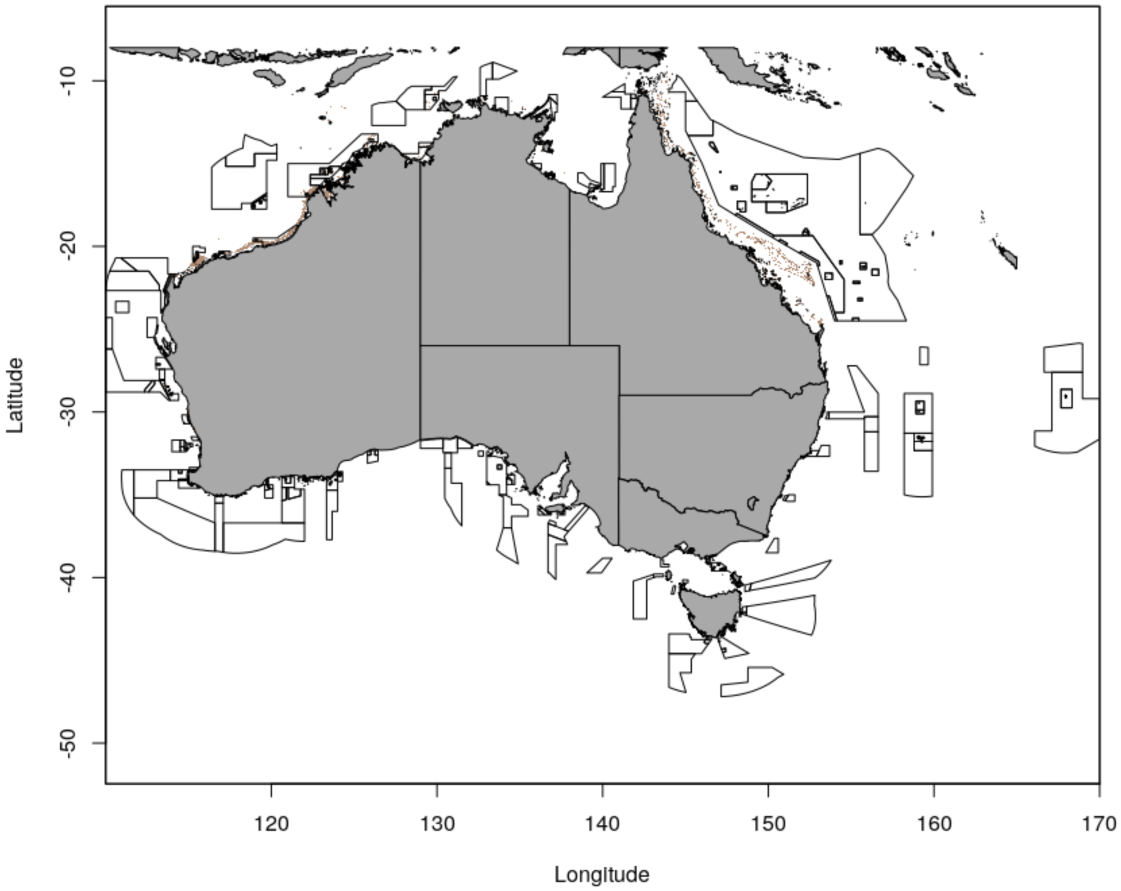

Figure 9.16: Shallow coral reefs

9.2.17 Oceanic shallow coral reefs

Coral reefs occurring seaward of the continental shelf break in depths shallower than 30m.

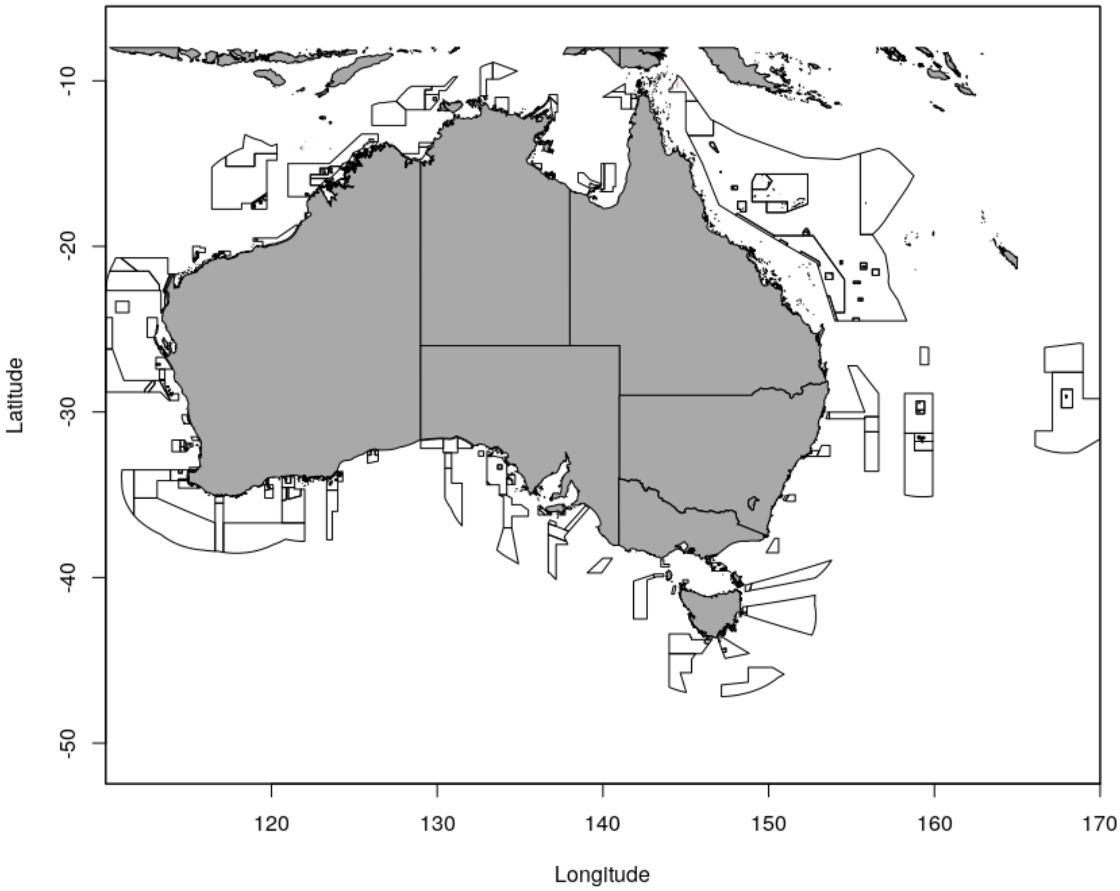

Figure 9.17 Oceanic shallow coral reefs

9.2.18 Mesophotic coral reefs

Coral reef formations on tropical continental shelf areas in the mesophotic zone: a reduced light zone between 30m and the maximum depth at which there is sufficient penetration of sunlight to support photosynthesis. The maximum depth is variable dependent upon water clarity and may extend to 150m in the clearest of waters however, as a national average it is nominally defined as 70m.

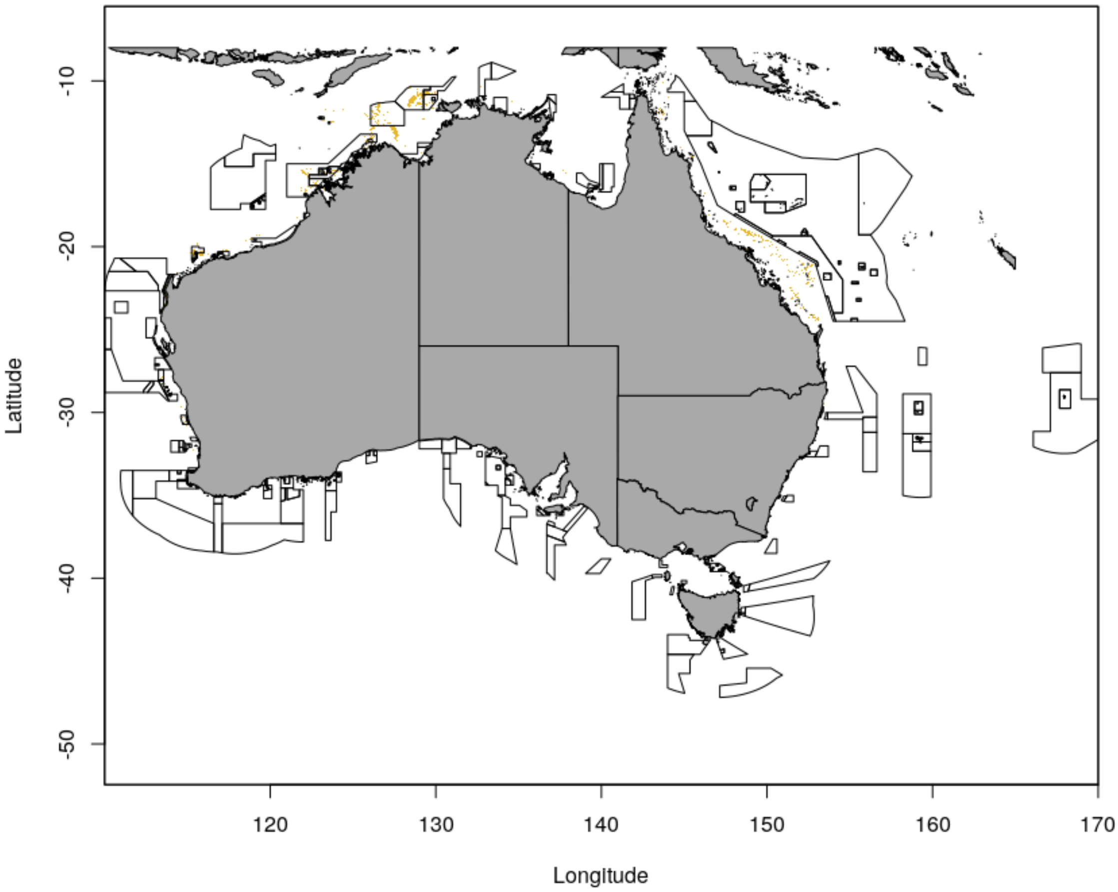

Figure 9.18: Mesophotic coral reefs

9.2.19 Oceanic mesophotic coral reefs

Coral reefs occurring seaward of the continental shelf break in in the mesophotic zone: a reduced light zone between 30 m and the maximum depth at which there is sufficient penetration of sunlight to support photosynthesis. The maximum depth is variable dependent upon water clarity and may extend to 150 m in the clearest of waters however, as a national average it is nominally defined as 70m. .

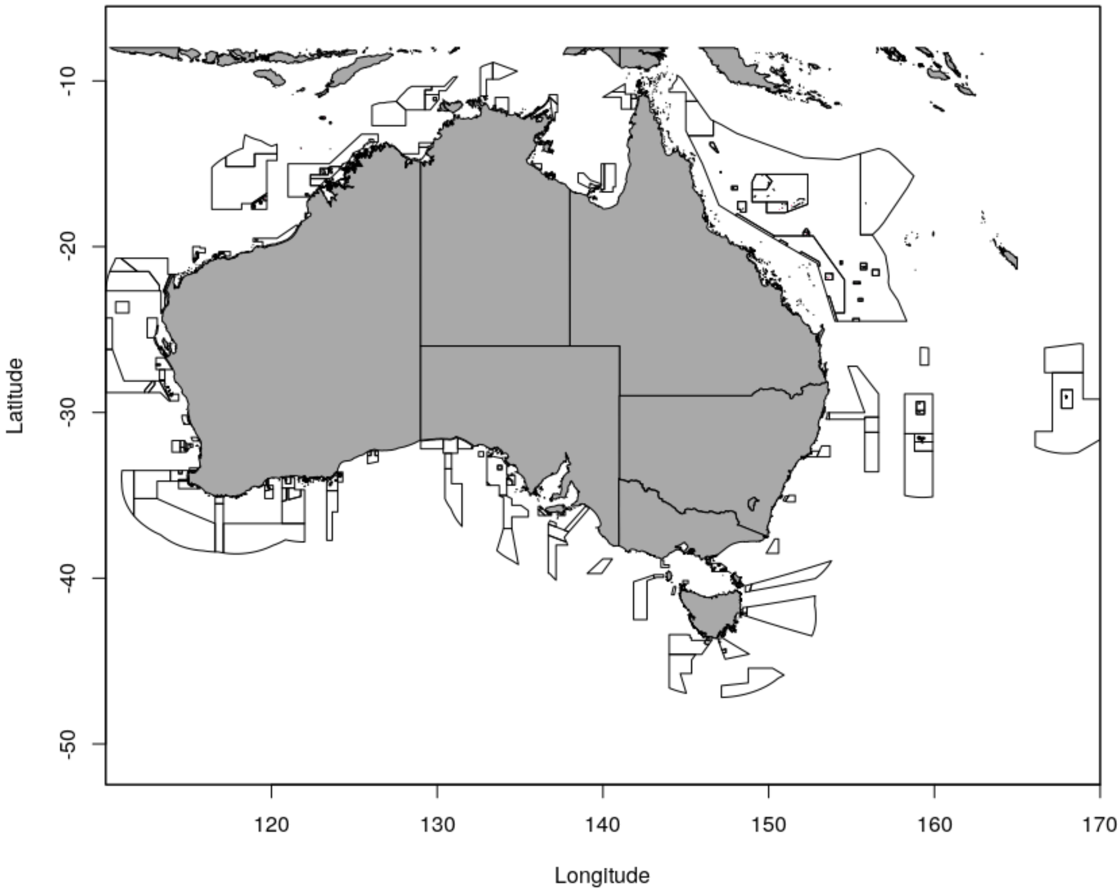

Figure 9.19: Oceanic mesophotic coral reefs

9.2.20 Bathypelagic and Abyssopelagic

The layers of the ocean between 1000m and 4000m (bathypelagic) and 4000m and 6000m (abyssopelagic), not influenced by the seafloor

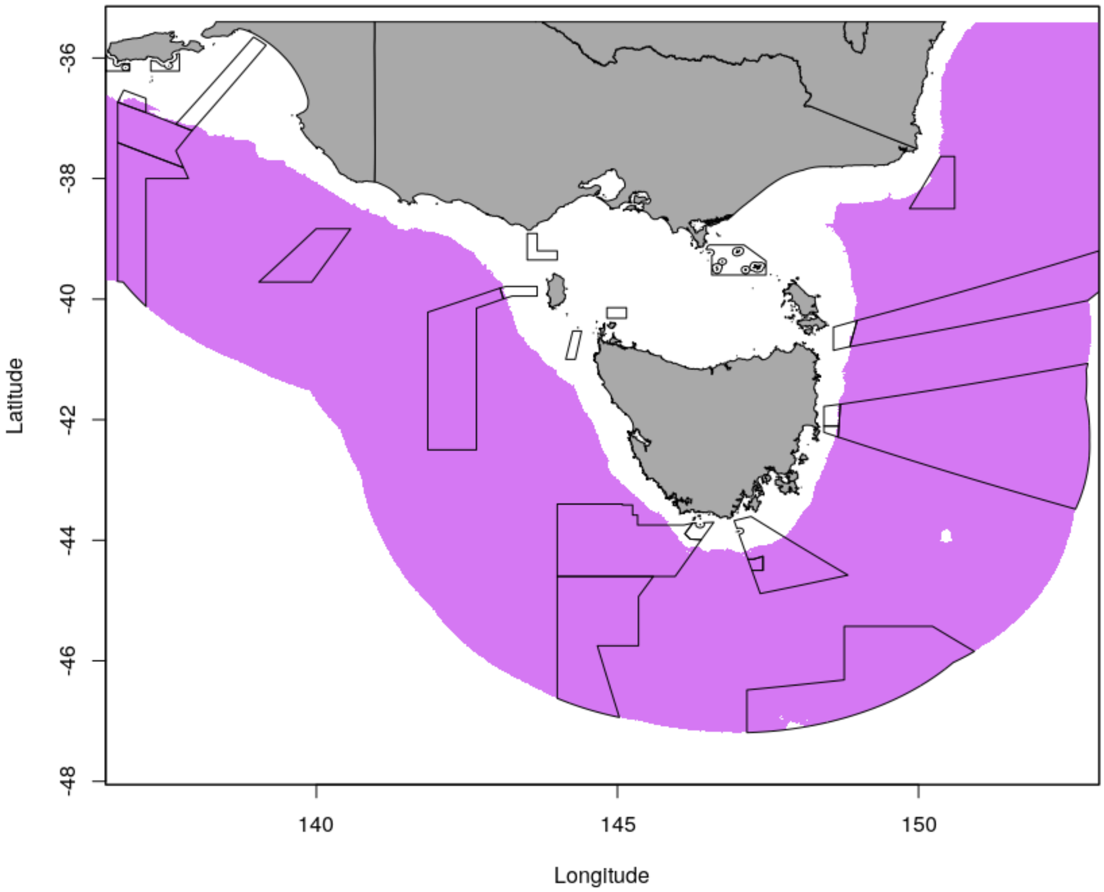

Figure 9.20: Bathypelagic & Abyssopelagic

9.2.21 Mesopelagic

The layer of the ocean between 200m and 1000m, not influenced by the seafloor

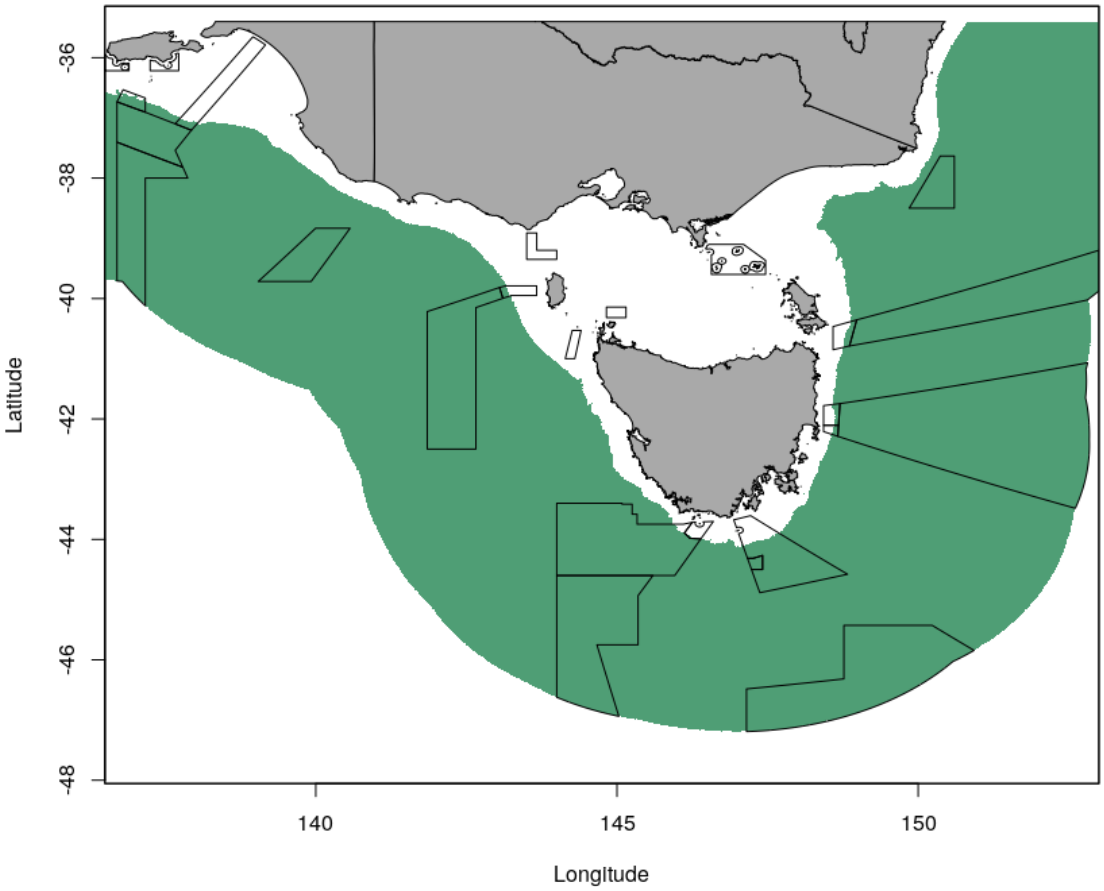

Figure 9.21: Mesopelagic

9.2.22 Off-shelf (oceanic) epipelagic

The uppermost layer of the ocean extending from the surface to 200m, that occurs seaward of the continental shelf break.

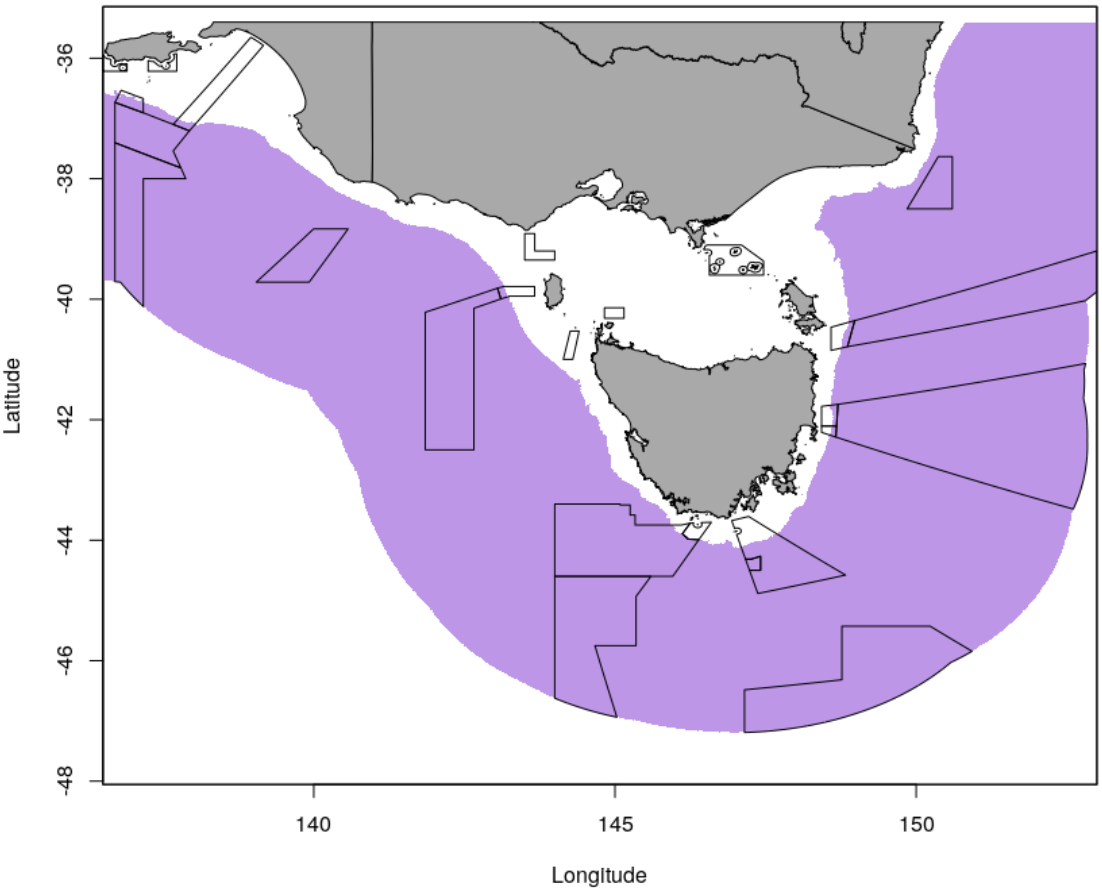

Figure 9.22: Off-shelf (oceanic) epipelagic

9.2.23 On shelf (neritic) epipelagic

The uppermost layer of the ocean extending from the surface to 200m, that occurs above the continental shelf.

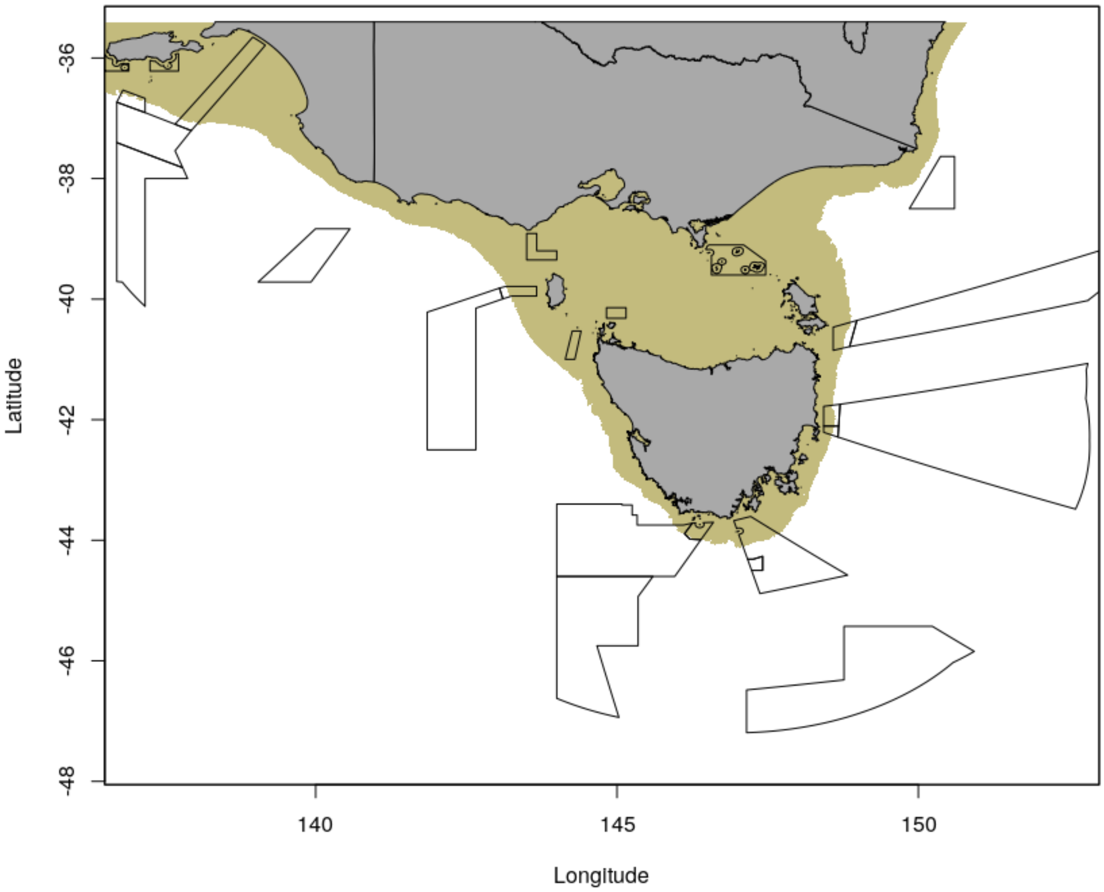

Figure 9.23: On shelf (neritic) epipelagic

10 APPENDIX D NEW MODEL OF SHELF REEF

This Appendix describes the modelling strategies, analysis methods and data sets used to predict the presence of hard-substrate reef throughout the Australian mainland's continental shelf, up to 200m depth. The reef modelling seeks to make binary predictions of reef/not-reef using expansive – that is across the Australian continental shelf – observations of environmental covariates.

A number of different analysis methods (and strategies) were utilized, several of which were deemed unsuccessful, before the most suitable approach was identified. The following sections of the report focus primarily on the most suitable approach but a summary of the alternative strategies that were investigated as part of the project is also included.

10.1 Reef observations and previous predictions

10.1.1 Global Archive BRUVs data

Habitat data were annotated from the background of the field of view of BRUV samples. A 5 x 4 grid was superimposed on 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 (2015)) was collected from each sample using Transect Measure 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'.

The spatial distribution of the available BRUV samples are shown in Figure 10.1.It is important to note that BRUV samples analysed here are not from a designed, national-scale, survey. Rather they are an amalgamation of individual surveys, which targeted different environments, such as deep reefs in southern Tasmania and seagrass in Geographe Bay, often for different reasons. The spatial location of the samples reflects the different objectives of the individual surveys, and hence location will likely be confounded with objectives. Nonetheless, this data set is one of the most spatially extensive set of observations of where reef has been seen, and importantly where reef it has not been seen. This is an $n \times 1$ vector of observations y classified into binary categories of reef/not reef.

10.1.2 Seamap Australia (NESP D3 Tier 1 product)

A nationally standardised habitat mapping data was obtained from Seamap Australia (Lucieer et al., 2019). This product, which predominantly covers coastal state waters, was first rasterised in ArcMap to match the same cell resolution of national bathymetry data sets based on 'SC_Level1' attribute. This provided a raster layer that contained binary reef / not reef. This layer was then converted to points using the 'Raster to Point' tool in ArcMap. This is an $n \times 1$ vector of verified observations and predictions of predominately shallow reef p_d.

10.1.3 CSIRO deep water reef product

This derived data set was provided by Rudy Kloser and is the result of a classification of the multibeam records held by CSIRO before 2010 (Kloser, Penrose, and Butler 2010; Kloser and Keith 2013). This is an $n \times 1$ vector of partially verified predictions of deep reef p_c.

The NESP D3 Tier 1 product and CSIRO deep reefs products can be used to make new predictions and/or check the predictions made by a model based on the BRUV habitat data. There is, however, some ambiguity here. It is entirely possible that the data sets are offering different interpretations as to what ‘reef’ is, and how they arrived at this classification. Poor agreement may mean that this project’s prediction model is performing poorly. It may mean that the models used in the previous studies are performing poorly, or even that both may be poor, or that simply the models are predicting different quantities, for example hardness from multibeam versus reef-looking habitat from the BRUV’s field of view.

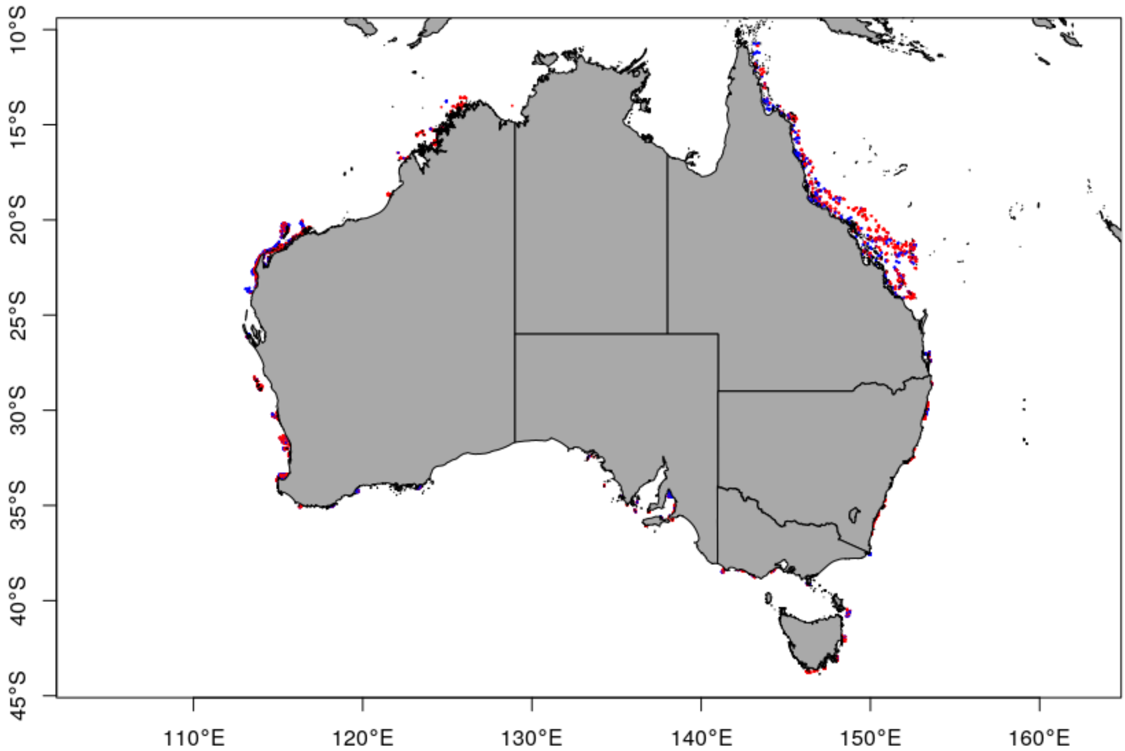

Figure 10.1: Location of the BRUV samples used in the development of the new shelf reefs model, showing locations where reef has been observed in the BRUV’s field of view (red dots) and locations where reef has not been observed (blue dots). Note this data set is an amalgamation of individual surveys, targeting different environments, for a variety of reasons.

10.2 Environmental covariates

10.2.1 Geoscience Australia 250m gridded bathymetry and derivatives

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 proxy 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.

Geoscience Australia also provided the same bathymetry-based derivatives for three finer-scale data sets: (i) a 2018, 50m resolution, spatially extensive (but incomplete) multibeam data set over the continental slope and parts of the shelf; (ii) a 2018, 30m complete multibeam data set over a region that includes a broad section of Australia's continental shelf, over 400 km wide, extending out from Western Australia and the Northern Territory; and, (iii) a 2018, 30m resolution, complete data set covering the Great Barrier Reef. These products allowed the project to explore the effects of using finer scale covariates. All of these products can be viewed on the AusSeabed Marine Data Portal https://portal.ga.gov.au/persona/marine.

10.2.2 Geoscience Australia sediments

Gridded sediment data (percent mud, sand and gravel) was obtained from the 2011 Geoscience Australia seabed sand content across the Australian continental EEZ data set. This data set provides spatially continuous predictions of the seabed sand content (sediment fraction 63-2000mm) expressed as a weight percentage ranging from 0 to 100%. The lineage of this data set is from Geoscience Australia's Marine Sediments database (MARS).

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 are similar to those reported by Li et al. (2012)). The spatial interpolation method used was experimentally selected from over 40methods/sub-methods based on assessment of predictive errors. It should be noted that the underlying MARS data assumes that substrata is not rock.

10.2.3 Geoscience Australia current velocity

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

10.2.4 Radial measure

A new delineator of space that we call *radial measure* was also calculated. This is designed to give a bearing around the country, from a single internal location. It performs a similar role to that of the string distance variable in the IMCRA analysis (Last et al. (2011)). To create this variable, an arbitrary location is chosen within the center of the country and angles, in radians, is calculated for each location within the grid. The center point has longitude=137 and latitude =-27. This point was chosen subjectively to avoid confusion between sites in Victoria and Tasmania, and between sites in the southern part of western Australia. The radial measure ranges from $-\pi$ to π and increases in an anti-clockwise direction (so that Perth has a smaller value than Sydney).

Figure 10.2 plots some of the model covariates to illustrate the spatial extent and pattern of the gridded data. Note that some of the covariates (relief, slope and surface) are log 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. In this analysis, however, we are primarily interested in prediction.

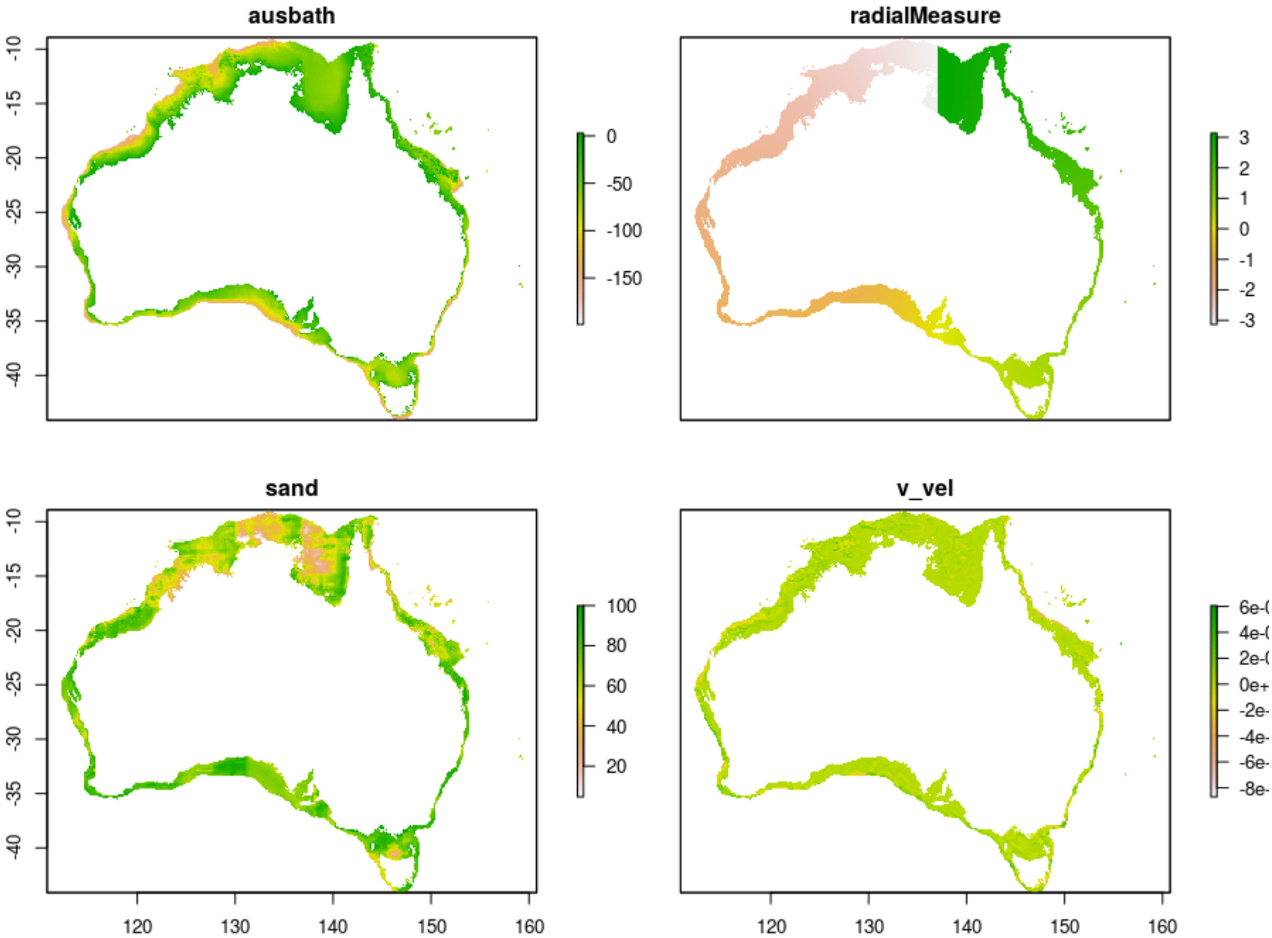

Figure 10.2: Examples of the some of the covariates used in the new shelf reefs model. Note that the radial measure variable is increasing in an anti-clockwise direction around the country (from the due north direction).

10.3 Model overview

The geo-location of reef is assumed to depend on p covariates, such as bathymetry, bathymetry derivatives (such as aspect and rugosity), and possibly other covariates, which are bundled into an $n \times p$ covariate matrix X.

The basic model structure is given by:

$$\text{logit}^{-1}[y|X, p_d, p_c] \quad = \alpha + f(X; b) + f_d(p_d; b_d) + f_c(p_c; b_c),$$

where we assume the effects of the different sources of covariates do not interact. All covariate parameters, b, b_d and b_c define the functions $f(\cdot)$, $f_d(\cdot)$, and $f_c(\cdot)$, which may be linear, non-linear, interacting, and so on. Further data are available to contribute to the estimation of the functions $f_d(\cdot)$ and $f_c(\cdot)$, but these will be based on the same covariates as available for the observations X.

The analysis ignores the fact that the previous reef predictions are not available everywhere across the new model prediction grid. Strictly speaking, to make up for this deficiency, the new analysis should integrate over the distribution(s) of the missing predictions (see for example Gelman et al. (2013)) and treat these predictions as incomplete data. This would lead to a model with a hierarchical structure similar to the classic modelling paper Laird and

Ware (1982), except that there would be non-linearities in the model due to multiple link functions.

A more direct approach, however, that does not enable interpretation of the different components of the model, is to ignore this integration and use only the point predictions that available. The integration mentioned in the previous paragraph is needed to account for errors-in-covariates (Carroll et al., 2006), which can undermine inferences in spatial ecology (Foster, Shimadzu, and Darnell 2012; Stoklosa et al., 2015). For prediction purposes, however, it doesn't really matter what the model covariates are (real or otherwise), they just need to be spatial. Irrelevant spatial covariates will lead to model predictions with that are not repeatable and have poor ecological plausibility.

The advantage of the direct approach is that the modelling process is simplified – the observations, y can be modelled as a function of the bathymetric derivatives and the predictions from the other products without recourse to hierarchical structures that would complicate the estimation procedure. Typically, this approach would be the first course of action in an ecological modelling exercise.

The disadvantages of this approach are two-fold. First, the parameters are no longer interpretable. For example, the effect of X is tied up in the function $f(X;b)$ and f_c. Secondly, it is not possible to propagate uncertainty about the model's covariates through to its predictions. When fitted directly, the model above assumes that there is no variability in the predictions from CSIRO deep reef layer nor the NESP D2 product. This is a convenient, but likely incorrect, assumption.

10.4 Details of the modelling approach

The analysis tried a large number of iterations of different models/algorithms before settling on a model configuration whose predictions made *sense*, in that reef was/wasn't predicted where reef isn't/is obviously not. Whilst this is not satisfying from a statistical viewpoint (where formal inference is the goal), it nevertheless is necessary and highlights that not all analytical approaches are equally effective in this situation.

10.4.1 Predictive model

The predictive model is a very simple form of a generalized additive model (GAM, see Hastie and Tibshirani (1990),Wood (2006)). In particular, it is a regression spline approach (see 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 50m or 180m 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 sufficiently 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. Figure 10.3 shows the point predictions of the model.

Since the model is a simplified GAM, we are also able to obtain confidence intervals for the point prediction. These give bounds where the point estimate might be if all the data were to be collected again. We stress that the width of these intervals are likely to be under-estimated as there are levels of uncertainty that are missing. Primarily, the uncertainty in the model specification/selection process. Figure 10.4 shows these prediction intervals.

The model's point predictions provide a prediction of reef probability. For communication and for subsequent analysis, however, a simplified presence/absence of reef is desirable. To accommodate this, we identified grid cells that we believe are likely to contain reef and those cells that we think are likely to contain not-reef (Figure 10.5). This was done using cut-off values so that 10% of the non-reef (reef) sites are above (below) the cut-off value. The error rates associated with this categorisation were calculated on the internal validation (cross-validation) method described below. Note again, that this subsequent analysis should, but currently does not, account for uncertainty in the model's point predictions (see Carroll et al. 2006; Foster et al., 2012; Stoklosa et al. 2015).

10.4.2 Internal validation

To assess how well the model performs we undertook a 5-fold cross-validation procedure (e.g. Hastie and Tibshirani (1990),Hastie, Tibshirani, and Friedman (2001) among others). This is an *internal* validation procedure as it assess how well the BRUV data can be predicted when trained with the BRUV data. To perform the cross validation, we repeatedly withheld $1/5$ of the data, estimated using the remaining $4/5$ and predicted the withheld data. This was done 200 times. For each of the withheld data sets, we assess the model's ability to predict by inspecting the average prediction for the reef/not-reef categories in the withheld data, as well as the AUC statistic. Given then there are 200 hold-out samples, we can also calculate the confidence intervals for the values (Table 10.1).

Table 10.1: Internal validation results for the BRUV reef data.

	noReef	Reef	AUC
low.CI	0.585	0.700	0.680
mean	0.595	0.707	0.699
high.CI	0.606	0.715	0.720

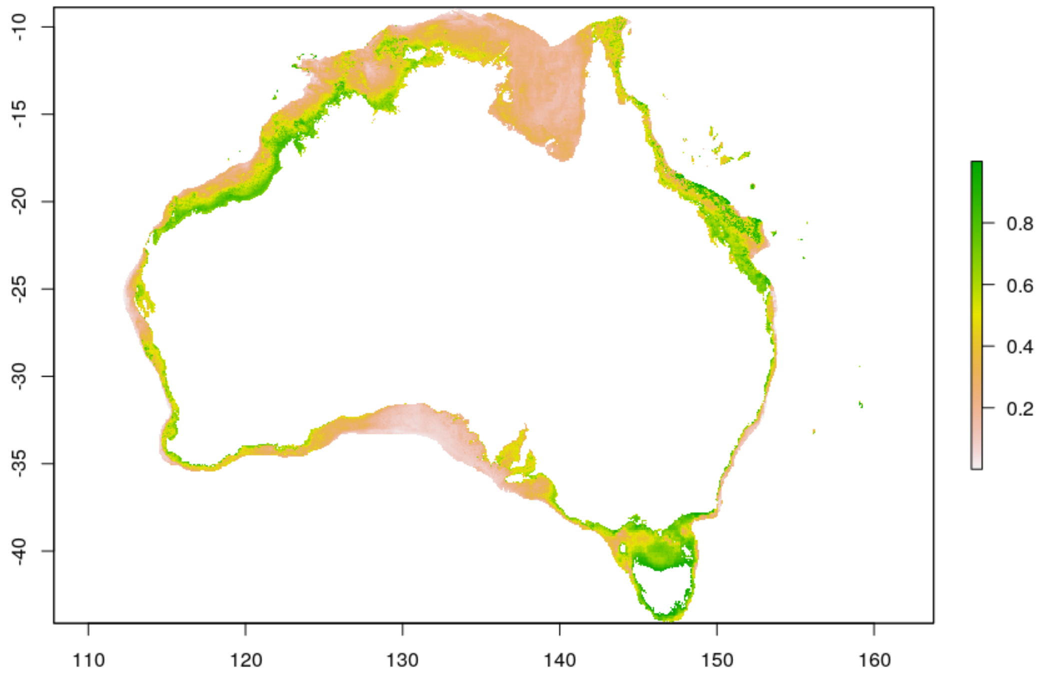

Figure 10.3: Point predictions of the shelf reef model.

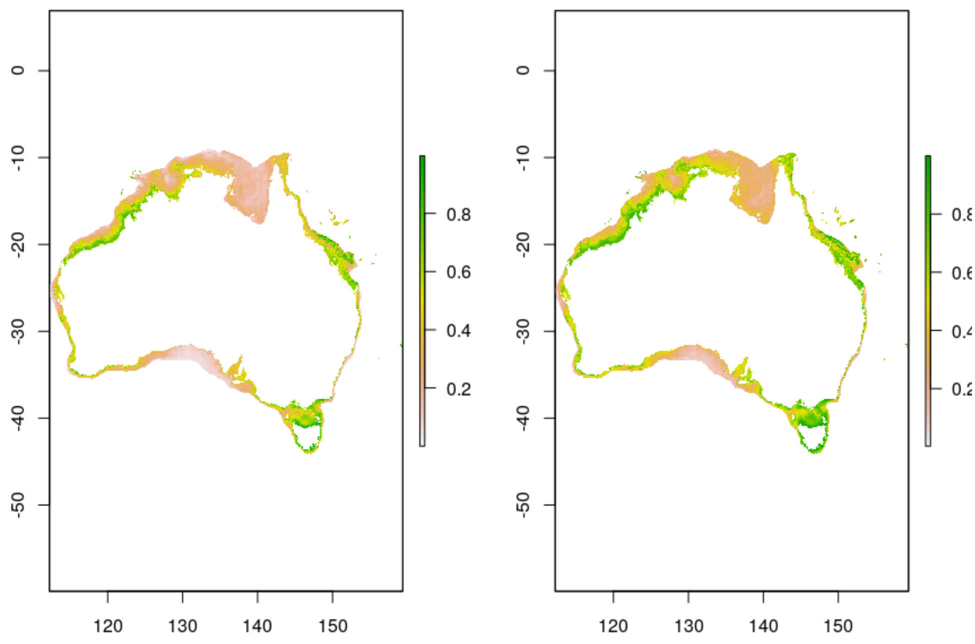

Figure 10.4: Confidence interval predictions for the shelf reefs model. Left panel shows the lower 95% CI. Right panel shows the upper 95% CI.

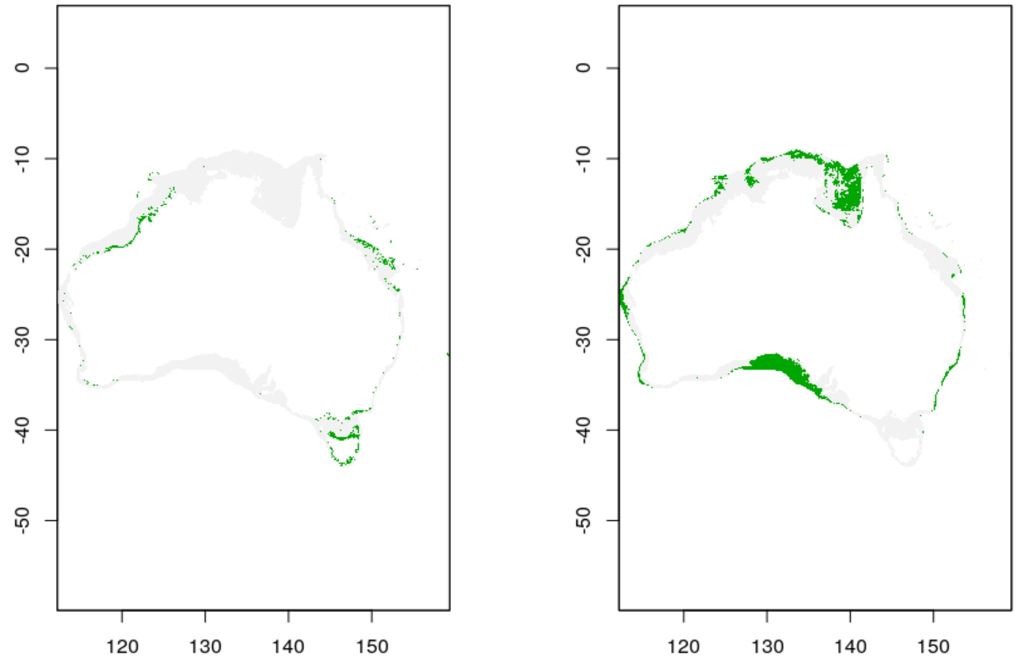

Figure 10.5: Binarized predictions from the shelf reefs model. Left panel shows where reef is likely to be. Right panel shows where not-reef is likely to be. In both cases the cut-off in the model's predicted probability of reef is chosen so that there is 10% chance of all not-reef (reef) locations being above (below) that value.

It is clear from Table 10.1 that the model has a modest (at best) ability to predict reef/not-reef. With sites that are not-reef having a predicted probability of almost 60%, and sites that are reef having a predicted probability of just over 70%. This is not great discrimination, as verified by the AUC statistic of 0.7, which is quite low.

Whilst performing the internal validation, we also examined the distribution of the predicted probabilities for reef and not-reef. For this, the distribution (via a histogram) for each hold-out set (and for reef/not-reef) was stored and a point-wise average was taken over the hold-out sets. This gives an estimate of the distribution of predictions for hypothetical new data. If the model had good discrimination, then these distributions should be well separated, but our interest lies mostly in the tails. In the tails lies information about whether we can reliably distinguish between sites that are highly likely to be reef/not-reef. It should also provide information about how to choose a reasonable cut-off value for the binarized plots given earlier.

To obtain the cut-off value for reef predictions, we find the predicted probability above which contains 10% of the not-reef sites. Likewise, for the cut-off for not-reef predictions. No doubt, other sensible metrics could be used, like the cumulative `posterior' probability of reef given prediction, but this would require knowledge of the prior distribution of the amount of reef that we do not have (except that it is low).

10.4.3 External validation

For these data, it is possible to take the validation further. In particular, we can move away from internal (cross-) validation and move towards an external validation where predictions are compared against completely independent data sets. Here, these data are the NESP D2 Tier 1 product and the CSIRO deep-water reef data. We note that the deep-water reef data is qualitatively different to the other two – it is a predictive model that is both deeper than the BRUV and Tier 1 data and it is based upon backscatter data. The technical aspects of the comparisons follow that of the internal validation, except that: (i) there is no scope for uncertainty estimation (there are no replicate external data sets); and (ii) we no longer try to find cut-off values. The results are shown in Table 10.2.

It is clear from Table 10.2 that the model predictions do not capture the variation in the Tier 1 data product; there is only a small difference in mean predicted probability for when the Tier 1 data informs reef /not-reef. The AUC statistic confirms this, saying that the result is little better than random chance.

The model does a better job at distinguishing the deep-reefs classification. Note, however, that none of these sites are predicted with high probability on average, presumably due to a negative modelled depth-reef relationship. This could be due to the scale of reefs in the deeper water better matching the environmental covariates used, the relationships between reef and environment better matching the model form, or it could just be random chance.

Table 10.2: External validation results for the new shelf reef model.

	no reef	reef	AUC
Seamap	0.612	0.652	0.559
Rudy	0.066	0.373	0.884

It is also important to note that the model is *extrapolating* to predict the deep-reef data. In particular, it is extrapolating in depth but possibly also in other covariates. The natural spline formulation of the smooth term will produce linear effects past the last knot point, which will be better than other kinds of splines (but still not foolproof).

The disagreement between the model and the Tier 1 data is disappointing and could be due a poor model or a fundamental difference in the data. To investigate this issue further, we performed a model-free comparison. For each BRUV deployment, we looked at all of the Tier 1 data within 100m (if any) and tabulated the congruence between the two (Table 10.3). The agreement is reasonably good – more than 70% – between the BRUV data (both reef locations and no-reef locations). This implies that the poor external validation result of the new model, to the Tier 1 data, is occurring because the new model is not adequately capturing the variation within the BRUV habitat data (which also accords with the results of the model's internal validation).

Table 10.3: Model-free external validation results for the new shelf reef model based solely on spatial proximity. First two columns are numbers in each cell and the right hand columns are standardised versions.

	Tier1 Reef	Tier1 no reef	Tier1 Reef	Tier1 no reef
BRUV Reef	938	323	0.744	0.256
BRUV no reef	171	437	0.281	0.719

10.5 Modelling dead ends

As mentioned earlier, there were a number of modelling dead-ends that were discarded prior to settling on the model presented earlier. These are now outlined, so that we can learn for future projects. Note that these are not `mistakes', rather they are just part of the research process (dead-ends). No results are given for any of these dead-ends, but we do mention them and describe what they were *trying* to achieve.

10.5.1 Random Forest (RF) and Boosted Regression Tree (BRT)

The first approach tried for modelling the BRUV reef data was to use the machine learning algorithm RF. This approach can give an extremely flexible functional forms (mapping the environment to the response), and so was very appealing. The flexibility is made even more appealing by the fact that it is good at exploring the interaction space of covariates (e.g. velocity acts different at depth). This possibly complex interaction space is useful for a national-scale model because there is some question as to whether the geographical/ecological processes are the same in all geographical regions and at all depths. However, it became quickly clear that the predictions were not sensible, in that they were predicting reef in locations where it is thought that reef should not be (e.g. at depth, GAB, …). Making the model less flexible (increasing the node sizes, decreasing the tree depth (less interactions), decreasing the number of covariates within each 'stump', and so on) made the model predictions slightly better, but still not tenable

The next approach involved using the BRT approach from machine learning. BRT is, in many ways, an extension of the ideas underpinning RF and should out-perform RF for well-behaved data. The results *were* better, but not acceptably so. There was still large over-prediction in some areas, presumably (like the RF) due to the BRT picking up unwanted effects in higher-order interactions. Like RF, making the model 'stiffer' did help but not to the point of acceptability.

10.5.2 Geographically weighted predictions

It struck us that the problem with the prediction approach *might* be because we are trying to fix a single geographical process to the entire continent. This is a large assumption and may not work. To potentially overcome this deficiency, we fit a series of geographically-local models to see if we can improve fits. This is not a new idea (Austin 2007). For this prediction problem, we use the radial measure as the delineator of space and adjust for the cyclic nature of the variable. This was done by using a cyclic B-spline of radial measure as the weights. The weights were then used in a BRT model, for each of the weightings. The predictions from each of the fitted BRTs were quite variable in terms of their predictions. Many of them produced *reasonable* predictions for some places in the country. Unfortunately, and this sinks the method, the spatial regions where a BRT for a region *was generally **not*** those same regions where the BRT was trained. Of course, this is an assessment done by eye and so it is not a formal result. Nevertheless, this is a curious observation. It suggests that there might be some sort of spatially related bias to *the collection* of the BRUV data. That is, the BRUVs may have been purposefully deployed onto reefs more often in some regions than in others.

10.5.3 GAMs, GLMs and GLMMs

After moving back to a single, national-scale model, we tried to increase `stiffness' in the model by including only main effects, and having those main effects constrained to be smooth functions. This is achieved by using GAMs, by way of cubic regression splines (Wood 2006). The resulting predictions are substantially better than the BRT and RF predictions. We concluded, however, that over-prediction was still evident. This led us to reducing the flexibility of each of the smooth curves (and the model that we presented earlier) by using low-order natural regression splines.

To complete the cycle, we also changed the natural regression splines to quadratic functions. This approach is even simpler than the natural regression spline approach. It didn't make much difference in terms of the apparent predictive accuracy of the reef maps, so we reverted back to the simple regression spline model.

To try and overcome the possible problem of geographical sampling bias (some areas targeting reef more than others), a random effect for mission was trialled. Inclusion of this random effect should adjust, somewhat, this geographical bias, but the model is fairly `clunky' in that is it a blunt spatial tool. The predictions from this model were quite different to those from previous models, implying that the random effect did have a pronounced effect. However, they were also non-sensible in that they over-predicted reef in areas known to be depositional (e.g. the Great Australian Bight).

10.5.4 Emulating external data sources

To try and improve the prediction of the BRUV reef data, we also tried including a layer based upon the NESP Tier 1 data and (separately) the CSIRO deep reef data. However, neither of these data sources are expansive – they are not available everywhere – and so we first had to *emulate* those data. This involved using a BRT/RF to describe the relationship between the Tier 1/deep-reef data and the environment, then predicting (or emulating) using those models to the locations of the BRUV data. The emulated data were then used as any other covariate in the new model. While this should be a good idea, as it approximates a data-integration type approach, it does rely on: (i) the emulators being a "good" representation of the Tier 1 and deep reef data; and (ii) there being a correspondence between the BRUV reef data and the external data sets. We already know, from the previous description of model-free external validation, that there is some agreement between Tier 1 and the BRUV data. Irrespectively, adding these emulated variables did not improve the model's predictions (of BRUV reef). Presumably, this is largely because the ability to emulate the Tier 1 and deep reef data, using BRTs, is as poor as prediction is for BRUV data (using BRTs and no emulators).

11 APPENDIX E DATA SET SUMMARY

Table 11.1: Summary of the data sets used to create activity and sub-activity layers. Data proxy codes are as follows: 0 = Data available that can be attributed by sub-activity, not a proxy, 1 = Directly attributable data unavailable, available data used as a proxy for the sub-activity, 2 = Data available but cannot be attributed to the sub-activity, not a proxy

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Climate change	Altered ocean currents	Altered ocean currents	1	0	various	2003	2014
Climate change	Increased frequency and intensity of severe weather events	Increased frequency and intensity of severe weather events	1	0	various	1842	2019
Climate change	Increased sea surface temperature	Increased sea surface temperature	1	0	deg C Days	2013	2018
Climate change	Ocean acidification	Ocean acidification	1	0	arrag	2003	2013
Climate change	Sea level rise	Sea level rise	1	0		2008	2013
Climate change adaptation	Carbon storage and sequestration	Habitat modification (physical disturbance and removal)	na	na	na	na	na
Commercial aquaculture	Aquaculture (including commercial pearling)	Habitat modification (due to changes in nutrients and organic matter)	1	1		2016	2016
Commercial aquaculture	Aquaculture (including commercial pearling)	Habitat modification (physical disturbance and removal)	1	1		2016	2016
Commercial aquaculture	Aquaculture (including commercial pearling)	Introduced pathogens/disease	1	1		2016	2016
Commercial aquaculture	Aquaculture (including commercial pearling)	Marine debris (including microplastics and litter on islands)	1	2	kgs	2016	2016
Commercial aquaculture	Aquaculture (including commercial pearling)	Marine pests	1	1		2016	2016
Commercial aquaculture	Aquaculture (including commercial pearling)	Noise pollution	1	1		2016	2016

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Commercial aquaculture	Vessel transiting	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Commercial aquaculture	Vessel transiting	Marine pests	1	1		2013	2016
Commercial aquaculture	Vessel transiting	Noise pollution	1	1	?	2013	2016
Commercial fishing	Danish Seine	Extraction of benthic mobile invertebrates	1	1	hrs	2015	2015
Commercial fishing	Danish Seine	Extraction of fish and free-swimming invertebrates	1	0	hrs	2015	2015
Commercial fishing	Danish Seine	Extraction of megafauna (excluding fish)	1	1	hrs	2015	2015
Commercial fishing	Danish Seine	Habitat modification (physical disturbance and removal)	1	1	hrs	2015	2015
Commercial fishing	Demersal trawl	Extraction of benthic mobile invertebrates	1	1	hrs	2015	2015
Commercial fishing	Demersal trawl	Extraction of fish and free-swimming invertebrates	1	0	hrs	2015	2015
Commercial fishing	Demersal trawl	Extraction of megafauna (excluding fish)	1	1	hrs	2015	2015
Commercial fishing	Demersal trawl	Habitat modification (physical disturbance and removal)	1	1	hrs	2015	2015
Commercial fishing	Demersal trawl	Noise pollution	1	1	hrs	2015	2015
Commercial fishing	Dropline	Extraction of benthic mobile invertebrates	na	na	na	na	na
Commercial fishing	Dropline	Extraction of fish and free-swimming invertebrates	na	na	na	na	na
Commercial fishing	Dropline	Extraction of megafauna (excluding fish)	na	na	na	na	na
Commercial fishing	Dropline	Habitat modification (physical disturbance and removal)	na	na	na	na	na
Commercial fishing	Hand collection	Extraction of benthic mobile invertebrates	1	1	Nops	2011	2018

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Commercial fishing	Hand collection	Extraction of fish and free-swimming invertebrates	1	0	Nops	2011	2018
Commercial fishing	Hand collection	Human presence (disturbance of mobile fauna communities or populations)	1	1	Nops	2011	2018
Commercial fishing	Hand net	Extraction of benthic mobile invertebrates	1	0	Nops	2011	2018
Commercial fishing	Hand net	Extraction of fish and free-swimming invertebrates	1	0	Nops	2011	2018
Commercial fishing	Hand net	Human presence (disturbance of mobile fauna communities or populations)	1	1	Nops	2011	2018
Commercial fishing	Longline (demersal, auto-longline)	Extraction of benthic mobile invertebrates	1	1	Nhooks	2015	2015
Commercial fishing	Longline (demersal, auto-longline)	Extraction of fish and free-swimming invertebrates	1	0	Nhooks	2015	2015
Commercial fishing	Longline (demersal, auto-longline)	Extraction of megafauna (excluding fish)	1	1	Nhooks	2015	2015
Commercial fishing	Longline (demersal, auto-longline)	Habitat modification (physical disturbance and removal)	1	1	Nhooks	2015	2015
Commercial fishing	Longline (pelagic)	Extraction of benthic mobile invertebrates	1	1	Nhooks	2015	2015
Commercial fishing	Longline (pelagic)	Extraction of megafauna (excluding fish)	1	1	Nhooks	2015	2015
Commercial fishing	Longline (pelagic)	Habitat modification (physical disturbance and removal)	1	1	Nhooks	2015	2015
Commercial fishing	Longline (pelagic)	Extraction of fish and free-swimming invertebrates	1	0	Nhooks	2015	2015
Commercial fishing	Minor line	Extraction of benthic mobile invertebrates	1	1	Nops	2015	2015
Commercial fishing	Minor line	Extraction of fish and free-swimming invertebrates	1	0	Nops	2015	2015
Commercial fishing	Minor line	Extraction of megafauna (excluding fish)	1	1	Nops	2015	2015
Commercial fishing	Minor line	Habitat modification (physical disturbance and removal)	1	1	Nops	2015	2015

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Commercial fishing	Net - demersal	Extraction of benthic mobile invertebrates	1	1	kms	2015	2015
Commercial fishing	Net - demersal	Extraction of fish and free-swimming invertebrates	1	0	kms	2015	2015
Commercial fishing	Net - demersal	Extraction of megafauna (excluding fish)	1	1	kms	2015	2015
Commercial fishing	Net - demersal	Habitat modification (physical disturbance and removal)	1	1	kms	2015	2015
Commercial fishing	Net - pelagic	Extraction of benthic mobile invertebrates	1	1	kms	2013	2018
Commercial fishing	Net - pelagic	Extraction of fish and free-swimming invertebrates	1	0	kms	2013	2018
Commercial fishing	Net - pelagic	Habitat modification (physical disturbance and removal)	1	1	kms	2013	2018
Commercial fishing	Net - pelagic	Extraction of megafauna (excluding fish)	1	1	kms	2013	2018
Commercial fishing	Pot and Trap	Extraction of benthic mobile invertebrates	1	0	Nops	2011	2018
Commercial fishing	Pot and Trap	Extraction of fish and free-swimming invertebrates	1	0	Nops	2011	2018
Commercial fishing	Purse Seine	Extraction of benthic mobile invertebrates	1	1	Nops	2015	2015
Commercial fishing	Purse Seine	Extraction of fish and free-swimming invertebrates	1	0	Nops	2015	2015
Commercial fishing	Purse Seine	Extraction of megafauna (excluding fish)	1	1	Nops	2015	2015
Commercial fishing	Purse Seine	Habitat modification (physical disturbance and removal)	1	1	Nops	2015	2015
Commercial fishing	Scallop dredge	Extraction of benthic mobile invertebrates	na	na	Nops	2013	2018
Commercial fishing	Scallop dredge	Extraction of fish and free-swimming invertebrates	na	na	Nops	2013	2018
Commercial fishing	Scallop dredge	Extraction of megafauna (excluding fish)	na	na	Nops	2013	2018
Commercial fishing	Scallop dredge	Habitat modification (physical disturbance and removal)	na	na	Nops	2013	2018

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Commercial fishing	Scallop dredge	Noise pollution	na	na	Nops	2013	2018
Commercial fishing	Trawl - midwater	Extraction of benthic mobile invertebrates	na	na	Nops	2013	2018
Commercial fishing	Trawl - midwater	Extraction of fish and free-swimming invertebrates	na	na	Nops	2013	2018
Commercial fishing	Trawl - midwater	Extraction of megafauna (excluding fish)	na	na	Nops	2013	2018
Commercial fishing	Trawl - midwater	Habitat modification (physical disturbance and removal)	na	na	Nops	2013	2018
Commercial fishing	Trotline	Extraction of benthic mobile invertebrates	1	1	Nops	2015	2015
Commercial fishing	Trotline	Extraction of fish and free-swimming invertebrates	1	0	Nops	2015	2015
Commercial fishing	Trotline	Extraction of megafauna (excluding fish)	1	1	Nops	2015	2015
Commercial fishing	Trotline	Habitat modification (physical disturbance and removal)	1	1	Nops	2015	2015
Commercial fishing	Vessel transiting	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Commercial fishing	Vessel transiting	Marine debris (including microplastics and litter on islands)	1	2	kgs	2014	2014
Commercial fishing	Vessel transiting	Marine pests	1	1	kms	2013	2016
Commercial media	Commercial media	Human presence (disturbance of mobile fauna communities or populations)	0	na			
Commercial shipping	Vessel transiting	Habitat modification (due to suspended sediments - including smothering)	1	1	kms	2013	2016
Commercial shipping	Vessel transiting	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Commercial shipping	Vessel transiting	Introduced pathogens/disease	1	1	kms	2013	2016
Commercial shipping	Vessel transiting	Marine debris (including microplastics and litter on islands)	1	2	kgs	2014	2014

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Commercial shipping	Vessel transiting	Marine pests	1	1	kms	2013	2016
Commercial shipping	Vessel transiting	Noise pollution	1	2	?	2013	2016
Commercial shipping	Vessel transiting	Oil/fuel spill or leak	1	2	sum per year	1970	2015
Commercial shipping	Vessel transiting	Overabundant native species	1	1	kms	2013	2016
Commercial tourism	Charter fishing tours	Extraction of fish and free-swimming invertebrates	1	1	kms	2013	2016
Commercial tourism	Charter fishing tours	Habitat modification (physical disturbance and removal)	1	1	kms	2013	2016
Commercial tourism	Charter fishing tours	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Commercial tourism	Charter fishing tours	Introduced pathogens/disease	1	1	kms	2013	2016
Commercial tourism	Charter fishing tours	Marine debris (including microplastics and litter on islands)	1	2	kgs	2014	2014
Commercial tourism	Charter fishing tours	Marine pests	1	1	kms	2013	2016
Commercial tourism	Charter fishing tours	Noise pollution	1	1	kms	2013	2016
Commercial tourism	Commercial aviation tours (up to 3000 m above sea level)	Human presence (disturbance of mobile fauna communities or populations)	0	na			
Commercial tourism	Commercial aviation tours (up to 3000 m above sea level)	Noise pollution	0	na			
Commercial tourism	Non-fishing related tourism - nature watching	Habitat modification (physical disturbance and removal)	1	1	kms	2013	2016
Commercial tourism	Non-fishing related tourism - nature watching	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Commercial tourism	Non-fishing related tourism - nature watching	Marine debris (including microplastics and litter on islands)	1	2	kgs	2014	2014
Commercial tourism	Non-fishing related tourism - nature watching	Marine pests	1	1	kms	2013	2016

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Commercial tourism	Non-fishing related tourism - nature watching	Noise pollution	0	na	kms	2013	2016
Commercial tourism	Non-fishing related tourism - scuba/snorkel tour	Habitat modification (physical disturbance and removal)	1	1	kms	2013	2016
Commercial tourism	Non-fishing related tourism - scuba/snorkel tour	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Commercial tourism	Non-fishing related tourism - scuba/snorkel tour	Introduced pathogens/disease	1	1	kms	2013	2016
Commercial tourism	Non-fishing related tourism - scuba/snorkel tour	Marine pests	1	1	kms	2013	2016
Commercial tourism	Non-fishing related tourism - vessel transiting	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Commercial tourism	Non-fishing related tourism - vessel transiting	Marine pests	1	1	kms	2013	2016
General use, access & waste management	Ballast water discharge and exchange	Introduced pathogens/disease	1	1	m3	2016	2016
General use, access & waste management	Ballast water discharge and exchange	Marine pests	1	1	m3	2016	2016
General use, access & waste management	Camping	Human presence (disturbance of mobile fauna communities or populations)	0	na			
General use, access & waste management	Camping	Marine debris (including microplastics and litter on islands)	0	na			
General use, access & waste management	Camping	Terrestrial pest plants and animals	0	na			
General use, access & waste management	Disposal of waste from normal operations of vessels	Sewage waste	1	1	kms	2013	2016

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
General use, access & waste management	Non-commercial remote piloted aircraft	Noise pollution	0	na			
General use, access & waste management	Recreational use – boating (including vessel transiting)	Habitat modification (physical disturbance and removal)	1	1	number per year	2011	2015
General use, access & waste management	Recreational use – boating (including vessel transiting)	Human presence (disturbance of mobile fauna communities or populations)	1	0	number per year	2011	2015
General use, access & waste management	Recreational use – boating (including vessel transiting)	Introduced pathogens/disease	1	1	number per year	2011	2015
General use, access & waste management	Recreational use – boating (including vessel transiting)	Marine debris (including microplastics and litter on islands)	1	2	kgs	2014	2014
General use, access & waste management	Recreational use – boating (including vessel transiting)	Marine pests	1	1	number per year	2011	2015
General use, access & waste management	Recreational use - nature watching (above and below water)	Human presence (disturbance of mobile fauna communities or populations)	1	0	number per year	2011	2015
General use, access & waste management	Recreational use - nature watching (above and below water)	Marine debris (including microplastics and litter on islands)	1	2	number per year	2011	2015
Hunting and fishing	Cultural fishing	Extraction of benthic mobile invertebrates	0	na			
Hunting and fishing	Cultural fishing	Extraction of fish and free-swimming invertebrates	0	na			
Hunting and fishing	Cultural fishing	Habitat modification (physical disturbance and removal)	0	na			
Hunting and fishing	Traditional hunting	Extraction of megafauna (excluding fish)	0	na			

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Land-use intensification	Agricultural diffuse source runoff	Changes in nutrients and organic matter	1	0	?	2008	2013
Land-use intensification	Agricultural diffuse source runoff	Introduced pathogens/disease	1	1	?	2008	2013
Land-use intensification	Agricultural diffuse source runoff	Marine debris (including microplastics and litter on islands)	1	0	kgs	2014	2014
Land-use intensification	Agricultural diffuse source runoff	Noxious substances (including chemicals & heavy metals)	1	2	?	2008	2013
Land-use intensification	Agricultural diffuse source runoff	Habitat modification (due to suspended sediments - including smothering)	1	0			
Land-use intensification	Point discharges	Marine debris (including microplastics and litter on islands)	1	0	kgs	2014	2014
Land-use intensification	Point discharges	Noxious substances (including chemicals & heavy metals)	1	2	?	2008	2013
Land-use intensification	Point discharges	Sewage waste	1	0	?	2017	2017
Land-use intensification	Stock grazing of riparian and marine vegetation	Changes in nutrients and organic matter	0	na			
Land-use intensification	Stock grazing of riparian and marine vegetation	Habitat modification (physical disturbance and removal)	0	na			
Land-use intensification	Stock grazing of riparian and marine vegetation	Habitat modification (due to suspended sediments - including smothering)	0	na			
Land-use intensification	Stock grazing of riparian and marine vegetation	Terrestrial pest plants and animals	0	na			
Mining	Construction and operation of pipelines	Habitat modification (physical disturbance and removal)	1	0	P/A	2011	2015
Mining	Mining - seismic survey	Noise pollution	1	0	?	2011	2015
Mining	Mining operations including exploration	Habitat modification (due to suspended sediments - including smothering)	1	1	N	2015	2015

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Mining	Mining operations including exploration	Habitat modification (physical disturbance and removal)	1	0	N	2015	2015
Mining	Mining operations including exploration	Introduced pathogens/disease	1	1	N	2015	2015
Mining	Mining operations including exploration	Light pollution	1	2	?	2002	2016
Mining	Mining operations including exploration	Marine pests	1	1	N	2015	2015
Mining	Mining operations including exploration	Noise pollution	1	2	?	2013	2016
Mining	Mining operations including exploration	Noxious substances (including chemicals & heavy metals)	1	2	?	2008	2013
Mining	Mining operations including exploration	Oil/fuel spill or leak	1	2	sum per year	1970	2015
Mining	Vessel transiting	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Mining	Vessel transiting	Marine pests	1	1	kms	2013	2016
National security and emergency response	Actions by or under direction of the Commonwealth and Commonwealth agencies - defence, border protection, law enforcement and emergency response	#N/A	0	na			
Recreational fishing	Anchoring	Habitat modification (physical disturbance and removal)	0	na			
Recreational fishing	Recreational fishing (including spearfishing)	Extraction of benthic mobile invertebrates	0	na			

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Recreational fishing	Recreational fishing (including spearfishing)	Extraction of fish and free-swimming invertebrates	0	na			
Recreational fishing	Recreational fishing (including spearfishing)	Habitat modification (physical disturbance and removal)	1	1	kms	2013	2016
Recreational fishing	Recreational fishing (including spearfishing)	Human presence (disturbance of mobile fauna communities or populations)	1	1	kms	2013	2016
Recreational fishing	Recreational fishing (including spearfishing)	Introduced pathogens/disease	1	1	kms	2013	2016
Recreational fishing	Recreational fishing (including spearfishing)	Marine debris (including microplastics and litter on islands)	1	0	kgs	2014	2014
Recreational fishing	Recreational fishing (including spearfishing)	Marine pests	1	1	kms	2013	2016
Recreational fishing	Recreational fishing (including spearfishing)	Overabundant native species	0	na			
Recreational fishing	Vessel transiting	Human presence (disturbance of mobile fauna communities or populations)	1	0	kms	2013	2016
Recreational fishing	Vessel transiting	Marine pests	1	1	kms	2013	2016
Renewable energy	Wave, tidal and wind	Extraction of fish and free-swimming invertebrates	1	1	N	2016	2016
Renewable energy	Wave, tidal and wind	Extraction of megafauna (excluding fish)	1	1	N	2016	2016
Renewable energy	Wave, tidal and wind	Habitat modification (physical disturbance and removal)	1	1	N	2016	2016
Renewable energy	Wave, tidal and wind	Human presence (disturbance of mobile fauna communities or populations)	1	0	N	2016	2016
Renewable energy	Wave, tidal and wind	Marine pests	1	1	N	2016	2016
Research and monitoring	Research, collecting, tagging	Extraction of benthic mobile invertebrates	0	na			
Research and monitoring	Research, collecting, tagging	Extraction of fish and free-swimming invertebrates	0	na			

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Research and monitoring	Research, collecting, tagging	Extraction of megafauna (excluding fish)	0	na			
Research and monitoring	Research, collecting, tagging	Extraction of terrestrial biota	0	na			
Research and monitoring	Research, collecting, tagging	Habitat modification (physical disturbance and removal)	0	na			
Research and monitoring	Research, collecting, tagging	Human presence (disturbance of mobile fauna communities or populations)	0	na			
Research and monitoring	Research, collecting, tagging	Introduced pathogens/disease	0	na			
Research and monitoring	Research, collecting, tagging	Marine debris (including microplastics and litter on islands)	1	0	kgs	2014	2014
Research and monitoring	Research, collecting, tagging	Marine pests	0	na			
Structures and works	Artificial reefs	Extraction of fish and free-swimming invertebrates	0	na			
Structures and works	Artificial reefs	Habitat modification (physical disturbance and removal)	0	na			
Structures and works	Dredging or disposal of dredged material	Habitat modification (due to suspended sediments - including smothering)	0	na			
Structures and works	Dredging or disposal of dredged material	Habitat modification (physical disturbance and removal)	0	na			
Structures and works	Dredging or disposal of dredged material	Human presence (disturbance of mobile fauna communities or populations)	0	na			
Structures and works	Dredging or disposal of dredged material	Noise pollution	0	na			
Structures and works	Dredging or disposal of dredged material	Noxious substances (including chemicals & heavy metals)	0	na			

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Structures and works	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Habitat modification (due to suspended sediments - including smothering)	0	na			
Structures and works	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Habitat modification (physical disturbance and removal)	1	0	?	?	?
Structures and works	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Human presence (disturbance of mobile fauna communities or populations)	1	0	?	?	?
Structures and works	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Introduced pathogens/disease	0	na			
Structures and works	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Marine pests	1	1	?	?	?
Structures and works	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Noise pollution	0	na	?	?	?

Activity	Sub-activity	Specific pressure	Data	Proxy	Units	YrStart	YrEnd
Structures and works	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Noxious substances (including chemicals & heavy metals)	1	2	?	2008	2013
Structures and works	Excavation other than dredging, erection and maintenance of structures, and works (including cables, trenching & boring)	Oil/fuel spill or leak	1	2	sum per year	1970	2015
Structures and works	Fish aggregating devices	Extraction of fish and free-swimming invertebrates	1	1	N	2013	2020
Structures and works	Fish aggregating devices	Extraction of megafauna (excluding fish)	1	1	N	2013	2020
Structures and works	Fish aggregating devices	Human presence (disturbance of mobile fauna communities or populations)	1	1	N	2013	2020
Structures and works	Moorings	Extraction of megafauna (excluding fish)	1	1		2002	2016
Structures and works	Moorings	Habitat modification (physical disturbance and removal)	1	0	N	2002	2016
Structures and works	Moorings	Introduced pathogens/disease	1	1		2002	2016
Structures and works	Moorings	Light pollution	1	2	?	2002	2016
Structures and works	Moorings	Marine pests	1	1	N	2002	2016

12 APPENDIX F ACTIVITY/SUB-ACTIVITY COMBINATIONS

12.1 Climate change

12.1.1 Altered ocean currents

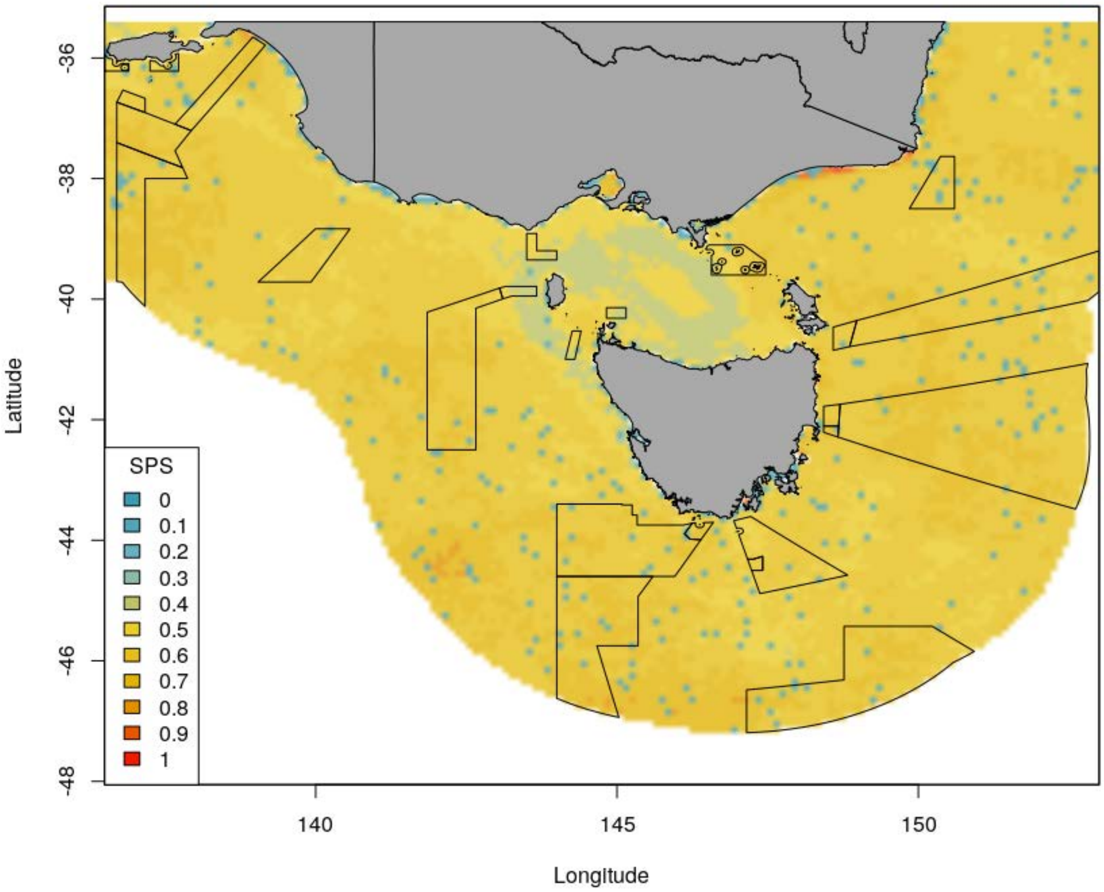

Figure 12.1: Pressure map for the altered ocean currents sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.1

Table 12.1: Altered ocean currents metadata

Data layer	Metadata record
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

12.1.2 Increased frequency and intensity of severe weather events

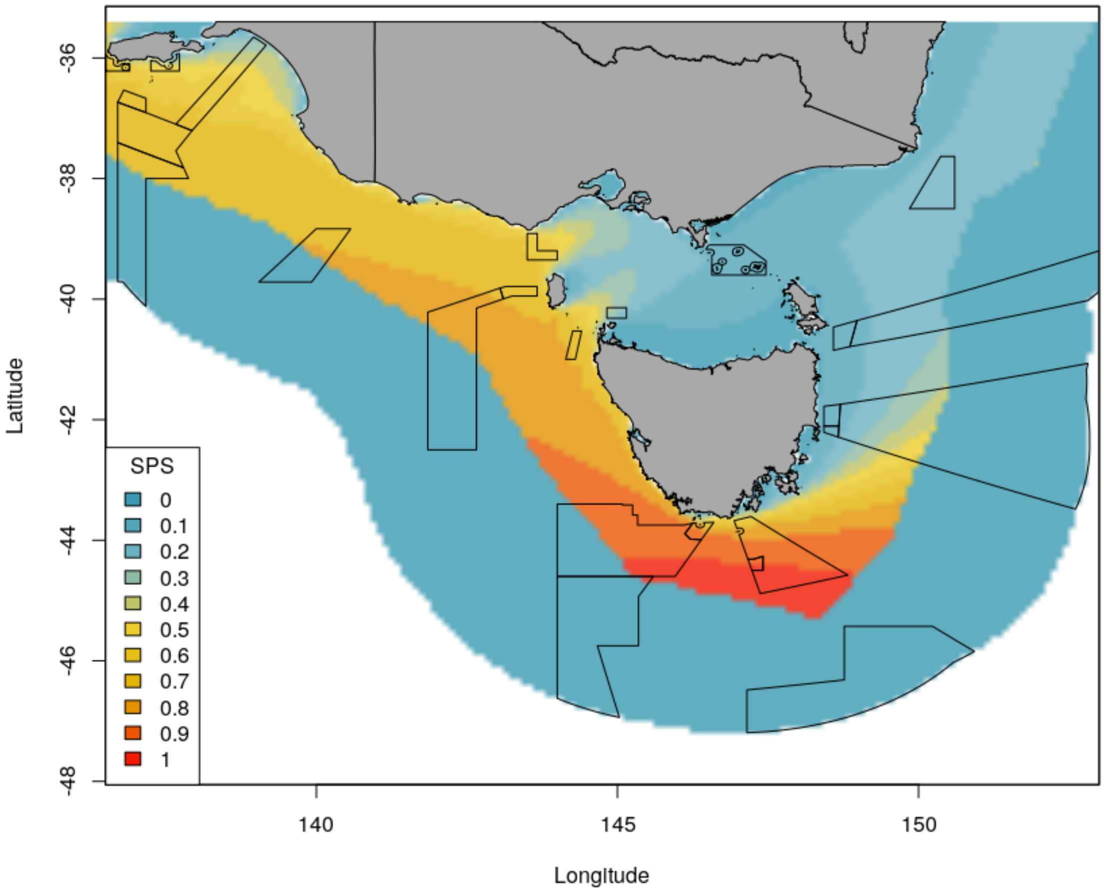

Figure 12.2: Pressure map for the increased frequency and intensity of severe weather events sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.2

Table 12.2: Severe weather events metadata

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

12.1.3 Increased sea surface temperature

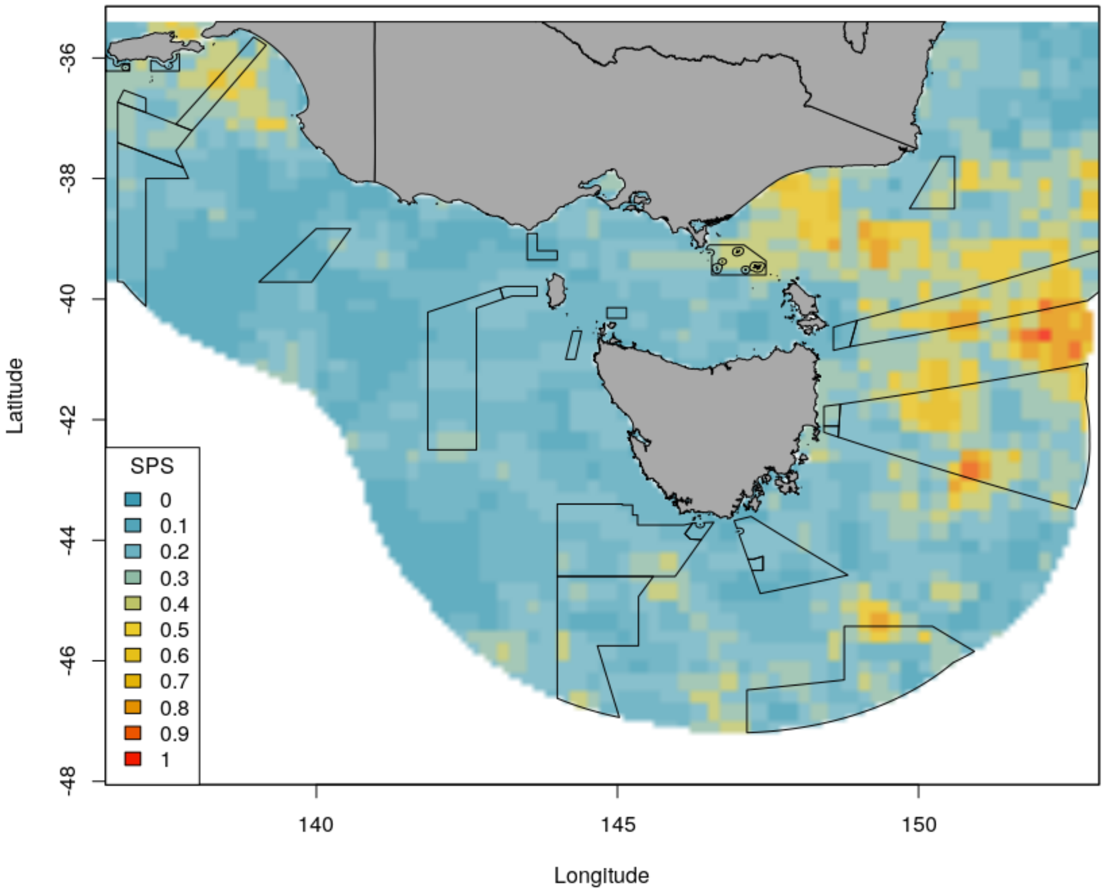

Figure 12.3: Pressure map for the increased sea surface temperature sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.3

Table 12.3: Increased SST metadata

Data layer	Metadata record
mhw_20132018_severe_masked_linearStd	https://protect-au.mimecast.com/s/QDvkC71Zl7fJWDlQS0Amrp?domain=marineheatwaves.org

12.1.4 Ocean acidification

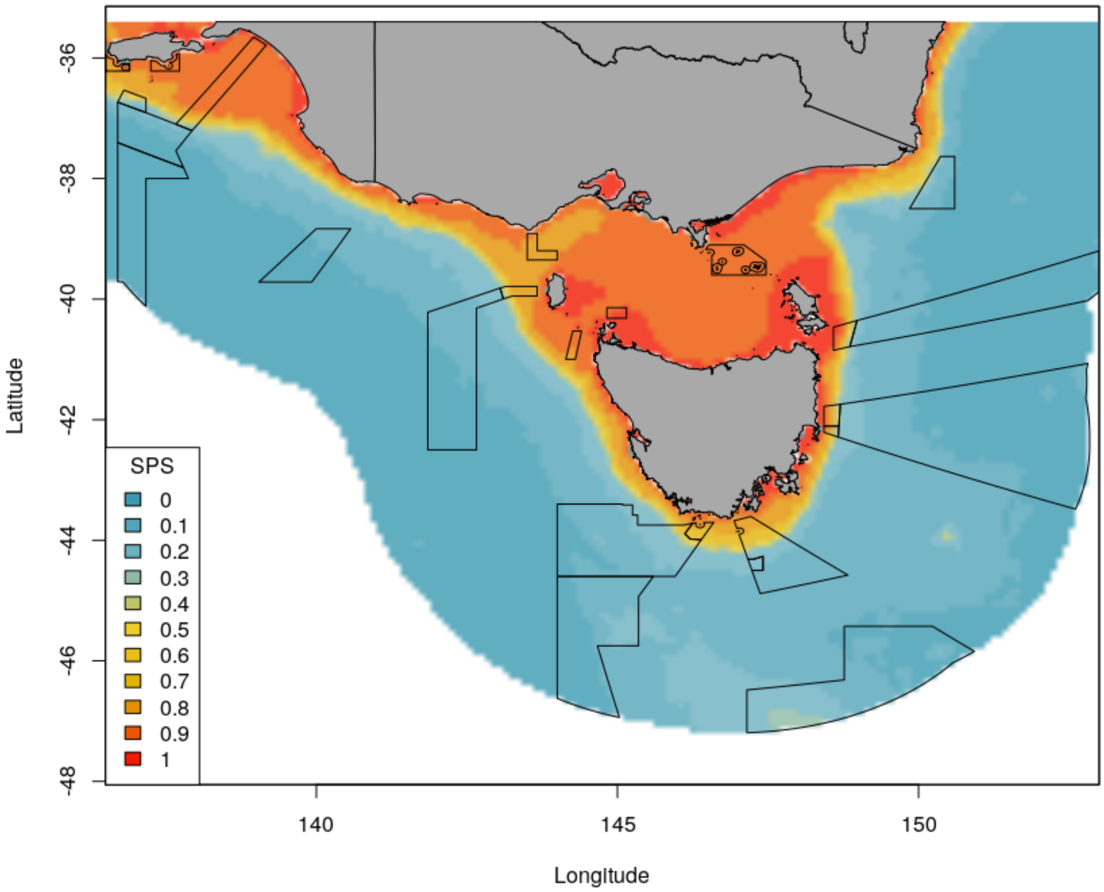

Figure 12.4: Pressure map for the ocean acidification sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.4

Table 12.4: Ocean acidification metadata

Data layer	Metadata record
oa_orrSpatiallyProcessed_masked_linearStd	https://knb.ecoinformatics.org/view/resource_map_doi%3A10.5063%2FF1707ZRQ

12.1.5 Sea level rise

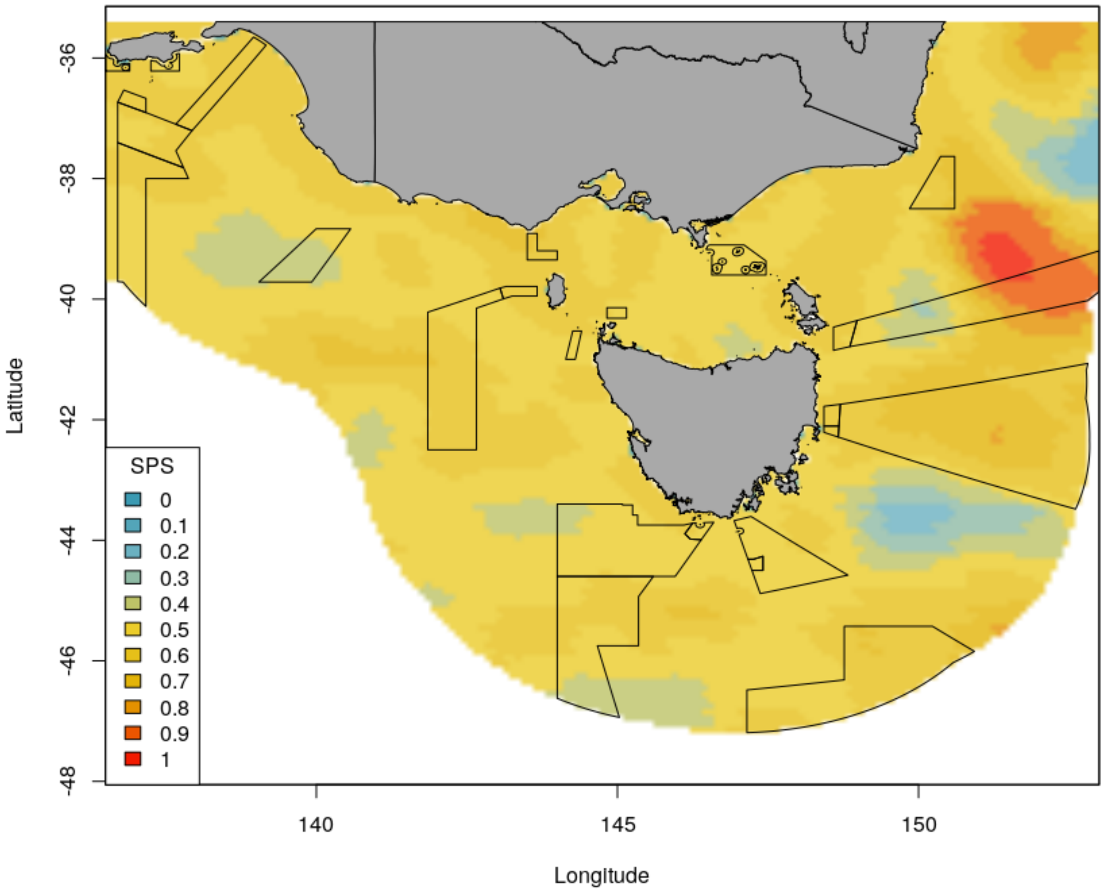

Figure 12.5: Pressure map for the sea level rise sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.5

Table 12.5: Sea level rise metadata

Data layer	Metadata record
slr_temporal_mean_years_2008.2013_masked_linearStd	https://knb.ecoinformatics.org/view/resource_map_doi%3A10.5063%2FF1377727

12.2 Commercial aquaculture

12.2.1 Aquaculture including commercial pearling

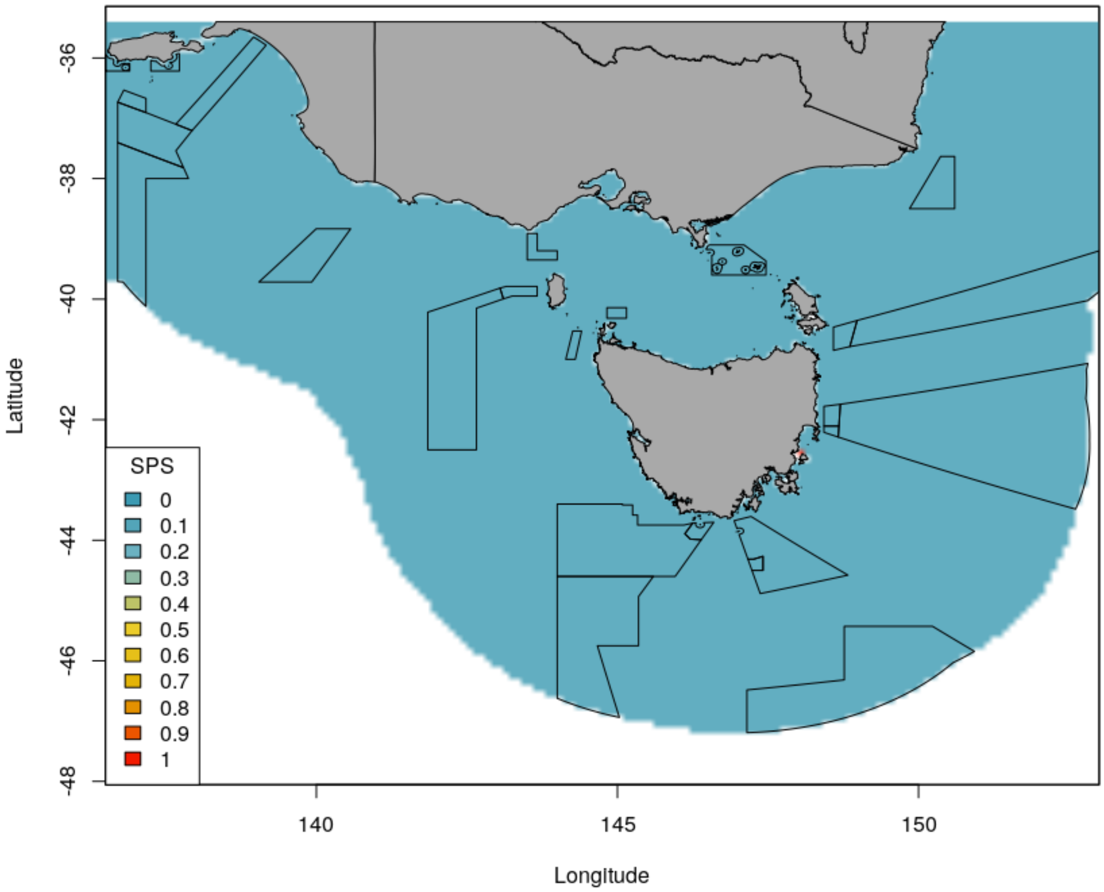

Figure 12.6: Pressure map for the aquaculture including commercial pearling sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.6

Table 12.6: Aquaculture metadata

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

12.2.2 Vessel transiting

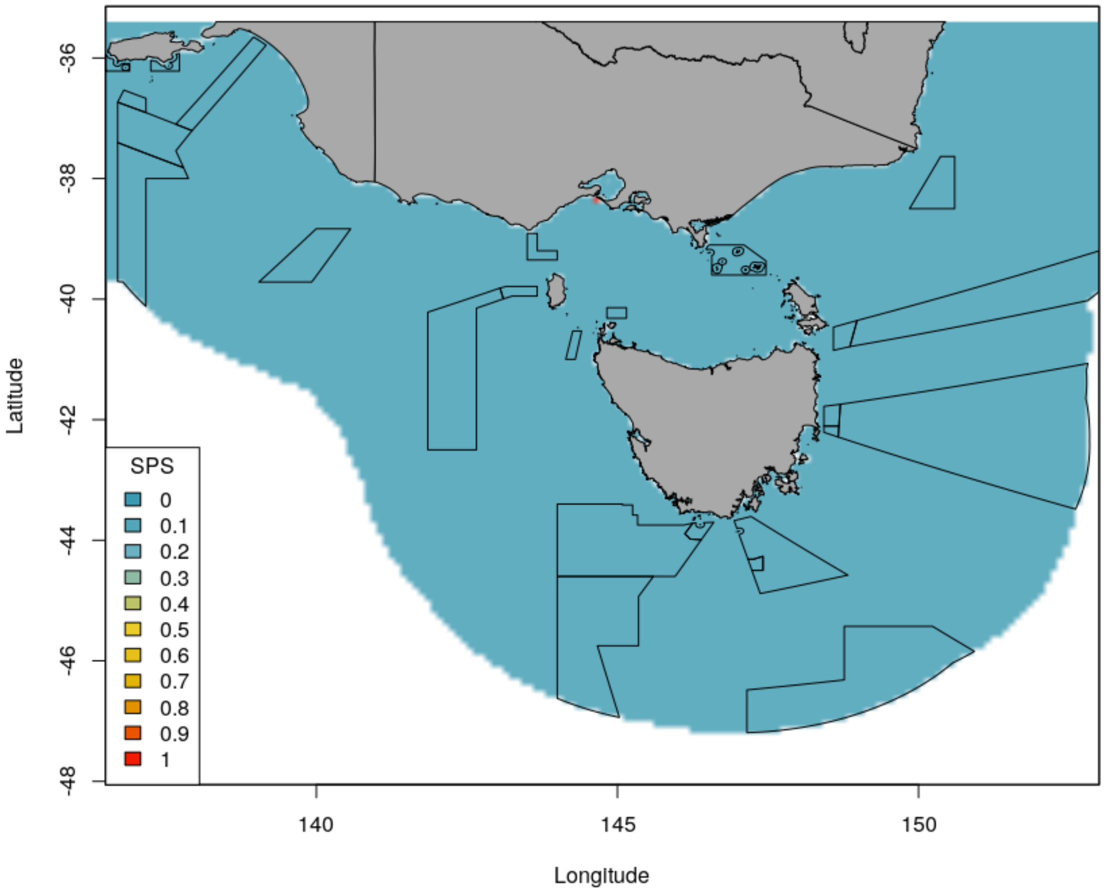

Figure 12.7: Pressure map for the commercial aquaculture activity-vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.6

Table 12.7: Aquaculture vessel transiting metadata

Data layer	Metadata record
transiting_distance_general_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f

12.3 Commercial fishing

12.3.1 Danish Seine

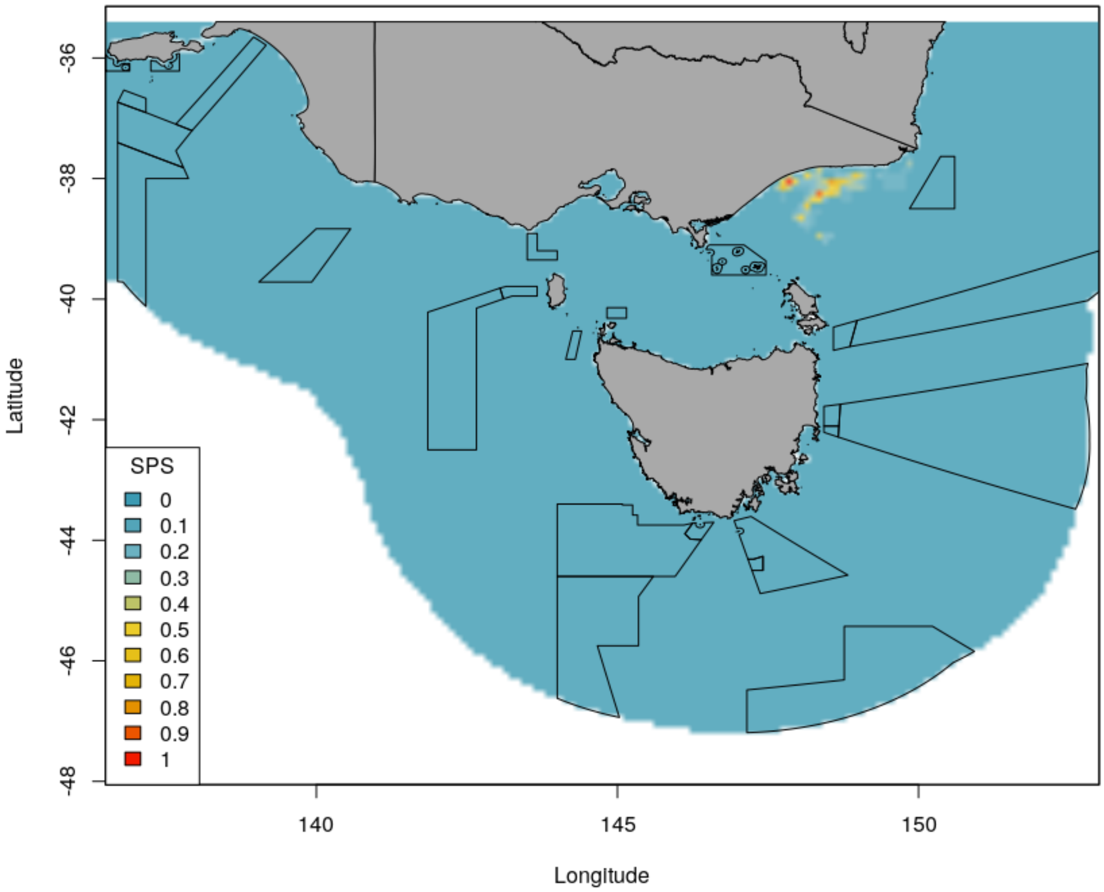

Figure 12.8: Pressure map for the Danish seine sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.8

Table 12.8: Danish seine metadata

Data layer	Metadata record
DS_20112015_fieldID_HOURS_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au
DS_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961

12.3.2 Demersal trawl

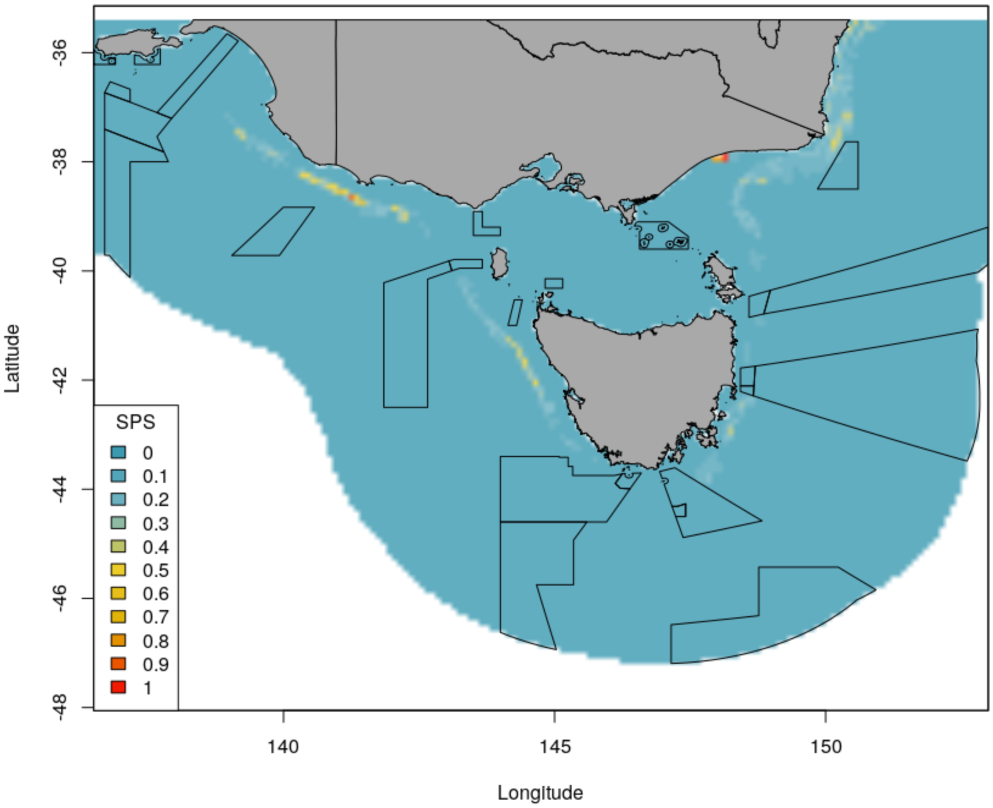

Figure 12.9: Pressure map for the Demersal trawl sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.9.

Table 12.9: Demersal trawl metadata

Data layer	Metadata record
TW_20112015_fieldID_HOURs_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au
NSWTW_DS_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511
Final_NT_effort_June2018_fieldID_A16_Demersal_trawl_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
qldeffort_Trawl20112015_Demersal_trawl_fieldID_Days_n_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/IelKC0YZ4yFLr1VMI9gSyN?domain=marlin.csiro.au
SA_DT_2011-2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/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
trawl_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce

12.3.3 Longline demersal auto-longline

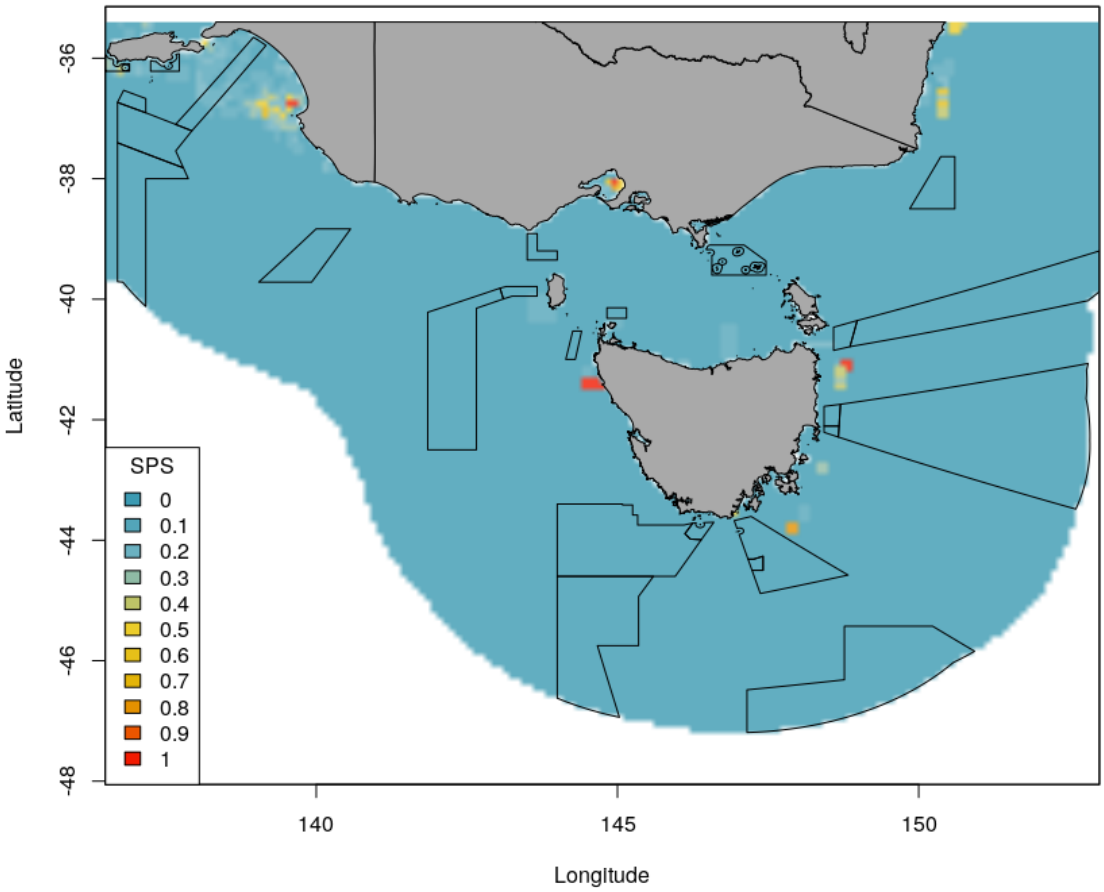

Figure 12.10: Pressure map for the Longline demersal auto-longline sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.10.

Table 12.10: Longline demersal auto-longline metadata

Data layer	Metadata record
AL_20112015_fieldID_HOOKSSET_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au
BL_20112015_fieldID_HOOKSSET_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au
NSWLL_DL_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511
LL_DL_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961
VICLLDL_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc
ll_dl_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce

12.3.4 Longline pelagic

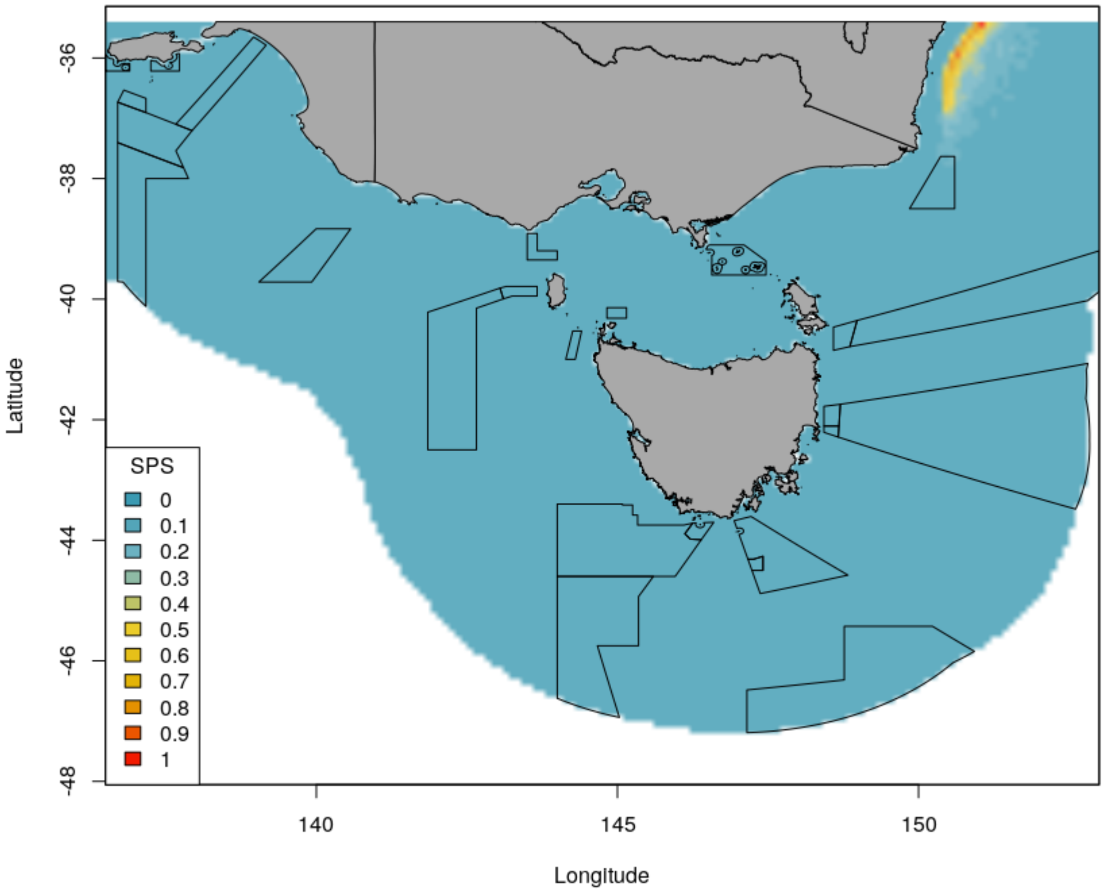

Figure 12.11: Pressure map for the Longline pelagic sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.11.

Table 12.11: Longline pelagic metadata

Data layer	Metadata record
LLP_20112015_fieldID_HOOKSSET_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au

12.3.5 Minor line

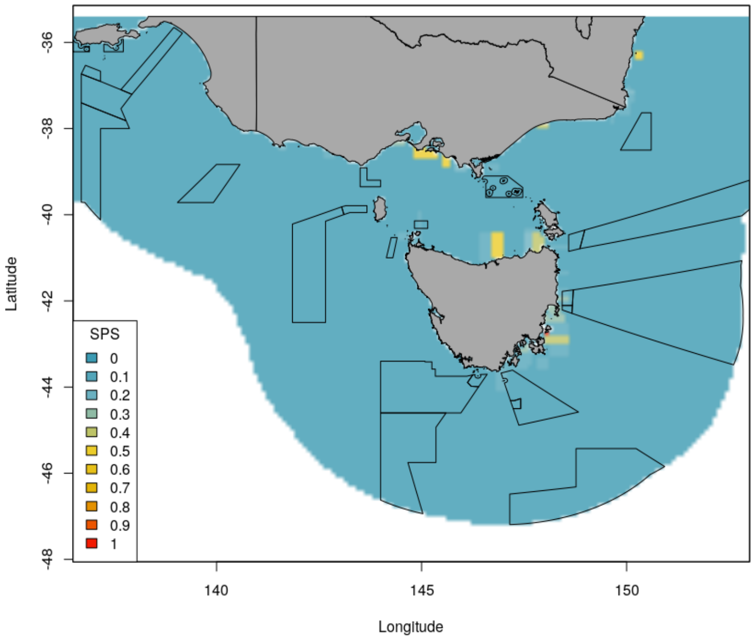

Figure 12.12: Pressure map for the Minor line sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.12.

Table 12.12: Minor line meta-data

Data layer	Metadata record
CSQ_ML_20062010_fieldID_OPERATIONS_SpatiallyProcessed_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au
HL_20112015_fieldID_OPERATIONS_SpatiallyProcessed_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au
TR_20112015_fieldID_OPERATIONS_SpatiallyProcessed_linearStd.1	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/aa53a4df-7fe6-46d1-93b7-2d3732f4883e
NSWHL_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511
Final_NT_effort_June2018_fieldID_A1_Minor_line_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
Final_NT_effort_June2018_fieldID_A4_Minor_line_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
Final_NT_effort_June2018_fieldID_A6_Minor_line_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?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
HL_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961
JIG_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961
Trolling_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961
VICDL_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc
VICHL_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc
line_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce

12.3.6 Net demersal

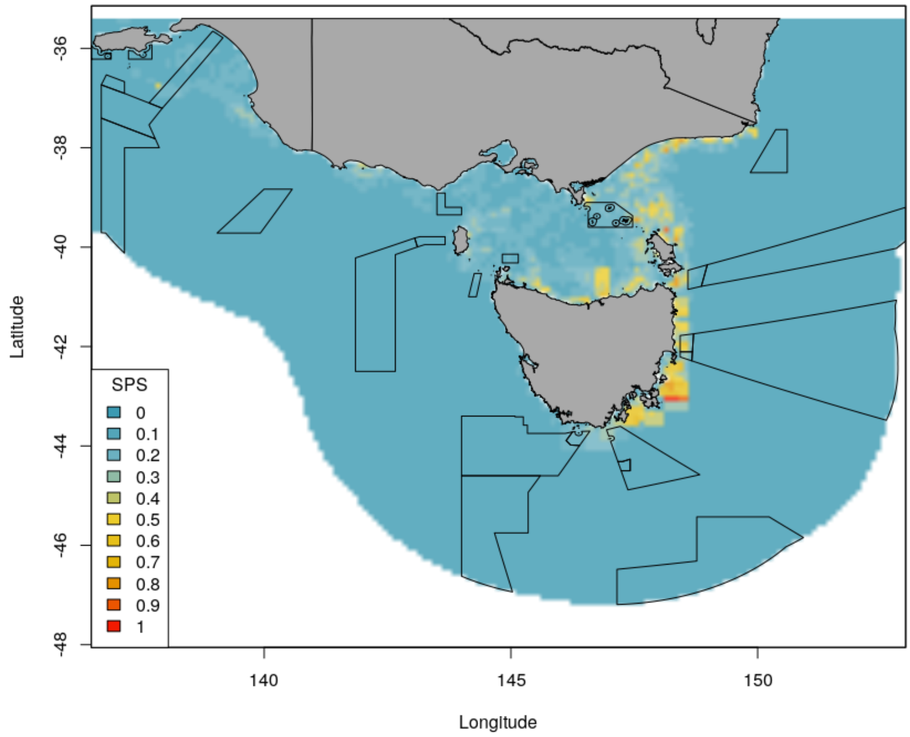

Figure 12.13: Pressure map for the Net demersal sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.13.

Table 12.13: Net demersal metadata

Data layer	Metadata record
GN_20112015_fieldID_NETLENGTH_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au
NSWGN_MN_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511
Final_NT_effort_June2018_fieldID_A2_Net_demersal_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
Final_NT_effort_June2018_fieldID_A3_Net_demersal_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
Final_NT_effort_June2018_fieldID_A7_Net_demersal_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?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
VICmesh_net_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc
VICNet_MN_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc
gillnet_net_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce

12.3.7 Purse seine

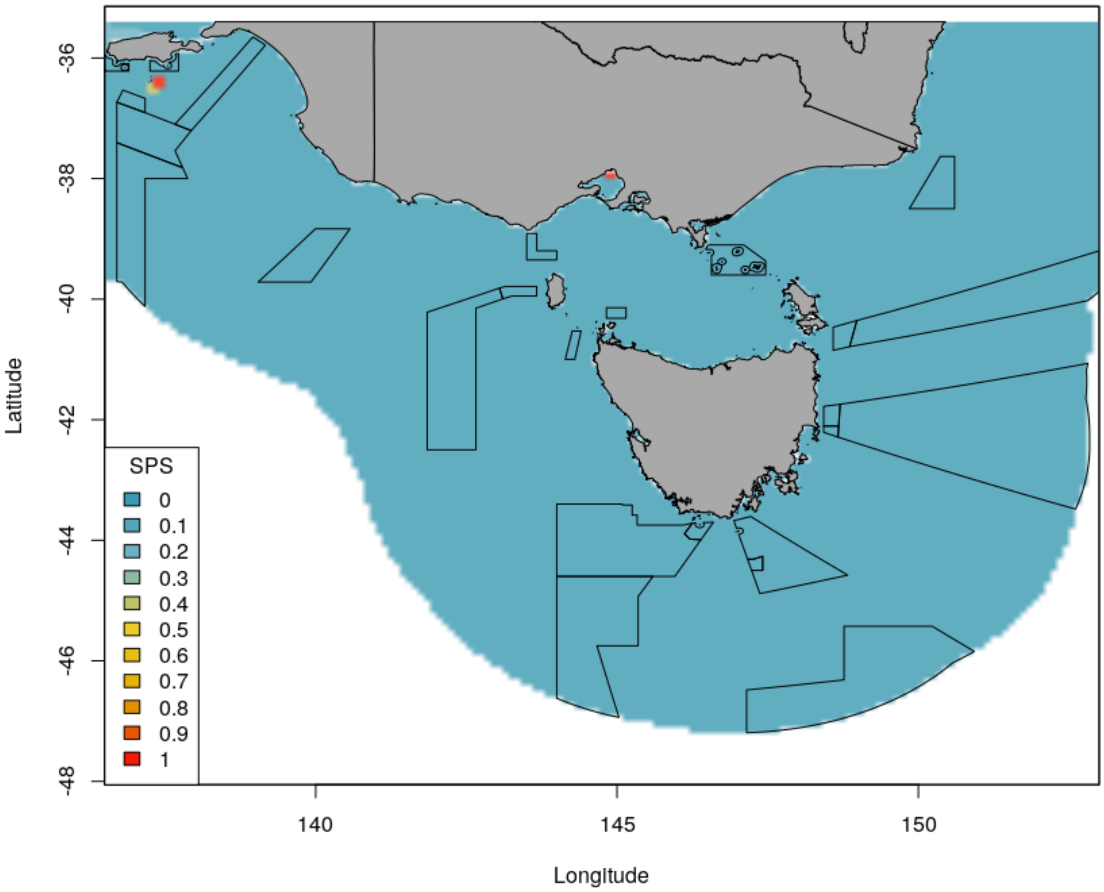

Figure 12.14: Pressure map for the Purse seine sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.14.

Table 12.14: Purse seine metadata

Data layer	Metadata record
PS_20112015_fieldID_OPERATIONS_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/fnJRC81Zm7fKwo1zTRgp69?domain=marlin.csiro.au
NSWSeine_shots_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511

12.3.8 Hand collection

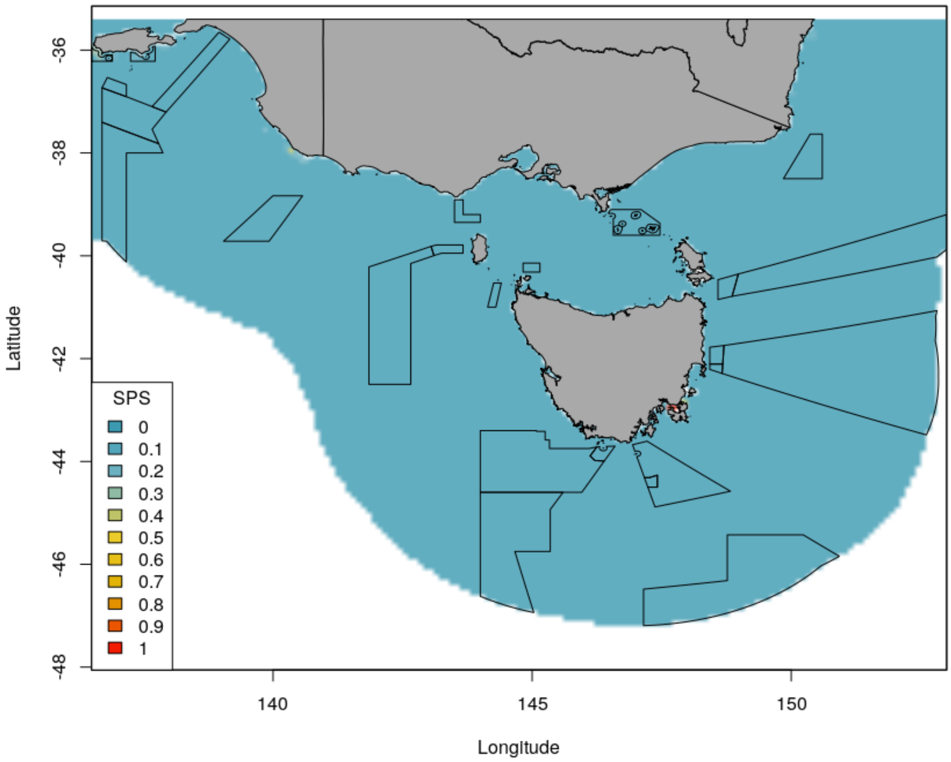

Figure 12.15: Pressure map for the Hand collection sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.15.

Table 12.15: Hand collection metadata

Data layer	Metadata record
NSWHG_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511
Final_NT_effort_June2018_fieldID_A12_Hand_collection_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
Final_NT_effort_June2018_fieldID_A13_Hand_collection_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
Final_NT_effort_June2018_fieldID_A9_Hand_collection_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
qldeffort_Harvest20112015_Hand_collection_fieldID_Days_n_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/IelKC0YZ4yFLr1VMI9gSyN?domain=marlin.csiro.au
SA_HG_2011-2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/be790a20-eed5-4570-85dc-dd548ce606d6
HG_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961

12.3.9 Hand net

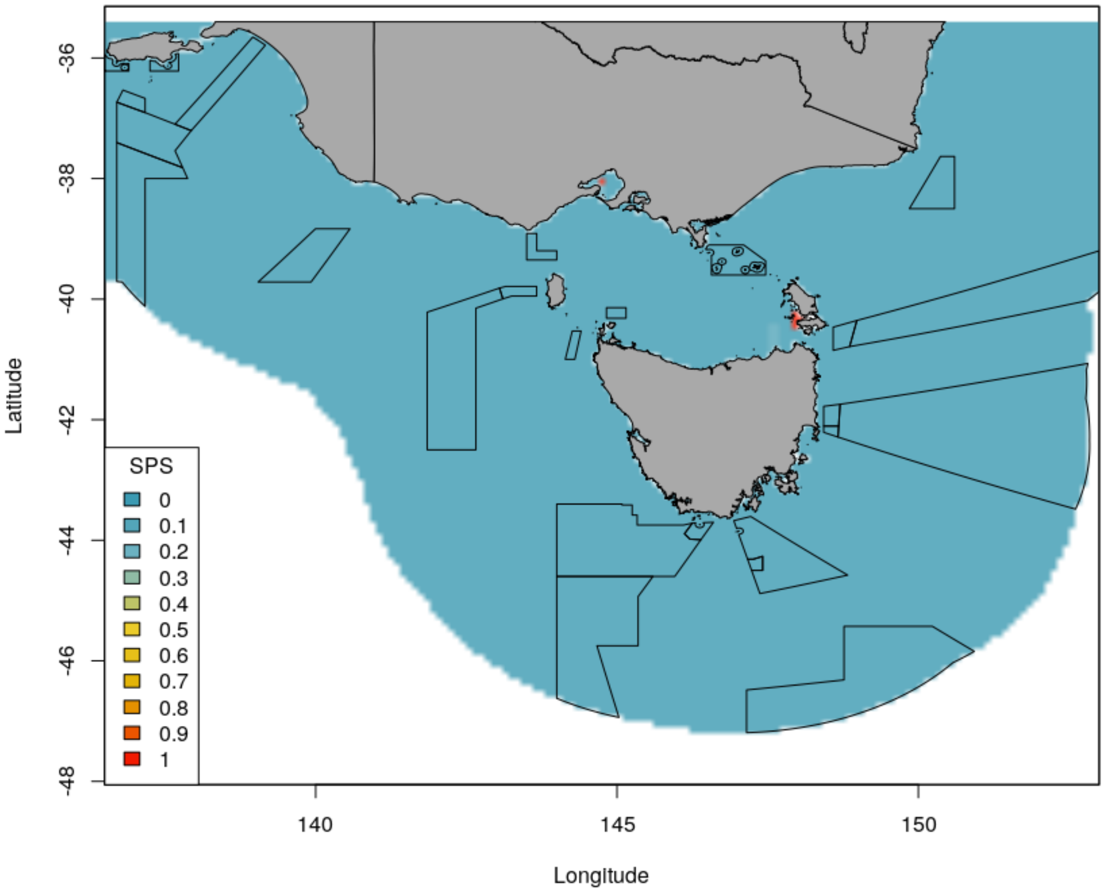

Figure 12.16: Pressure map for the Hand net sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.16.

Table 12.16: Hand net metadata

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

12.3.10 Pot and trap

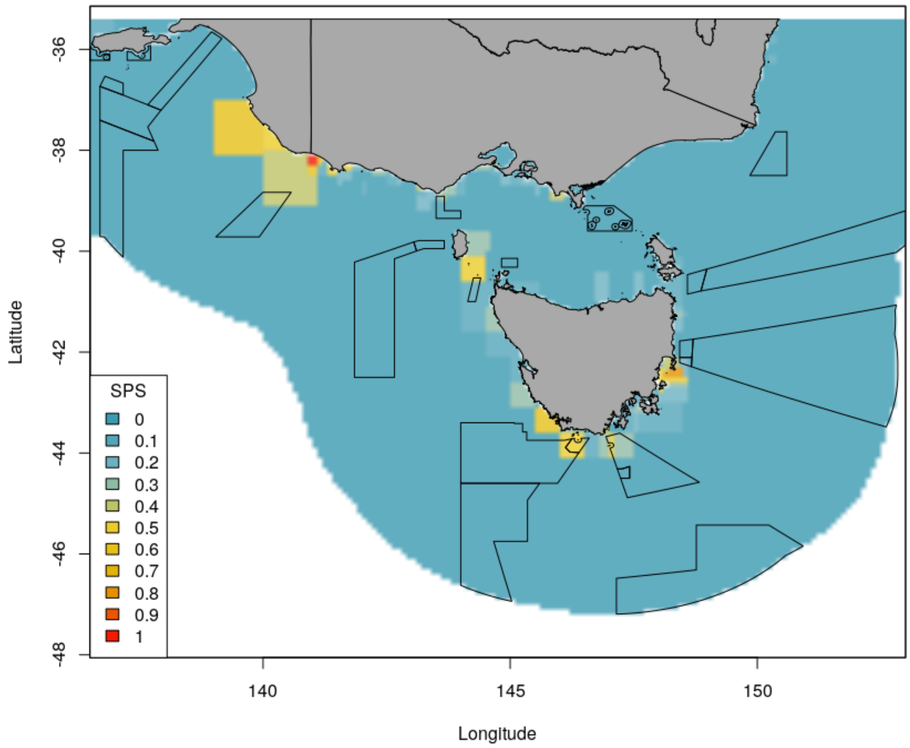

Figure 12.17: Pressure map for the Pot and trap sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.17.

Table 12.17: Pot and trap metadata

Data layer	Metadata record
NSWTrap_pot_nsw_2014.2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/04afcd60-1eb3-4edb-843d-623050bc7511
Final_NT_effort_June2018_fieldID_A18_Pot_and_trap_Spatially Processed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
Final_NT_effort_June2018_fieldID_A8_Pot_and_trap_Spatially Processed_masked_linearStd	https://protect-au.mimecast.com/s/aL82C91Zn7fpYGQMuGzJWj?domain=marlin.csiro.au
qldeffort_Pot20112015_Pot_and_trap_fieldID_Days_n_Spatially Processed_masked_linearStd	https://protect-au.mimecast.com/s/IelKC0YZ4yFLr1VMI9gSyN?domain=marlin.csiro.au
SA_MSF_2011-2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/be790a20-eed5-4570-85dc-dd548ce606d6
SA_POT_2011-2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/be790a20-eed5-4570-85dc-dd548ce606d6
DN_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961
Pot_tas_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/6db22a4c-0176-435d-943a-e568cf007961
VICtrap_pot_vic_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/eafc6022-a74f-4fd8-9f74-ebe54436b6fc
trap_and_pot_effort_WA_2011.2015_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/1be71f33-7478-4f2f-a641-aafafe1e69ce

12.3.11 Net pelagic

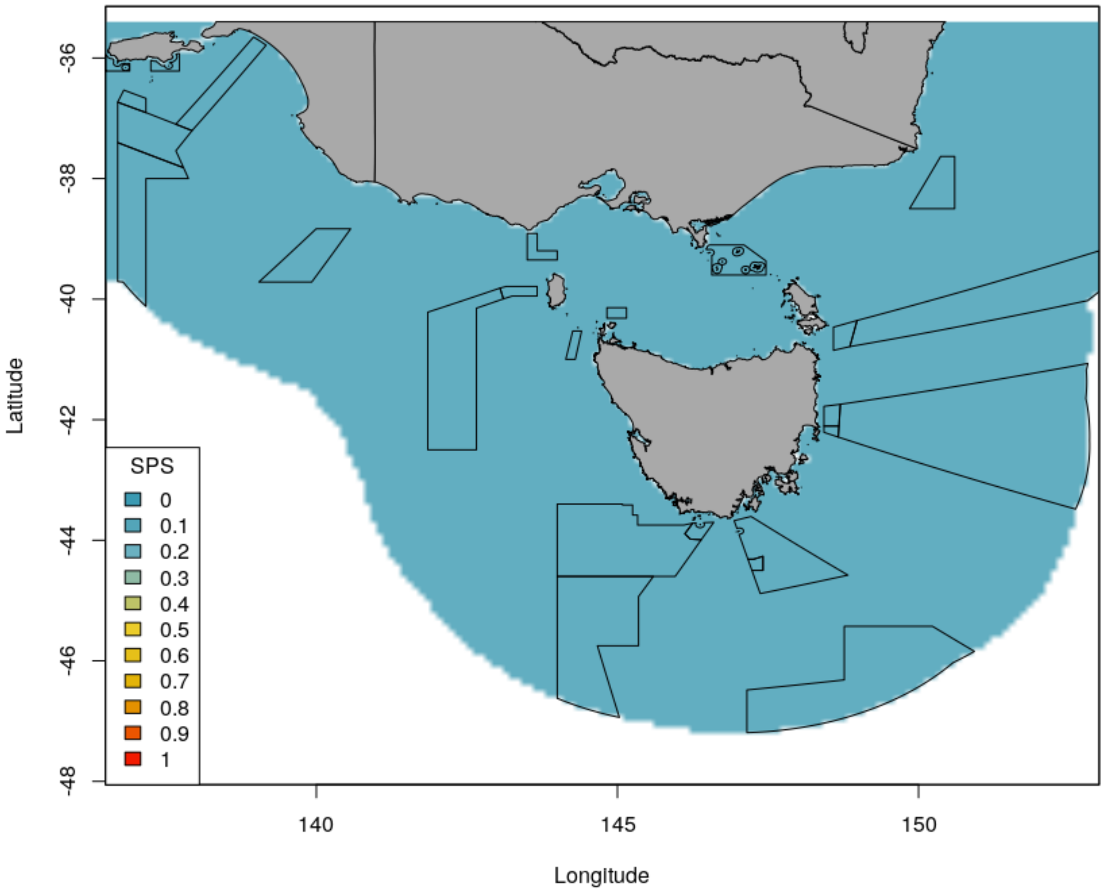

Figure 12.18: Pressure map for the Net pelagic sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.18.

Table 12.18: Net pelagic metadata

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

12.3.12 Trotline

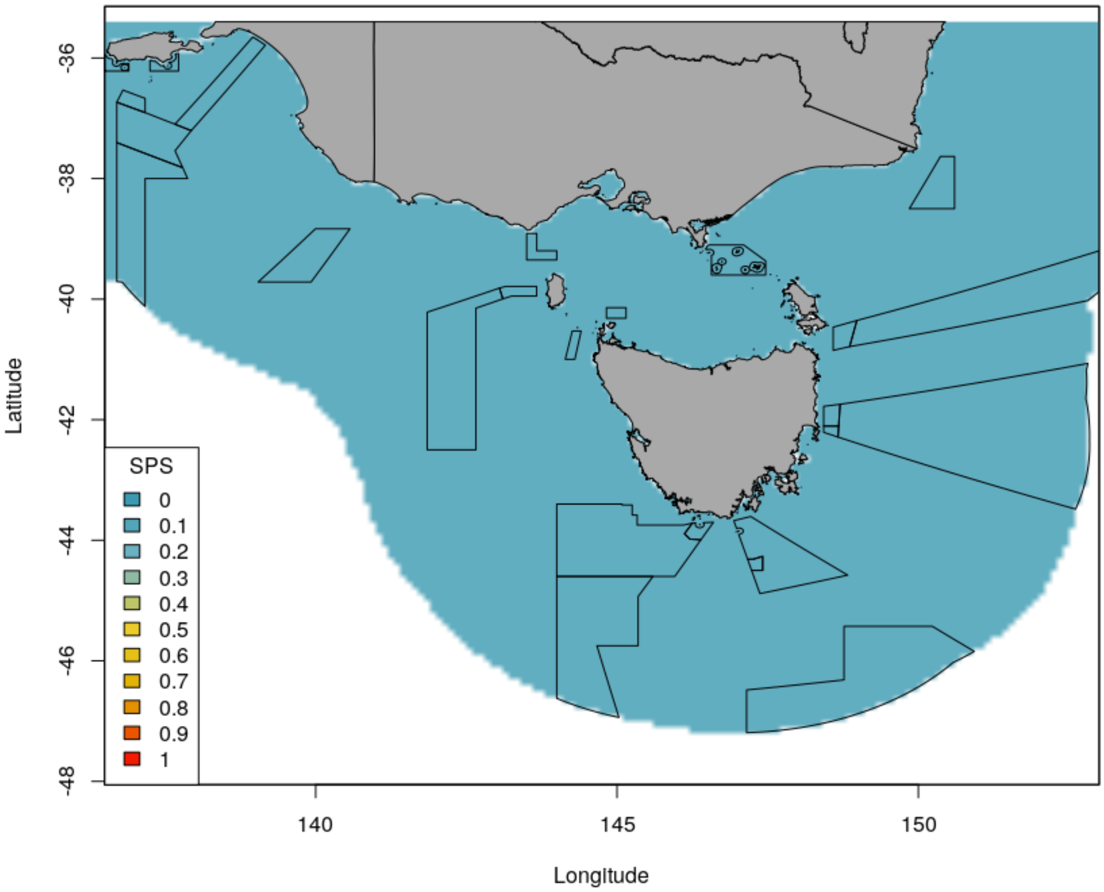

Figure 12.19: Pressure map for the Trotline sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.19.

Table 12.19: Trotline metadata

Data layer	Metadata record
TR_20112015_fieldID_OPERATIONS_SpatiallyProcessed_linearStd.2	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/aa53a4df-7fe6-46d1-93b7-2d3732f4883e

12.3.13 Vessel transiting

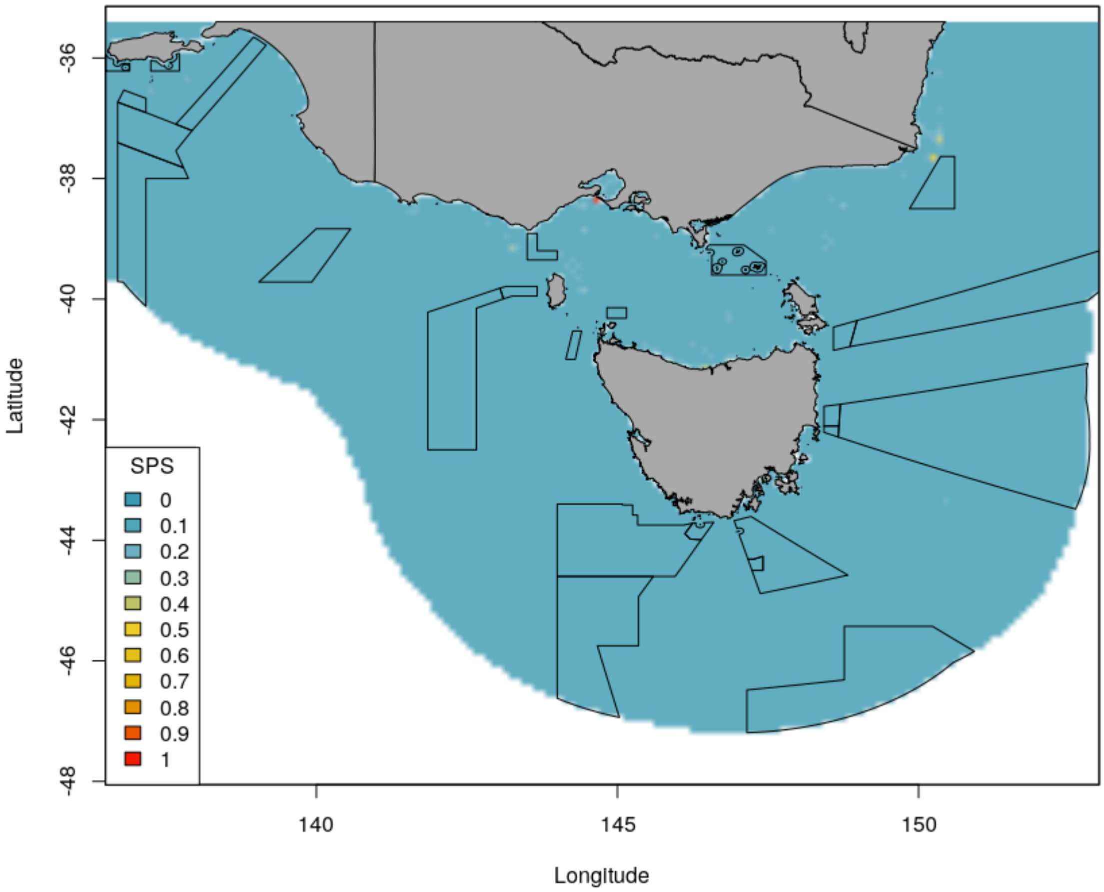

Figure 12.20: Pressure map for the commercial fishing activity, vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.20.

Table 12.20: Commercial fishing vessel transiting metadata

Data layer	Metadata record
transiting_distance_fishing_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f

12.4 Commercial shipping

12.4.1 Anchoring

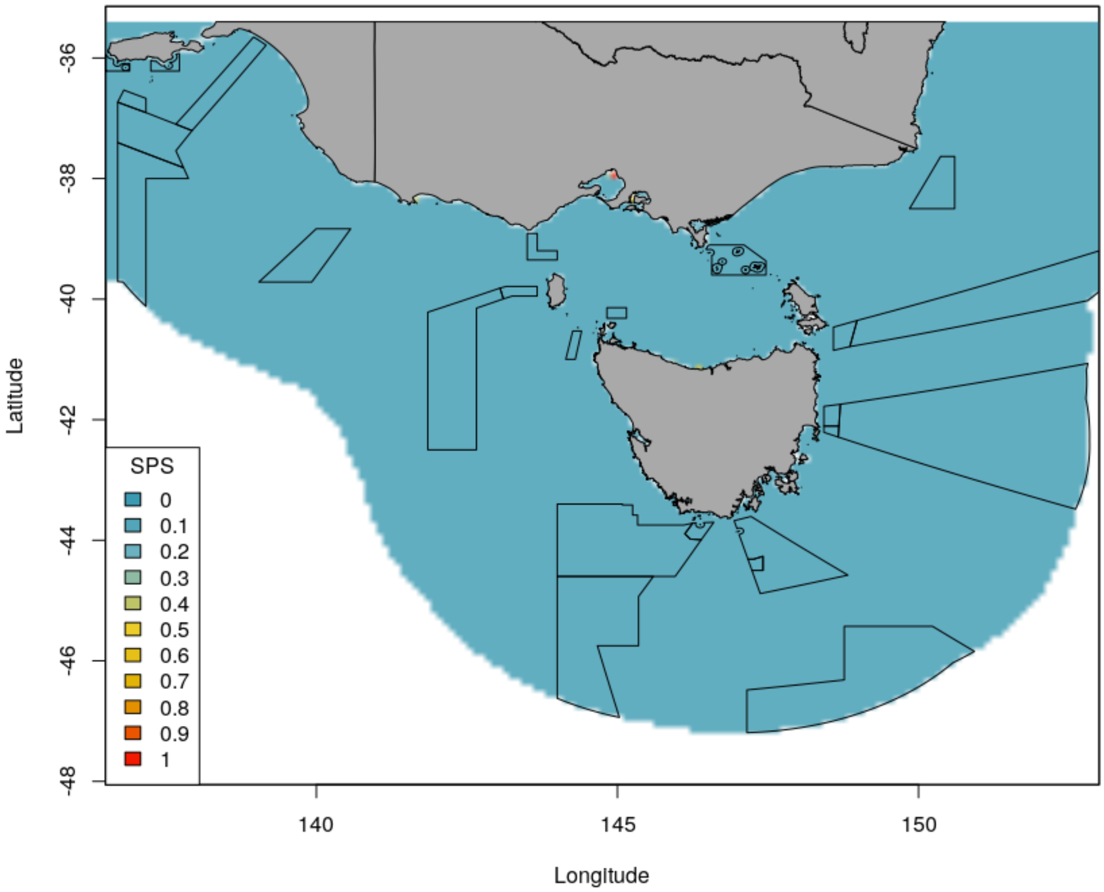

Figure 12.21: Pressure map for the commercial shipping activity, anchoring sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.21.

Table 12.21: Commercial shipping anchoring metadata

Data layer	Metadata record
Anchorages_temporal_sum_years_2013.2016_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f

12.4.2 Vessel transiting

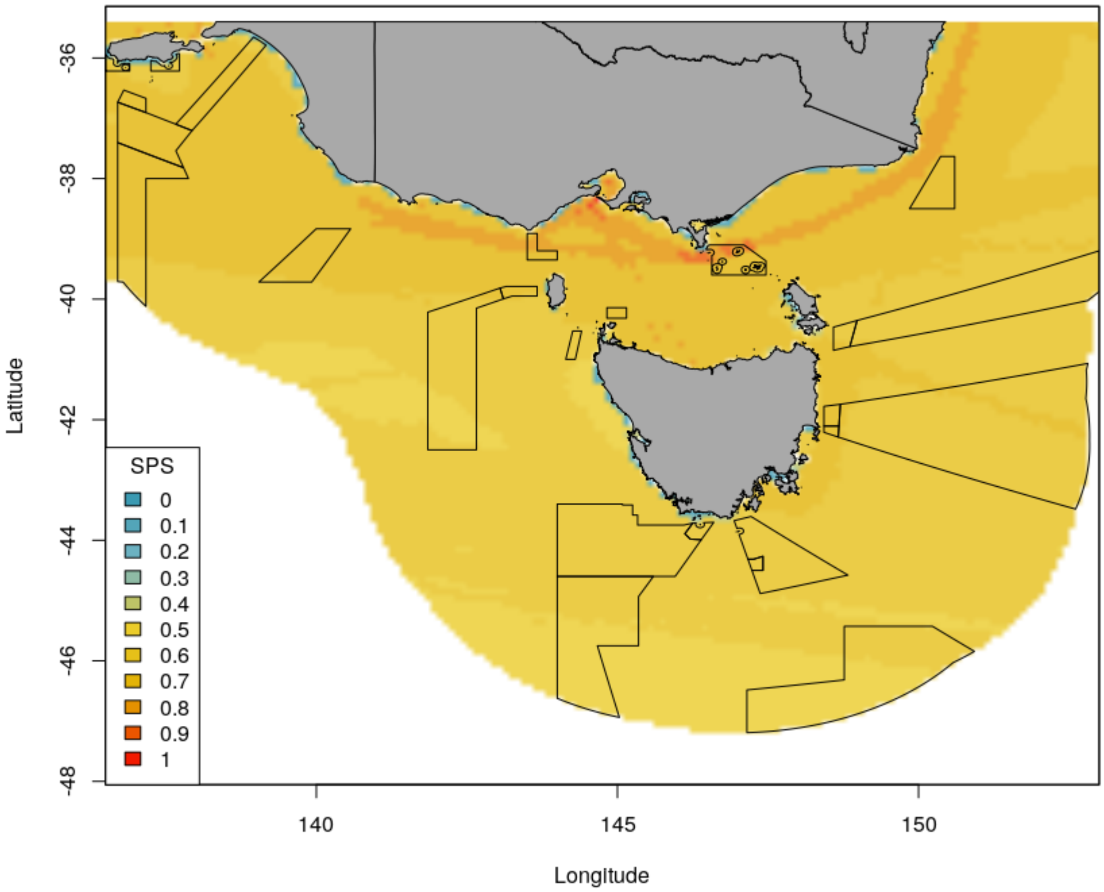

Figure 12.22: Pressure map for the commercial shipping activity, vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.22.

Table 12.22: Commercial shipping vessel transiting metadata

Data layer	Metadata record
NESPpressureNoise_SpatiallyProcessed_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f
transiting_distance_shipping_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f

12.5 Commercial tourism

12.5.1 Charter fishing tours

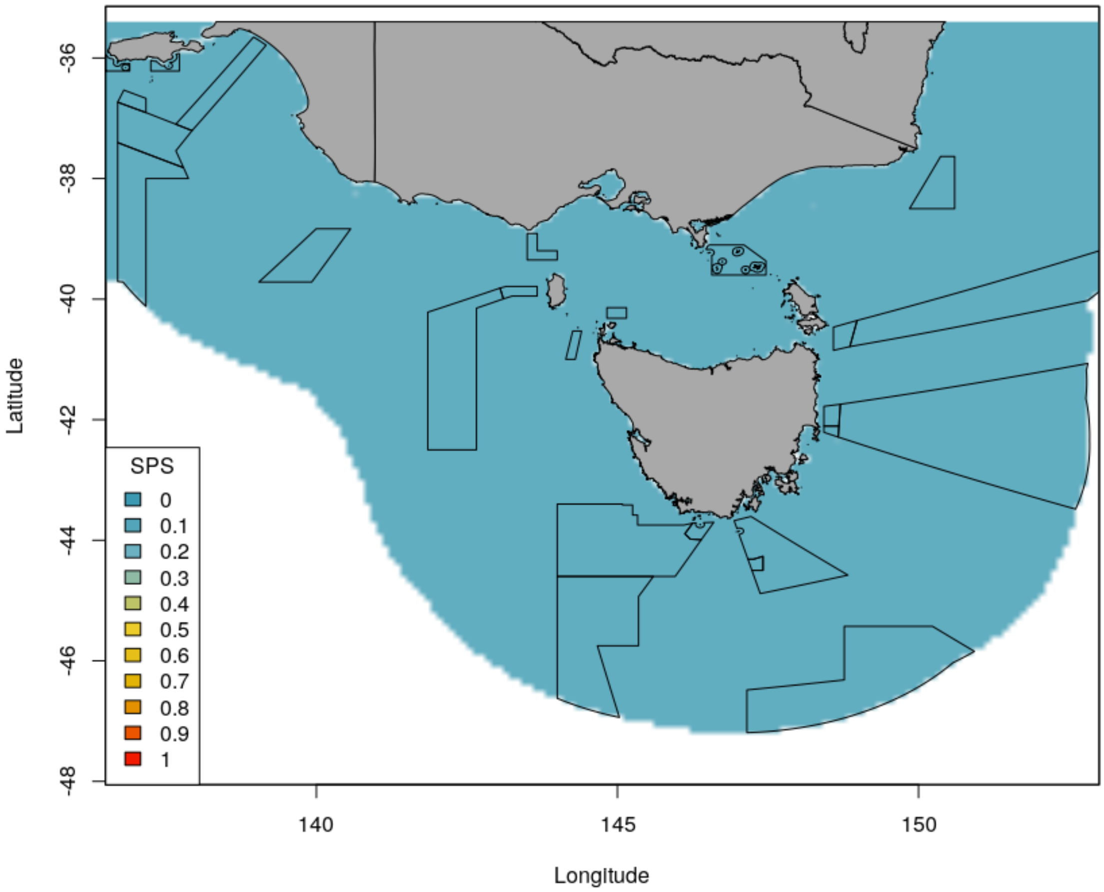

Figure 12.23: Pressure map for the charter fishing tours sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.23.

Table 12.23: Charter fishing tours metadata

Data layer	Metadata record
parks_authorised_vessels_anchorages_temporal_mean_years_2013_2018_linearStd.1	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f
parks_authorised_vessels_distance_temporal_mean_years_2013_2018_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f

12.6 General use access and waste management

12.6.1 Ballast water discharge and exchange

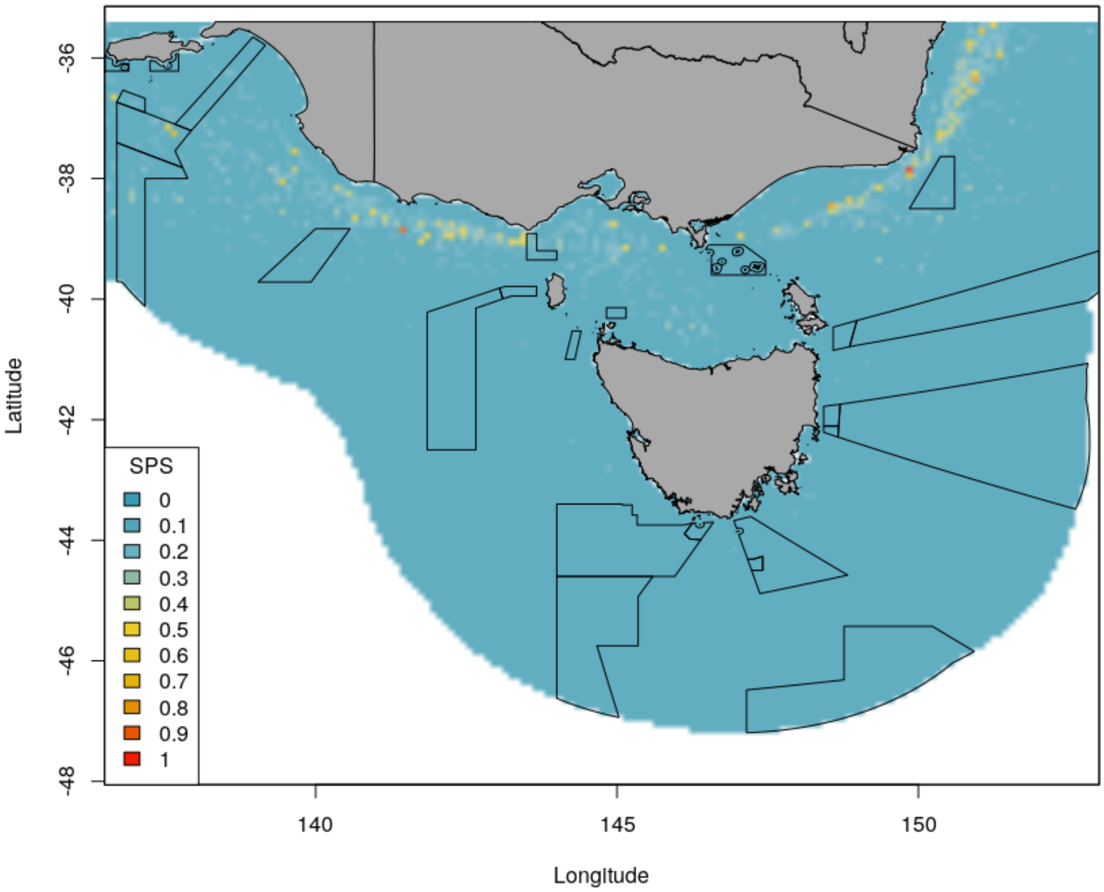

Figure 12.24: Pressure map for the Ballast water discharge and exchange sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.24.

Table 12.24: Ballast water discharge metadata

Data layer	Metadata record
ballast_exchange_volume_SpatiallyProcessed_linearStd	Awaiting response

12.6.2 Recreational use boating including vessel transiting

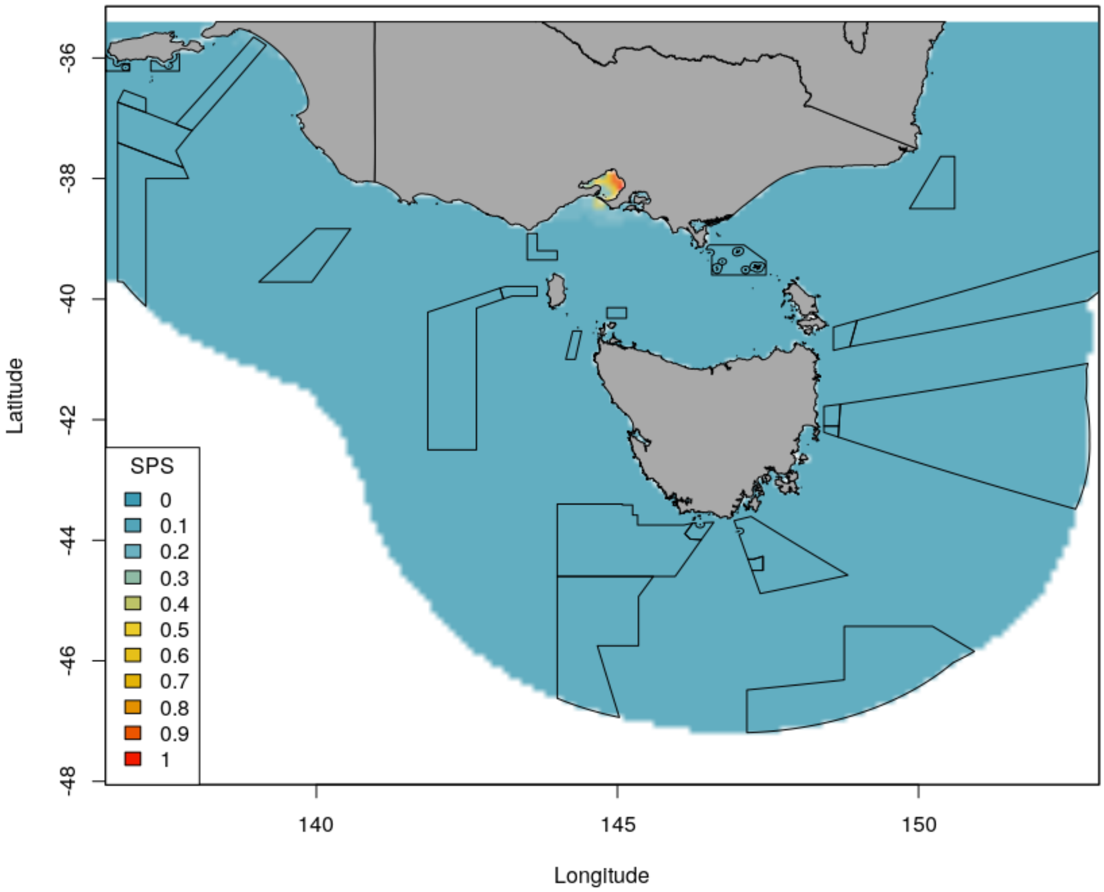

Figure 12.25: Pressure map for the Recreational use boating including vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.25.

Table 12.25: Recreational use boating metadata

Data layer	Metadata record
logV1_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc
logV2_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc
logV3_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc
logV4_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc
logV5_temporal_sum_years_allStates_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/4d86c80e-cfff-44ac-aea2-1d45ed1b55fc

12.7 Land use intensification

12.7.1 Agricultural diffuse source runoff

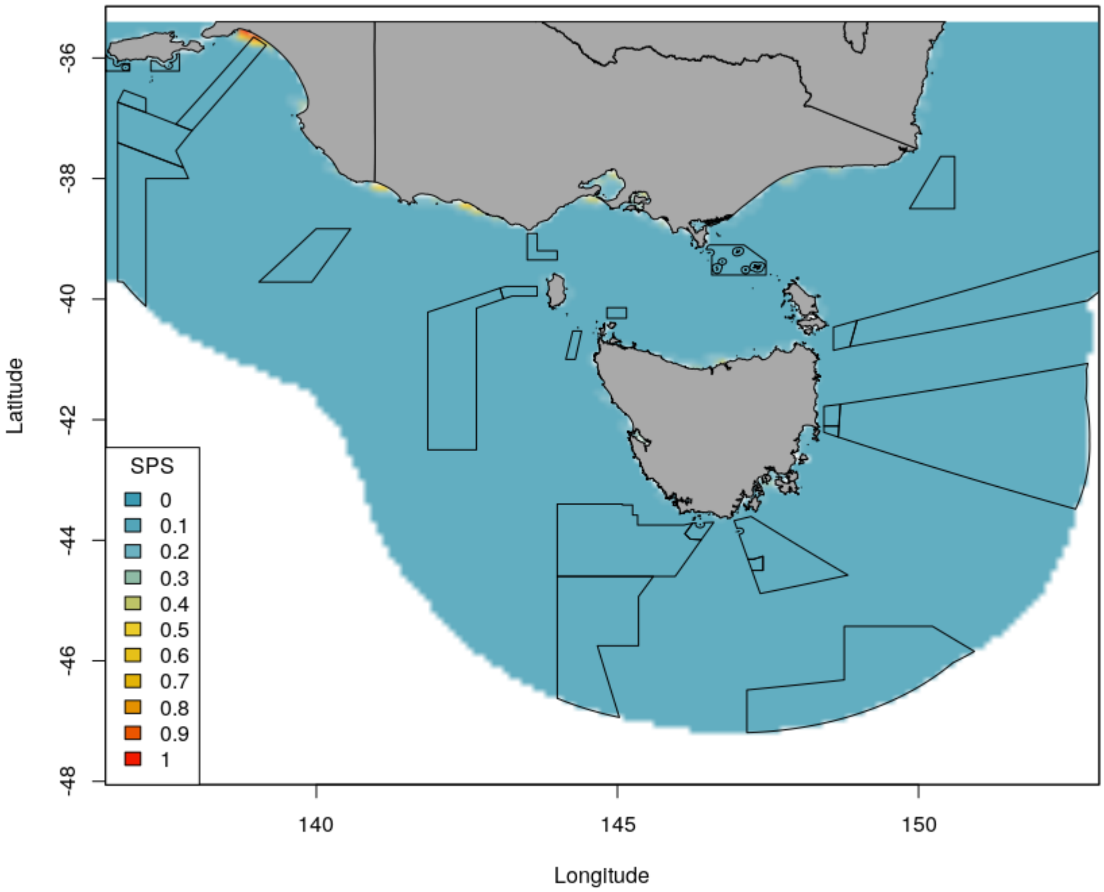

Figure 12.26: Pressure map for the Agricultural diffuse source runoff sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.26.

Table 12.26: Agricultural diffuse source run-off

Data layer	Metadata record
nutrient_temporal_mean_years_allStates_masked_linearStd	https://www.nespmarine.edu.au/project/project-c4-national-outfall-database

12.7.2 Point discharges

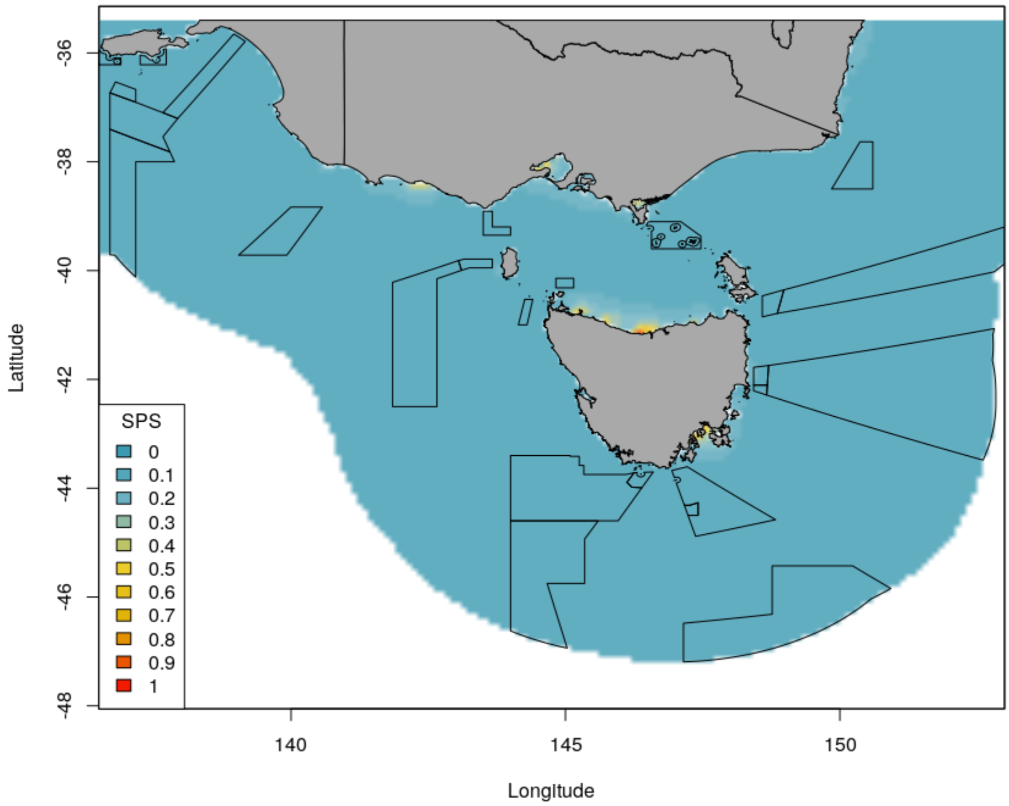

Figure 12.27: Pressure map for the Point discharges sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.27.

Table 12.27: Point discharges metadata

Data layer	Metadata record
NESP_NOD_ammonia_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mlJcoa4?domain=metadata.imas.utas.edu.au
NESP_NOD_nitrate_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mlJcoa4?domain=metadata.imas.utas.edu.au
NESP_NOD_nitrogen_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mlJcoa4?domain=metadata.imas.utas.edu.au
NESP_NOD_pathogens_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mlJcoa4?domain=metadata.imas.utas.edu.au
NESP_NOD_phosp_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mlJcoa4?domain=metadata.imas.utas.edu.au
NESP_NOD_TSS_exp_smoothed_SpatiallyProcessed_masked_linearStd	https://protect-au.mimecast.com/s/a7rqCgZovVC7YM9mlJcoa4?domain=metadata.imas.utas.edu.au

12.8 Marine pollution

12.8.1 Light pollution

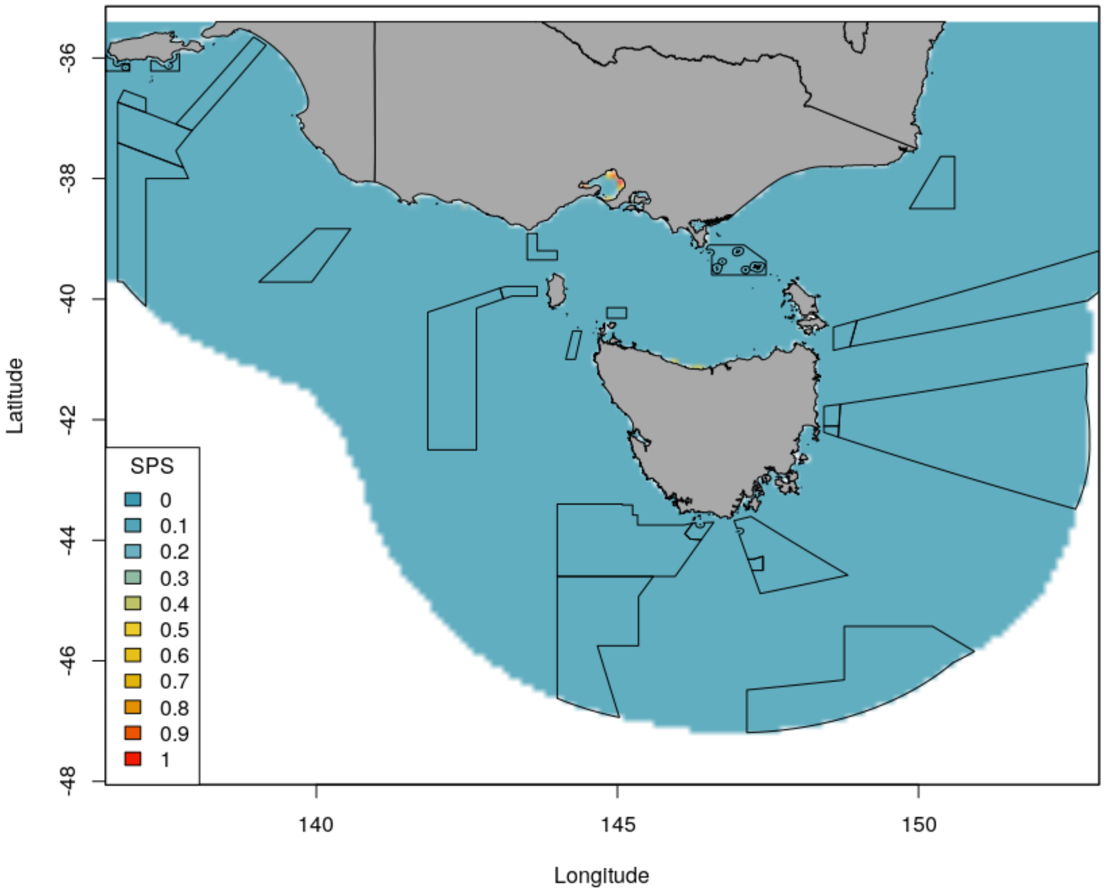

Figure 12.28: Pressure map for the Light pollution specific pressure. Map shows the standardised pressure sum (SPS) of the specific pressure in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.28.

Table 12.28: Light pollution metadata

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

12.8.2 Marine debris including microplastics

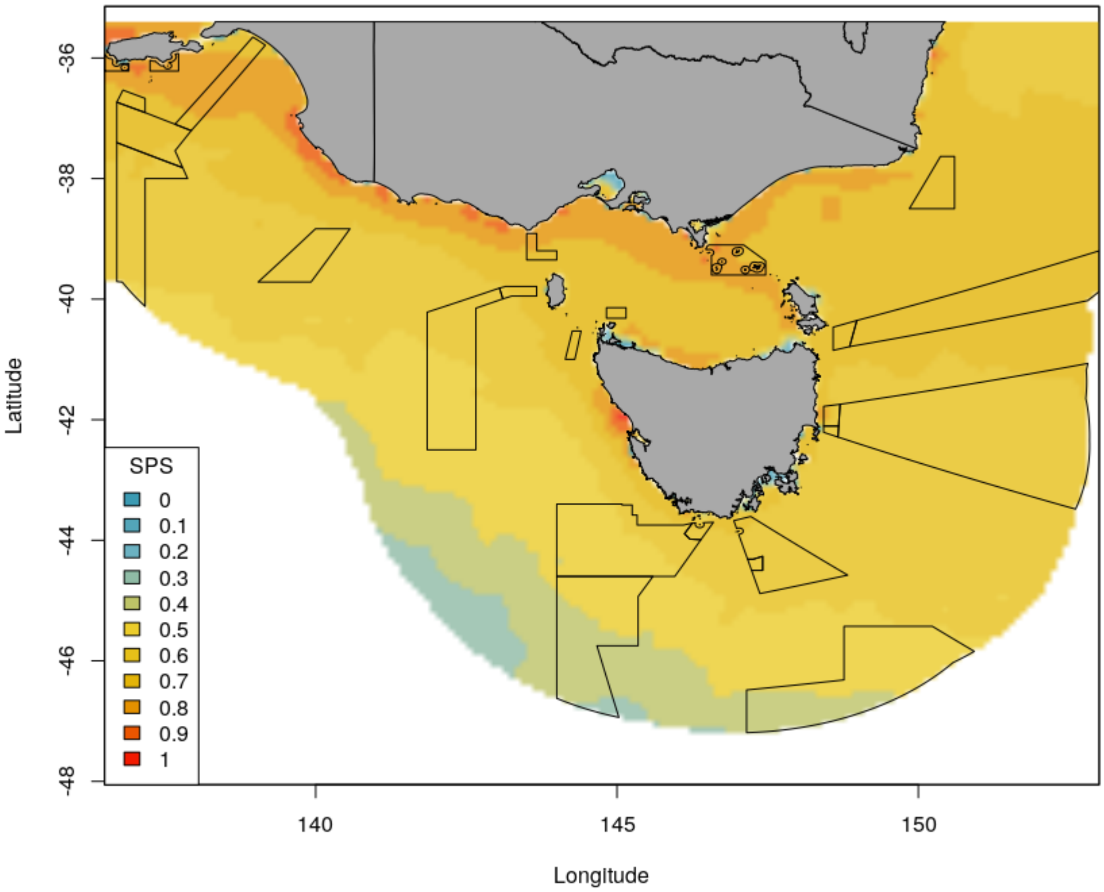

Figure 12.29: Pressure map for the Marine debris including microplastics specific pressure. Map shows the standardised pressure sum (SPS) of the specific pressure in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.29.

Table 12.29: Marine debris metadata

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

12.8.3 Noxious substances including chemicals and heavy metals

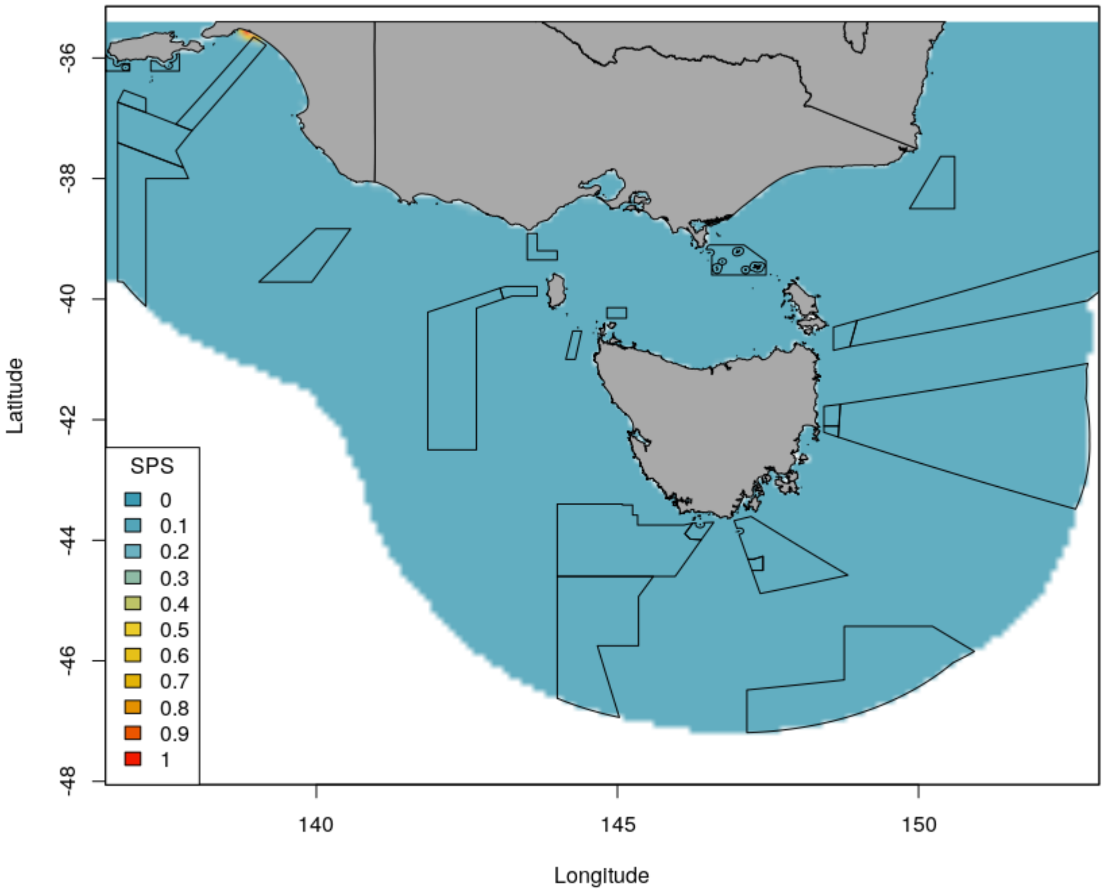

Figure 12.30: Pressure map for the Noxious substances including chemicals and heavy metals specific pressure. Map shows the standardised pressure sum (SPS) of the specific pressure in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.30.

Table 12.30: Noxious substances metadata

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

12.8.4 Oil fuel spill or leak

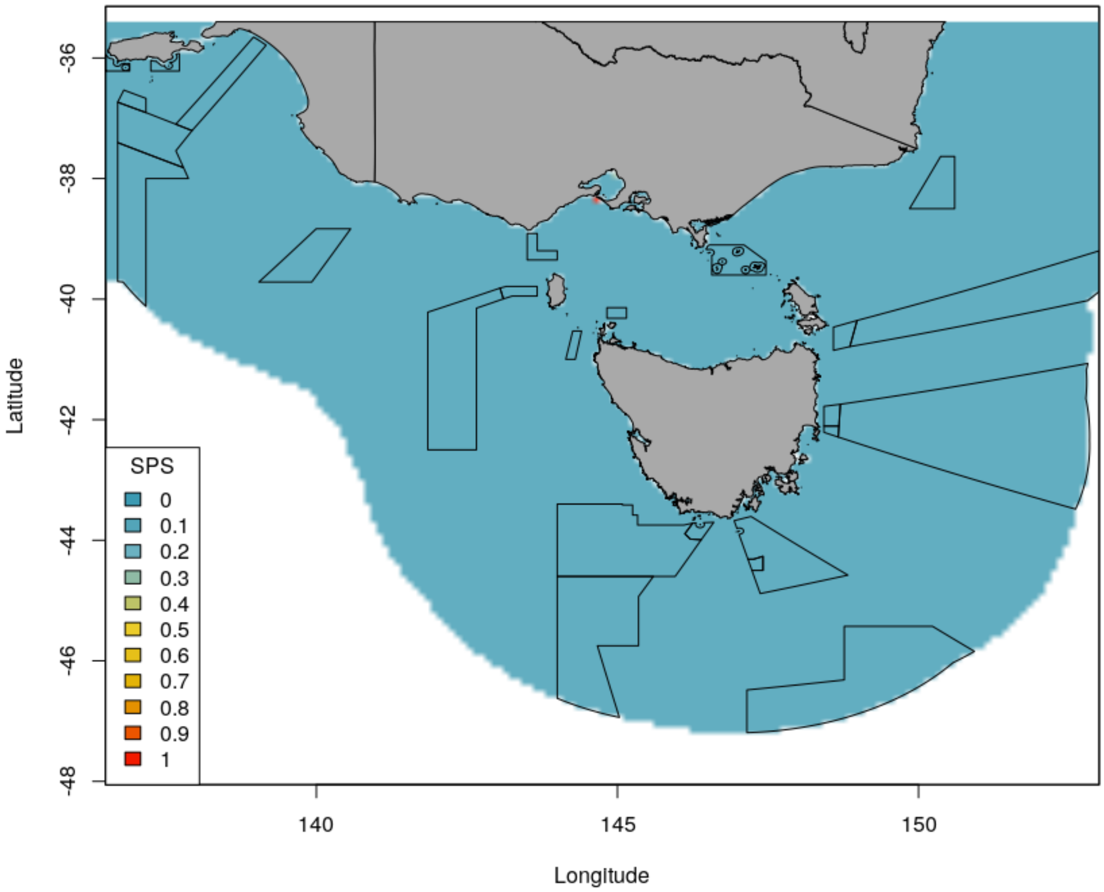

Figure 12.31: Pressure map for the Oil fuel spill or leak specific pressure. Map shows the standardised pressure sum (SPS) of the specific pressure in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.31.

Table 12.31: Oil fuel spill or leak metadata

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

12.9 Mining

12.9.1 Mining operations including exploration

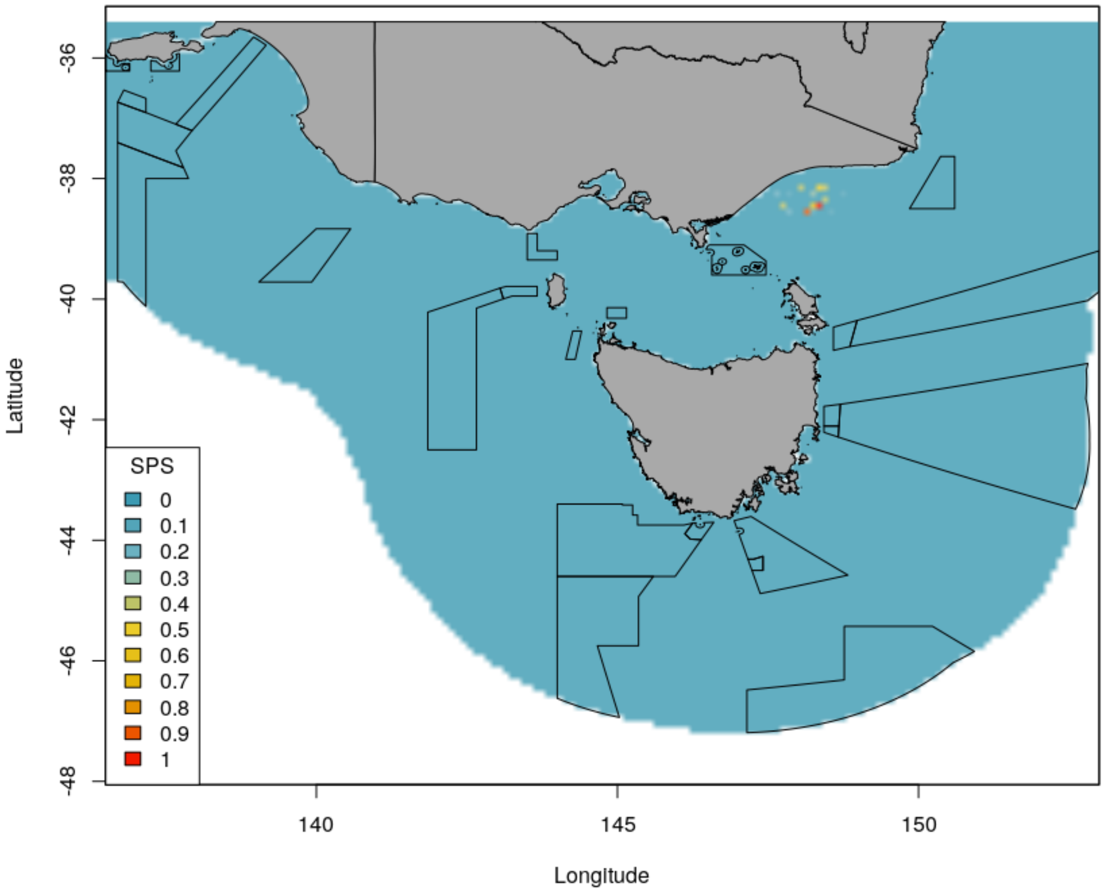

Figure 12.32: Pressure map for the Mining operations including exploration sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.32.

Table 12.32: Mining operations metadata

Data layer	Metadata record
wells.2015_fieldID_count_SpatiallyProcessed_masked_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/2eddbe26-0276-4468-a210-0c00ada8bf39

12.9.2 Mining seismic survey

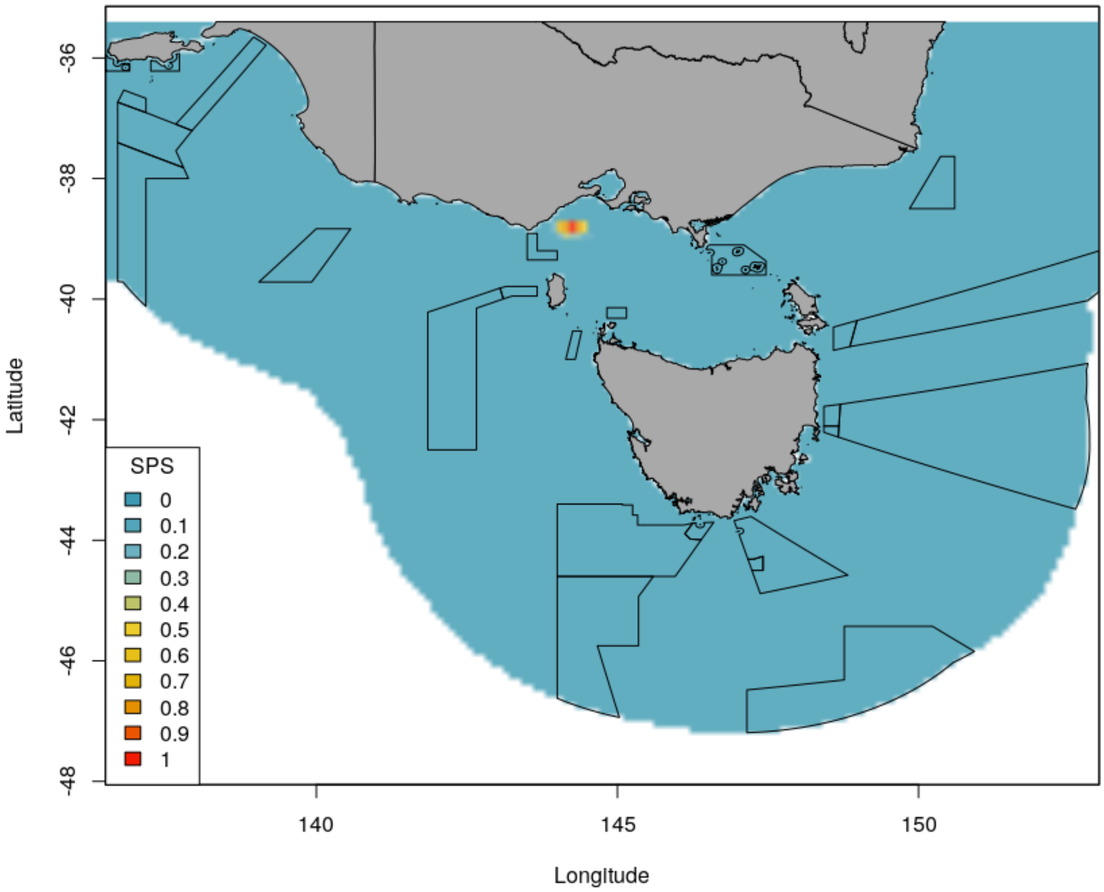

Figure 12.33: Pressure map for the Mining seismic survey sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.33.

Table 12.33: Seismic survey metadata

Data layer	Metadata record
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

12.9.3 Vessel transiting

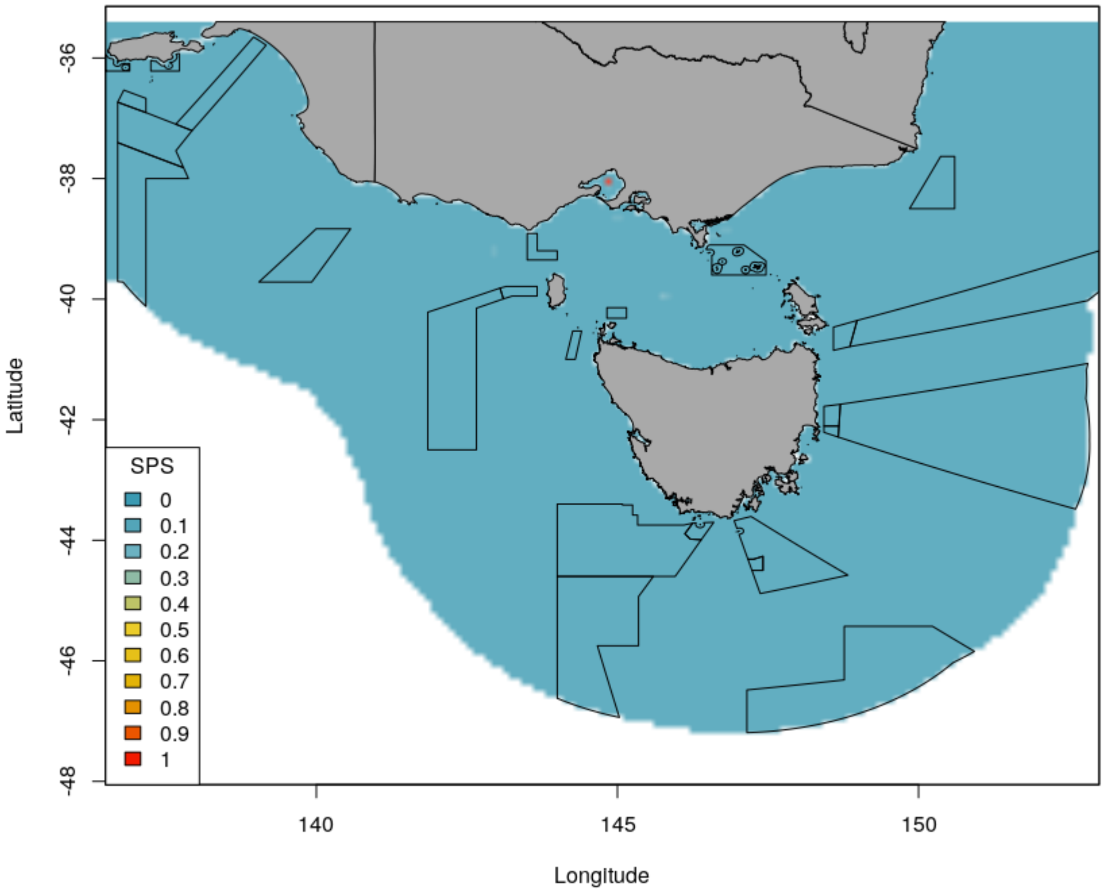

Figure 12.34: Pressure map for the Mining vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.34.

Table 12.34: Mining vessel transiting metadata

Data layer	Metadata record
transiting_distance_working_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f

12.10 Recreational fishing

12.10.1 Vessel transiting

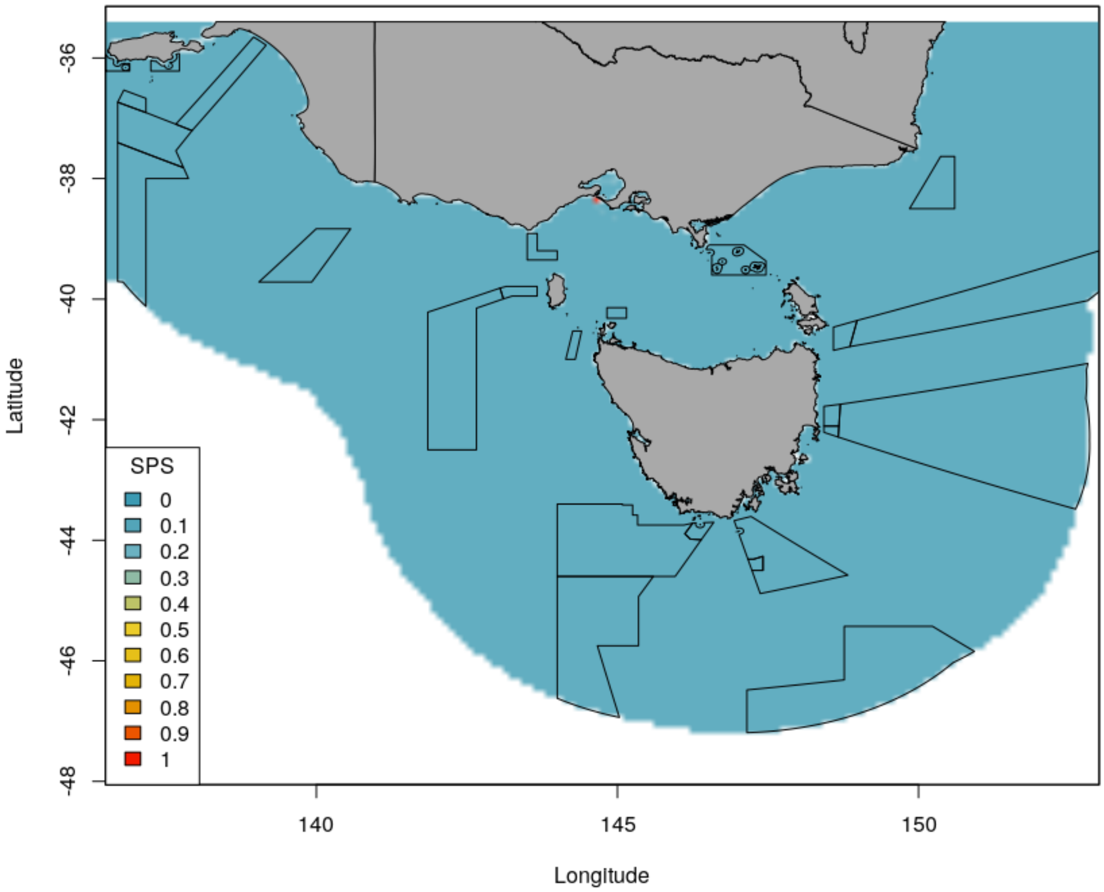

Figure 12.35: Pressure map for the Recreational fishing activity, vessel transiting sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.35.

Table 12.35: Recreational fishing vessel transiting metadata

Data layer	Metadata record
transiting_distance_recreation_temporal_mean_years_2013_2016_linearStd	https://marlin.csiro.au/geonetwork/srv/eng/catalog.search;jsessionid=1wduy78xk8tbzp8fo8ij2545e#/metadata/b8135966-33c6-4a1c-bcbc-d797c2a1155f

12.11 Renewable energy

12.11.1 Wave tidal and wind

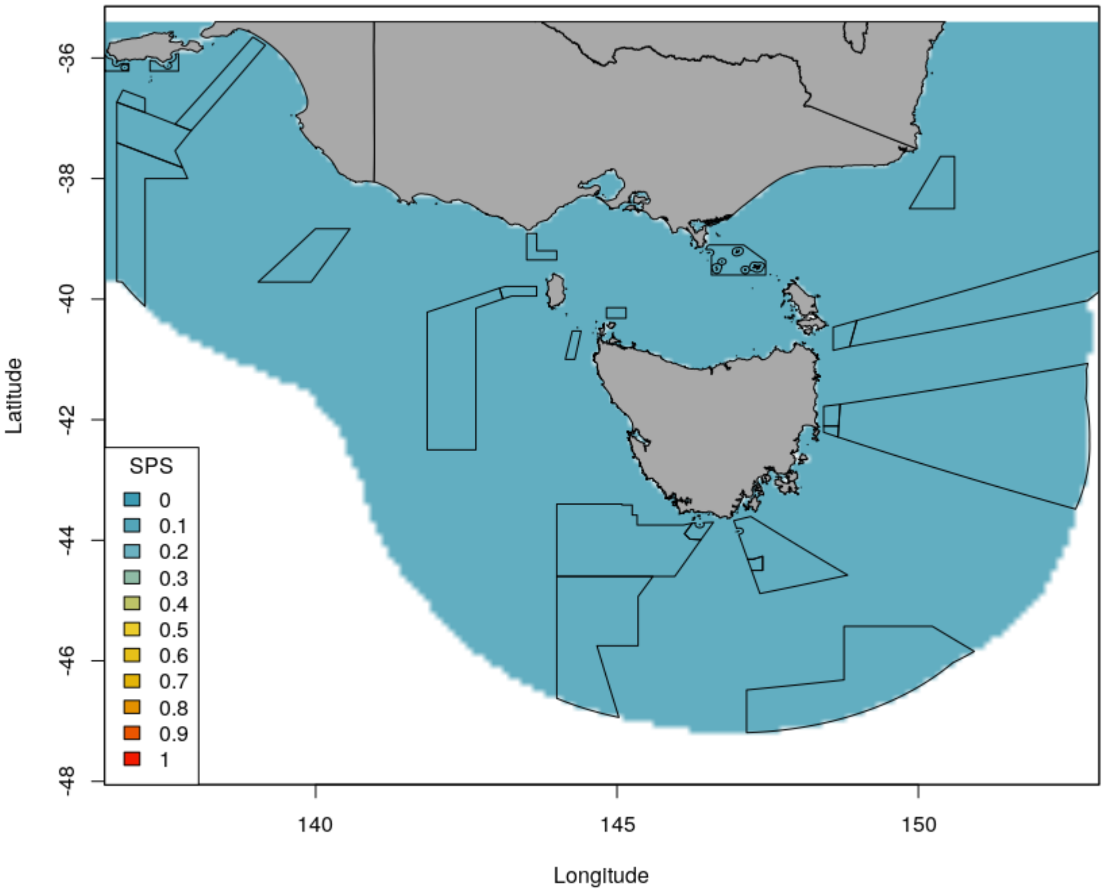

Figure 12.36: Pressure map for the Wave tidal and wind sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.36.

Table 12.36: Wave, tide and wind energy metadata

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

12.12 Structures and works

12.12.1 Fish aggregating devices

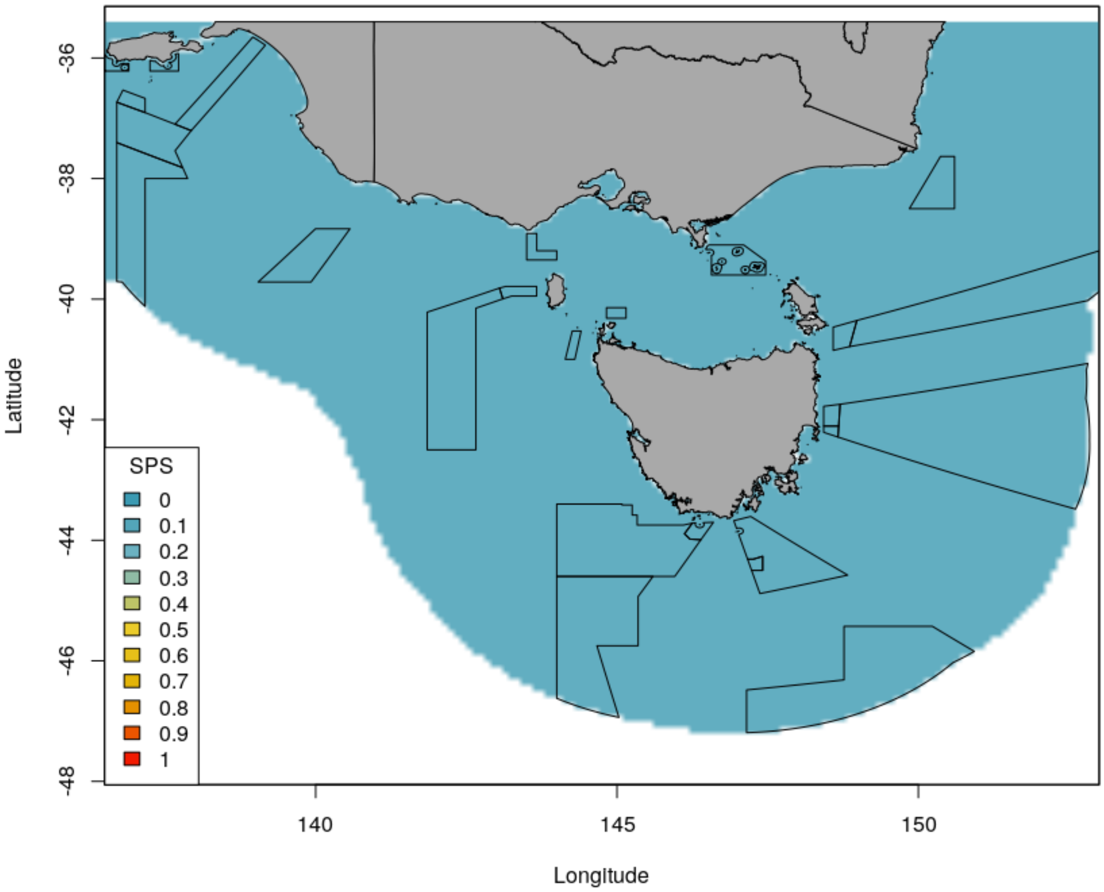

Figure 12.37: Pressure map for the Fish aggregating devices sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.37.

Table 12.37: Fish aggregating devices metadata

Data layer	Metadata record
fads_AU_linearStd	Parks

12.12.2 Moorings

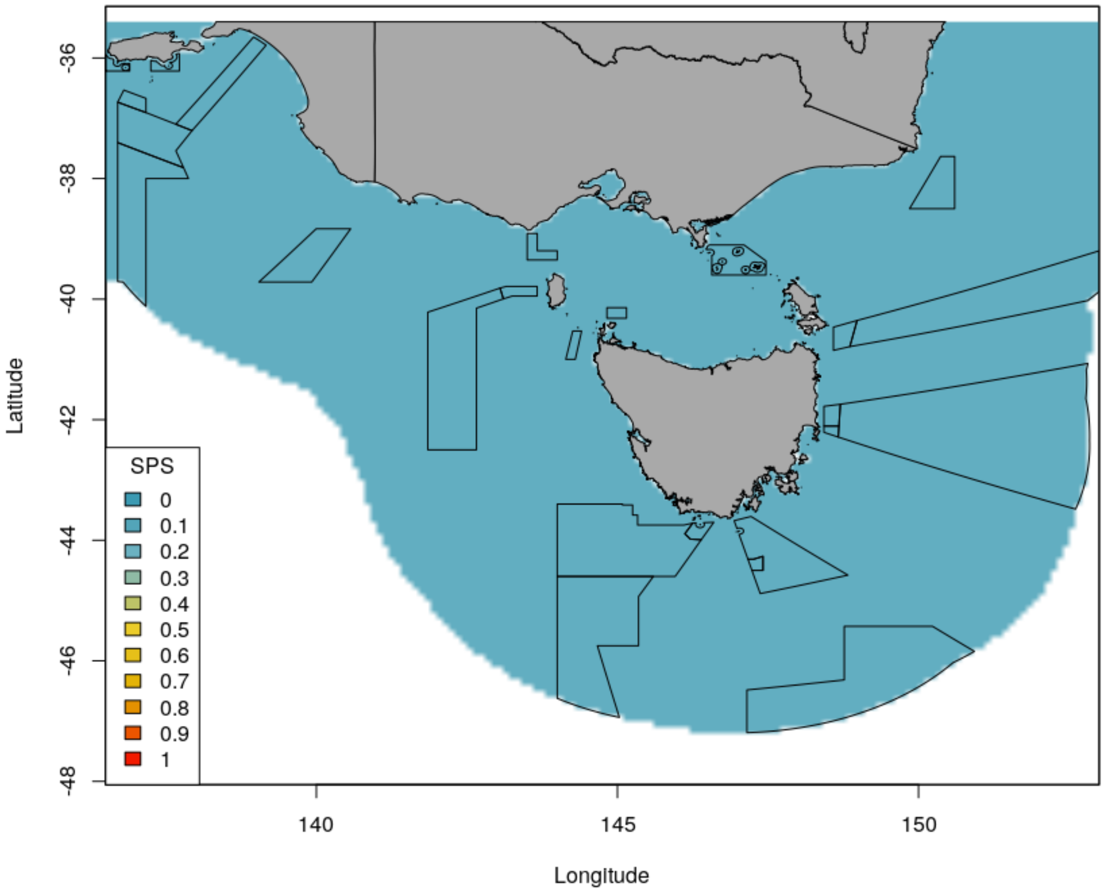

Figure 12.38: Pressure map for the Moorings sub-activity. Map shows the standardised pressure sum (SPS) of the sub-activity in the South-east marine region, together with the location and zone boundaries of the Australian marine parks in the South-east network

The standardised data layers used to produce this pressure layer, and the location of the meta-data records for the original (unstandardised) data are provided in Table 12.38.

Table 12.38: Moorings metadata

Data layer	Metadata record
parks_authorised_vessels_anchorages_temporal_mean_years_2013_2018_linearStd.2	Parks
SpatiallyProcessed_temporal_sum_years_MooringsAll_masked_linearStd	Parks

13 APPENDIX G KNV EQUIVALENT CONCEPTS

Several concepts equivalent (or similar) to the Key Natural Values are described in various national and international fora, including Ecologically or Biologically Significant Areas (EBSAs), Particularly Significant Seas Areas (PSSAs), Vulnerable Marine Ecosystems (VMEs) and Key Biodiversity Areas (KBAs). The criteria used to identify these locations are summarised in Table 13.1.

Table 13.1: KNV equivalent concepts and criteria

Criteria	UN CBD	UN IMO	UN FAO	AUS	AUS	Norway	Canada	Birdlife Int.	IUCN	IUCN
	EBSA	PSSA	VME	KEF	BIA	Environmental values	EBSA	IBA	IMMA	KBA
C1	uniqueness or rarity	x	x	x		x	x	x	x	x
C2	Special Importance for life history stages of species	x	x		x	x	x	x		x
C3	Importance for threatened, endangered or declining species and/or habitats	x	x	x	x	x	x	x		x
C4	Vulnerability, Fragility, Sensitivity or Slow Recovery	x	x			x	x			
C5	Biological Productivity	x		x		x	x			x
C6	Biological Diversity	x	x	x		x	x	x	x	x
C7	Naturalness	x					x			x
	Network	x								x
	Cultural	x								
	Scientific	x								

14 APPENDIX H CONCEPTUAL MODELS

Detailed conceptual models were developed from a `whole park' perspective and each of the ecosystem complexes identified in the natural values common language, based on the approach used for the simplified conceptual model in Figure 1.5. The detailed whole of park model includes all of the links between individual nodes, while the ecosystem complex models only include links between core components of the models (e.g. between pressures, values, benefits, management actions, and drivers).

Conceptual models represent our current understanding of the linkages between different ecosystem components, pressures, drivers, social and economic benefits and management actions in Australian Marine Parks. They are good communication and decision support tools that show links between management actions and ecosystem response. Conceptual models help provide information on:

What to manage

1. What Parks Australia aims to protect.
2. What are the relevant pressures acting on values and benefits?
3. What are the likely outcomes (consequences) of a specific management action?
4. What are the emerging issues?

What to monitor

1. Which components of the system are important for evaluating management effectiveness?
2. Inform selection of indicators for prioritised values and pressures (and drivers).
3. Use conceptual models to follow the chain of causal factors (i.e. understand how system components are related and may respond to management intervention).

What research to do (information gaps)

1. Inform the identification of knowledge and information gaps.
2. What does Parks Australia need to know to make decisions?
3. Contested areas and interactions become apparent (which may identify knowledge gaps or the need for further research).

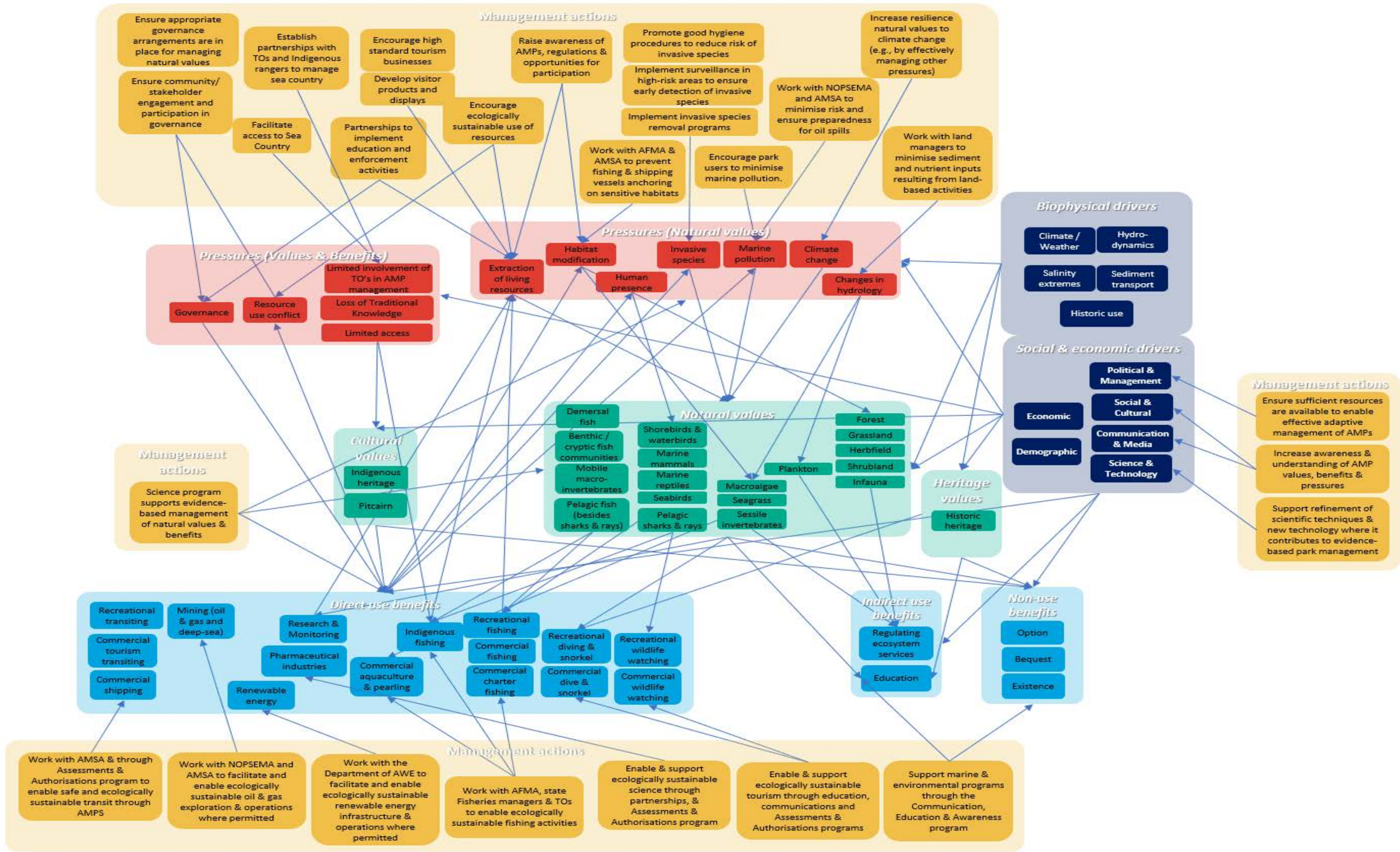

Figure 14.1: Conceptual model for all ecosystem complexes in AMPs.

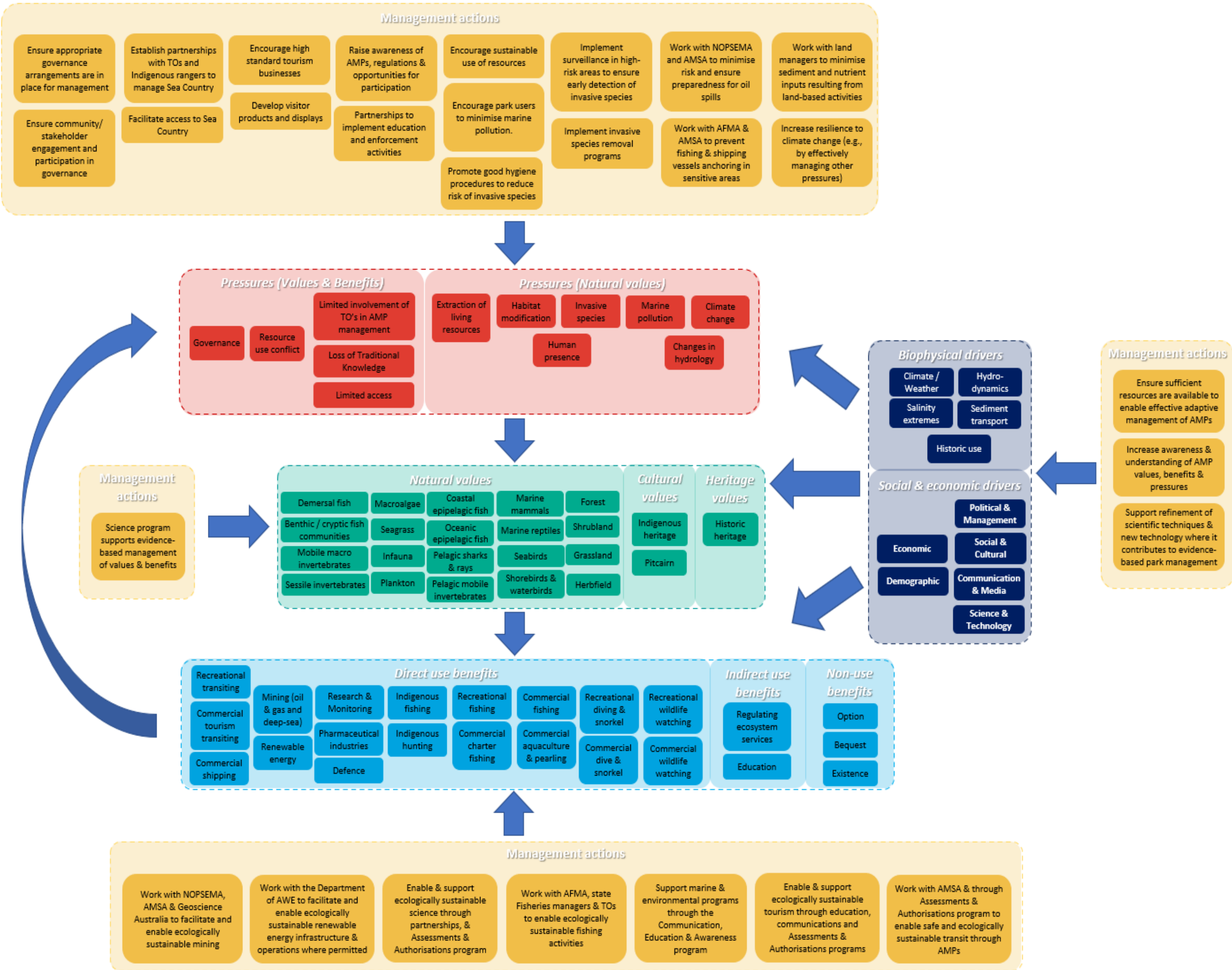

Figure 14.2: Conceptual model for all ecosystem complexes.

Shallow Reefs

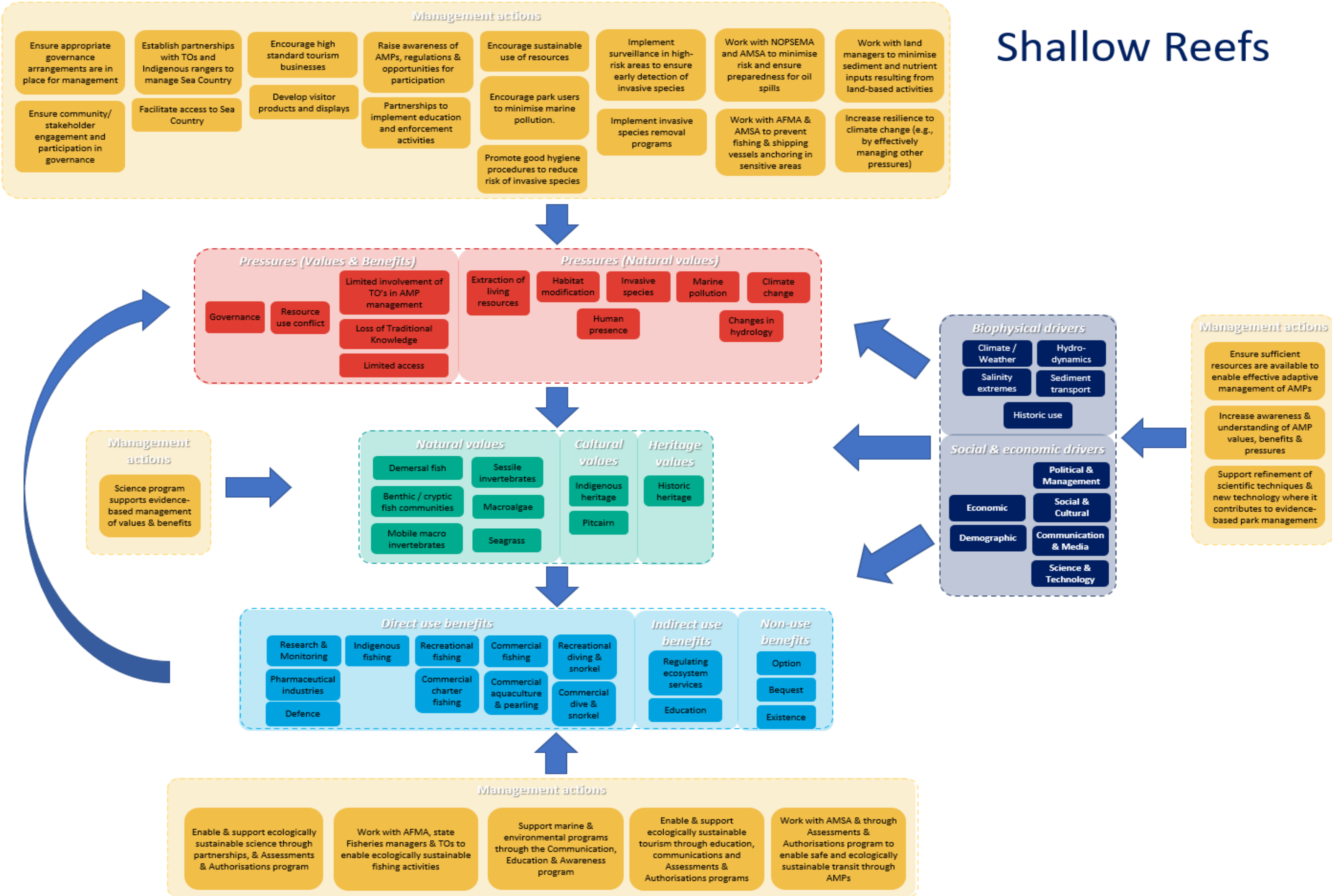

Figure 14.3: Conceptual model for shallow reefs.

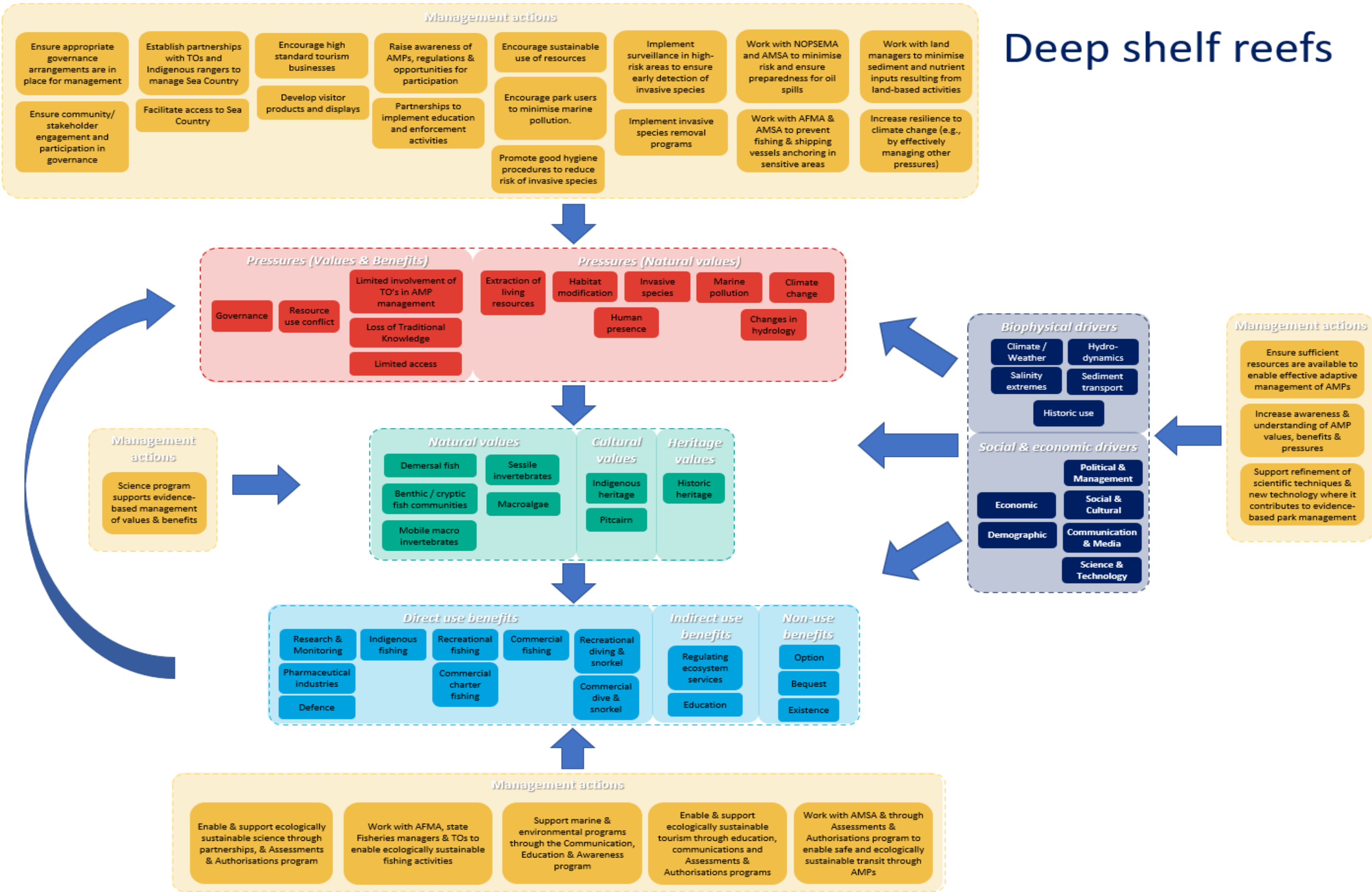

Figure 14.4: Conceptual model for Deep shelf reefs.

Oceanic coral reefs

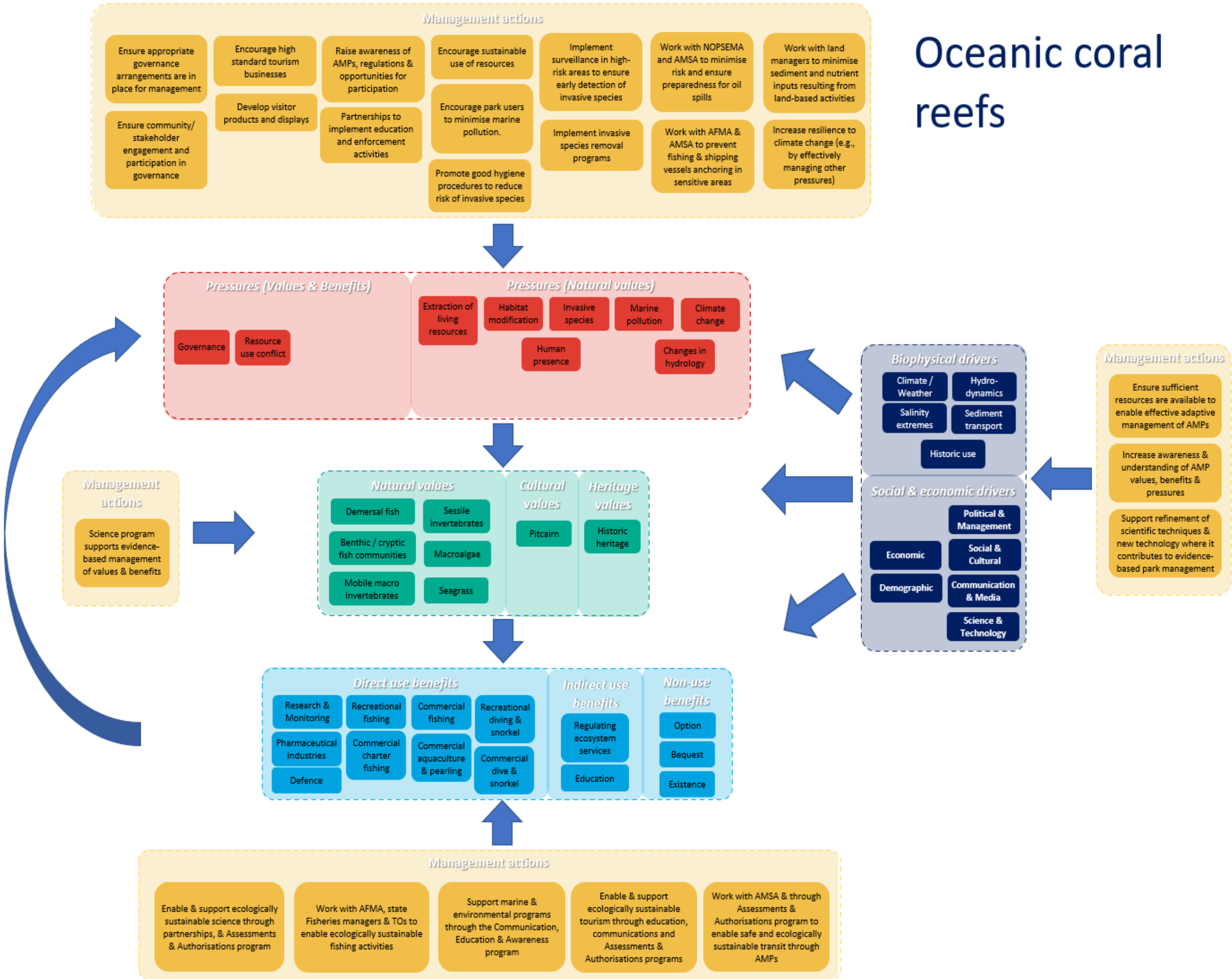

Figure 14.5: Conceptual model for Oceanic coral reefs.

Shelf, upper and mid-slope unvegetated sediments

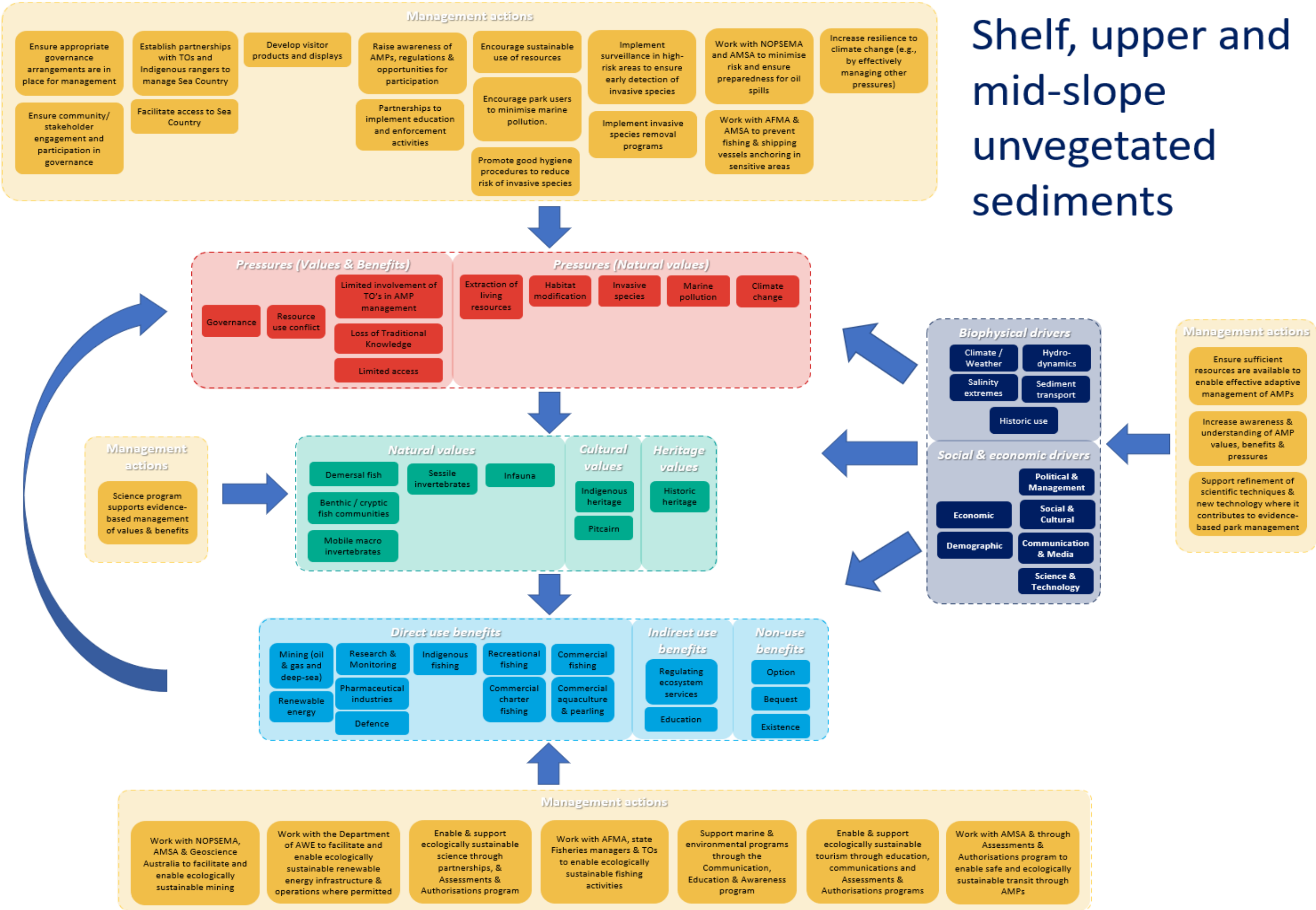

Figure 14.6: Conceptual model for Shelf, upper and mid slope unvegetated sediments.

Shelf vegetated sediments

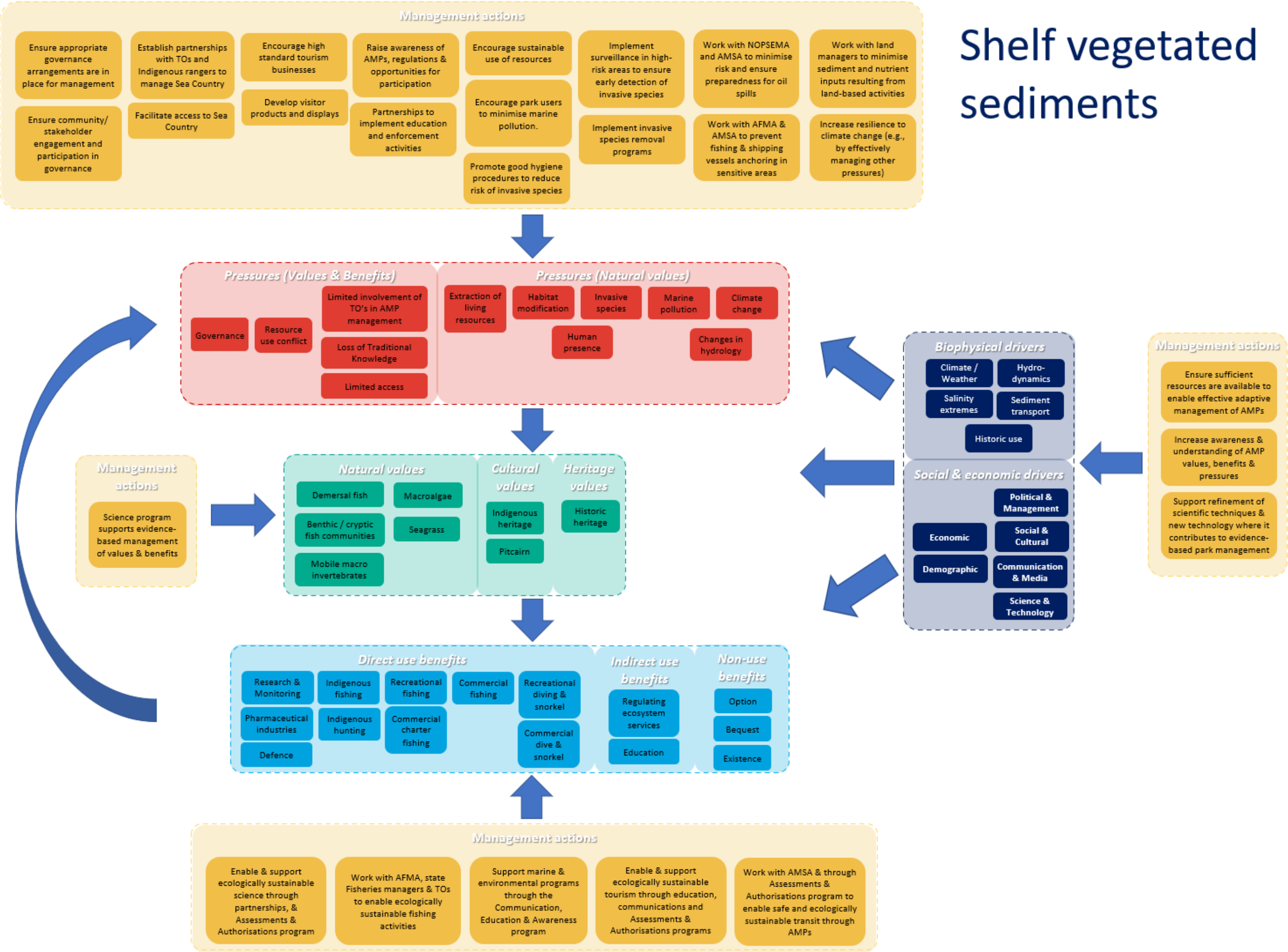

Figure 14.7: Conceptual model for Shelf vegetated sediments.

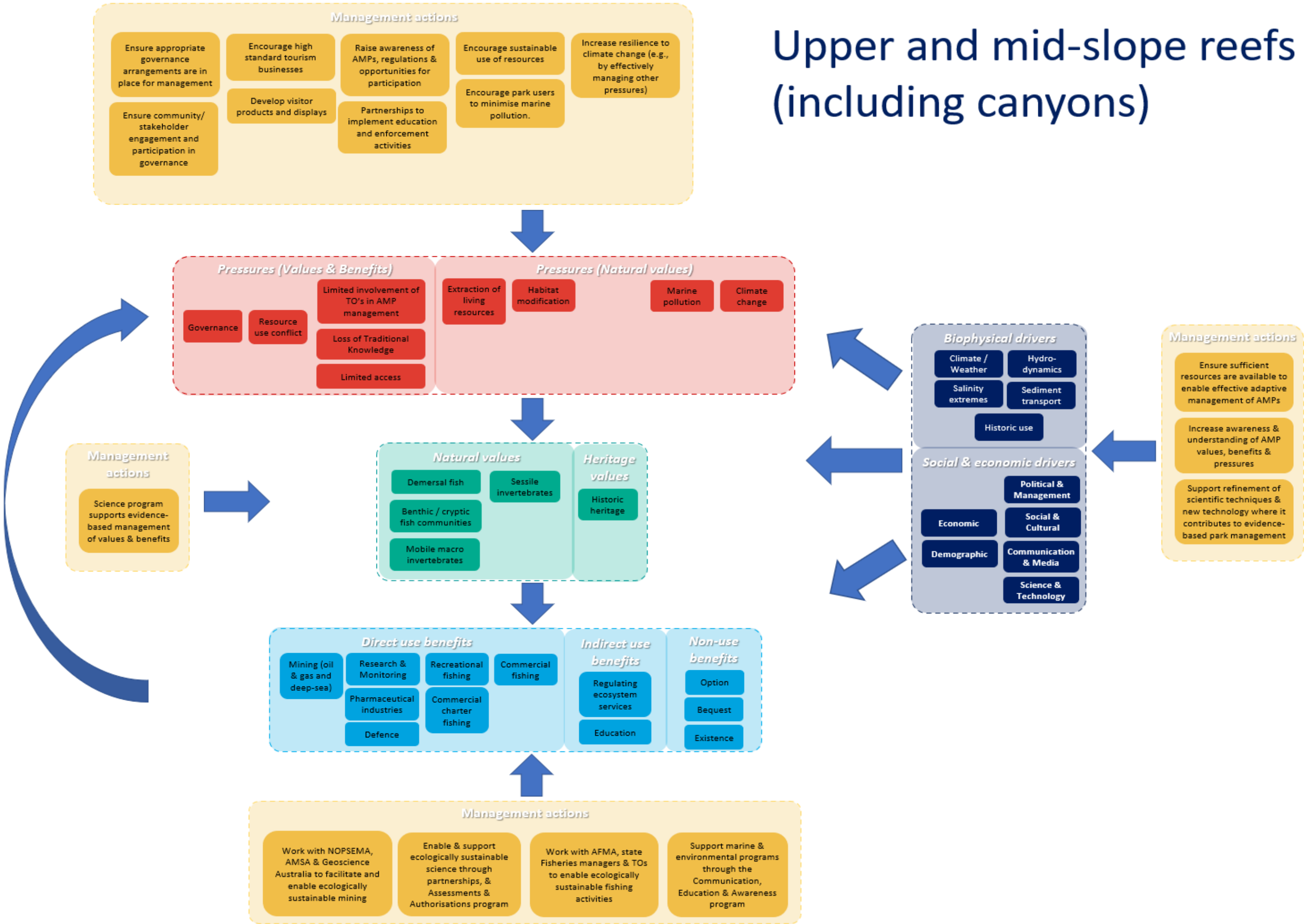

Figure 14.8: Conceptual model for Upper and mid slope reefs (including canyons).

Lower-slope and abyssal reef and sediments

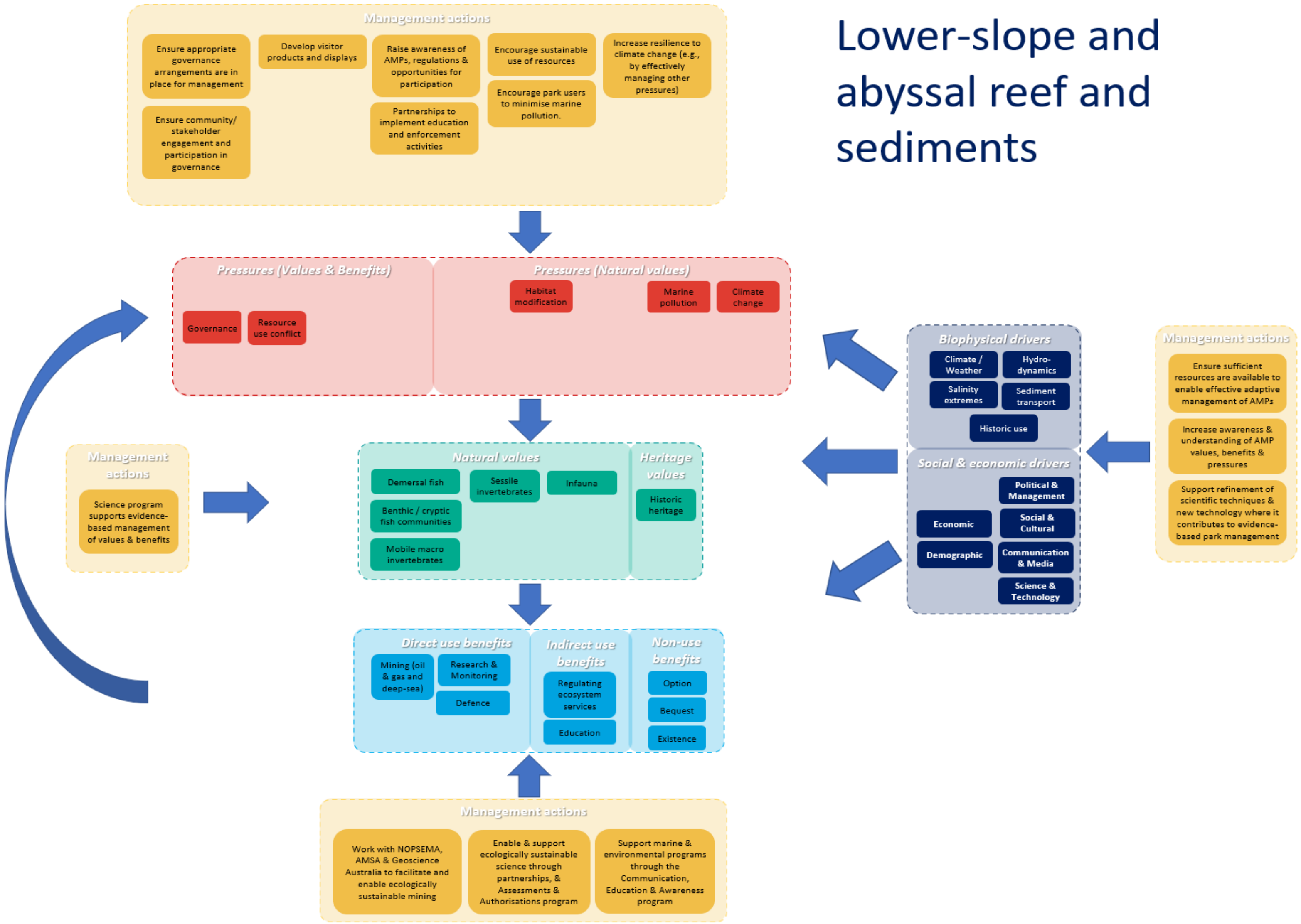

Figure 14.9: Conceptual model for Lower slope and abyssal reef and sediments.

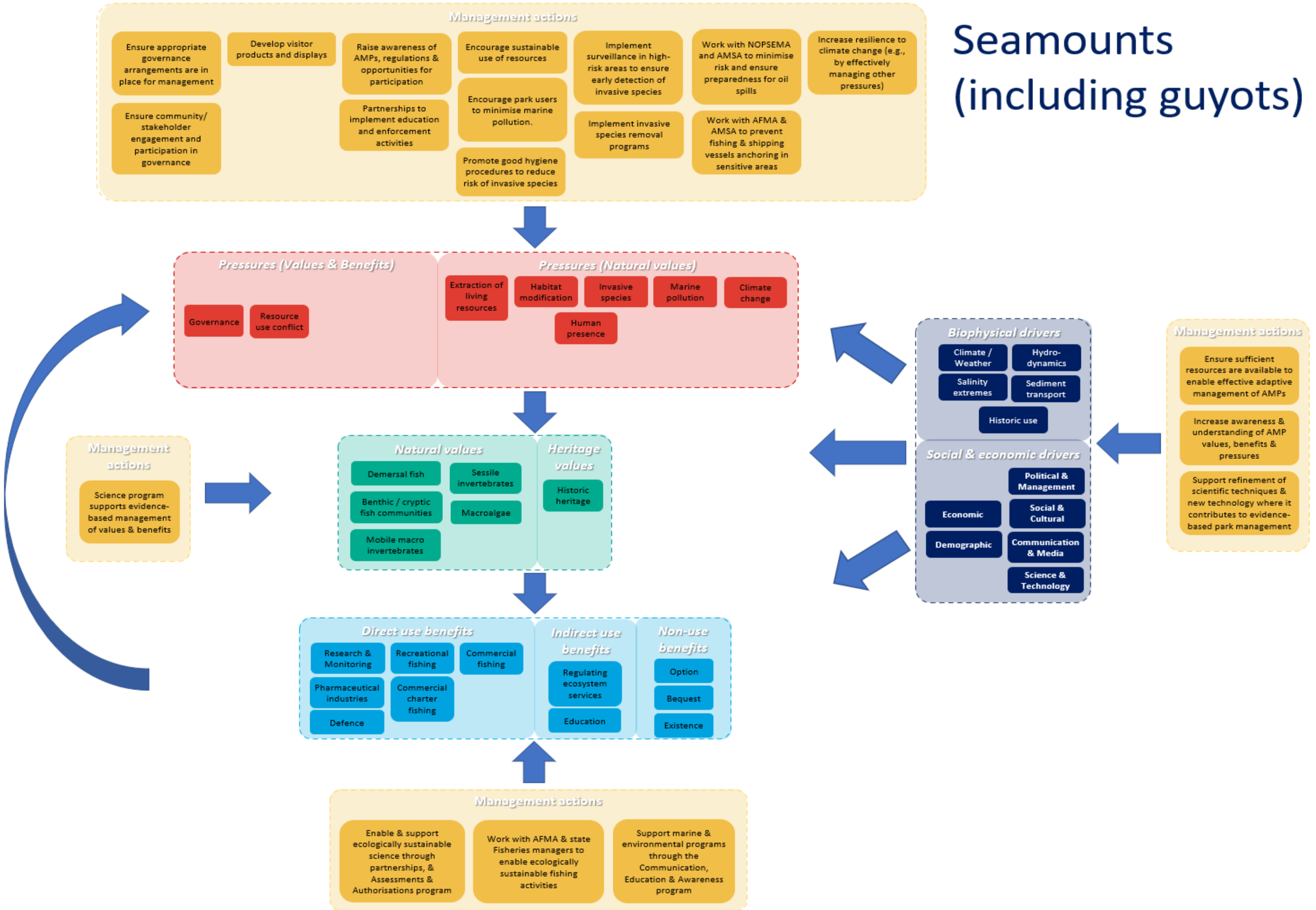

Figure 14.10: Conceptual model for Seamounts (including guyots).

Islands

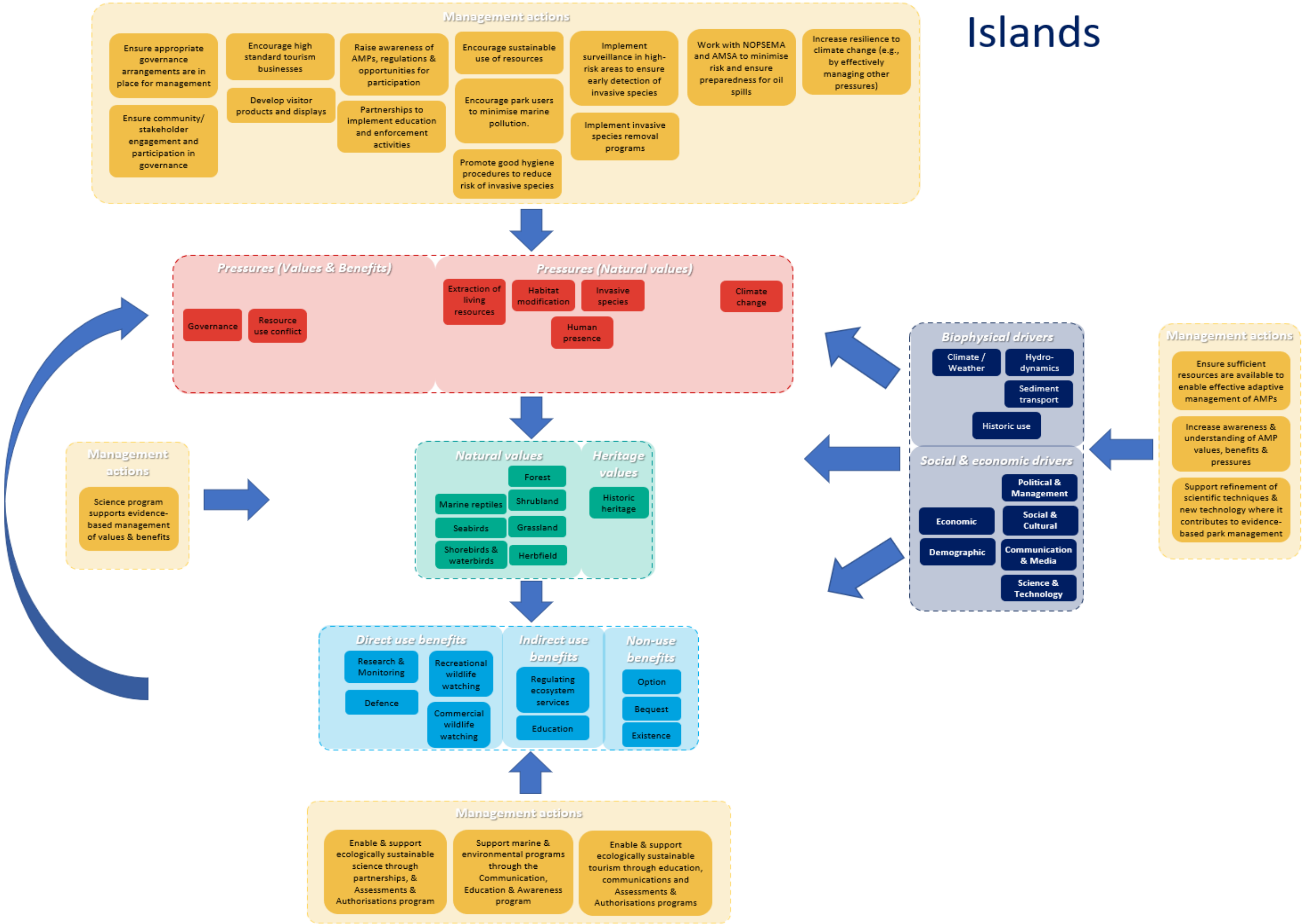

Figure 14.11: Conceptual model for Islands.

Intertidal areas

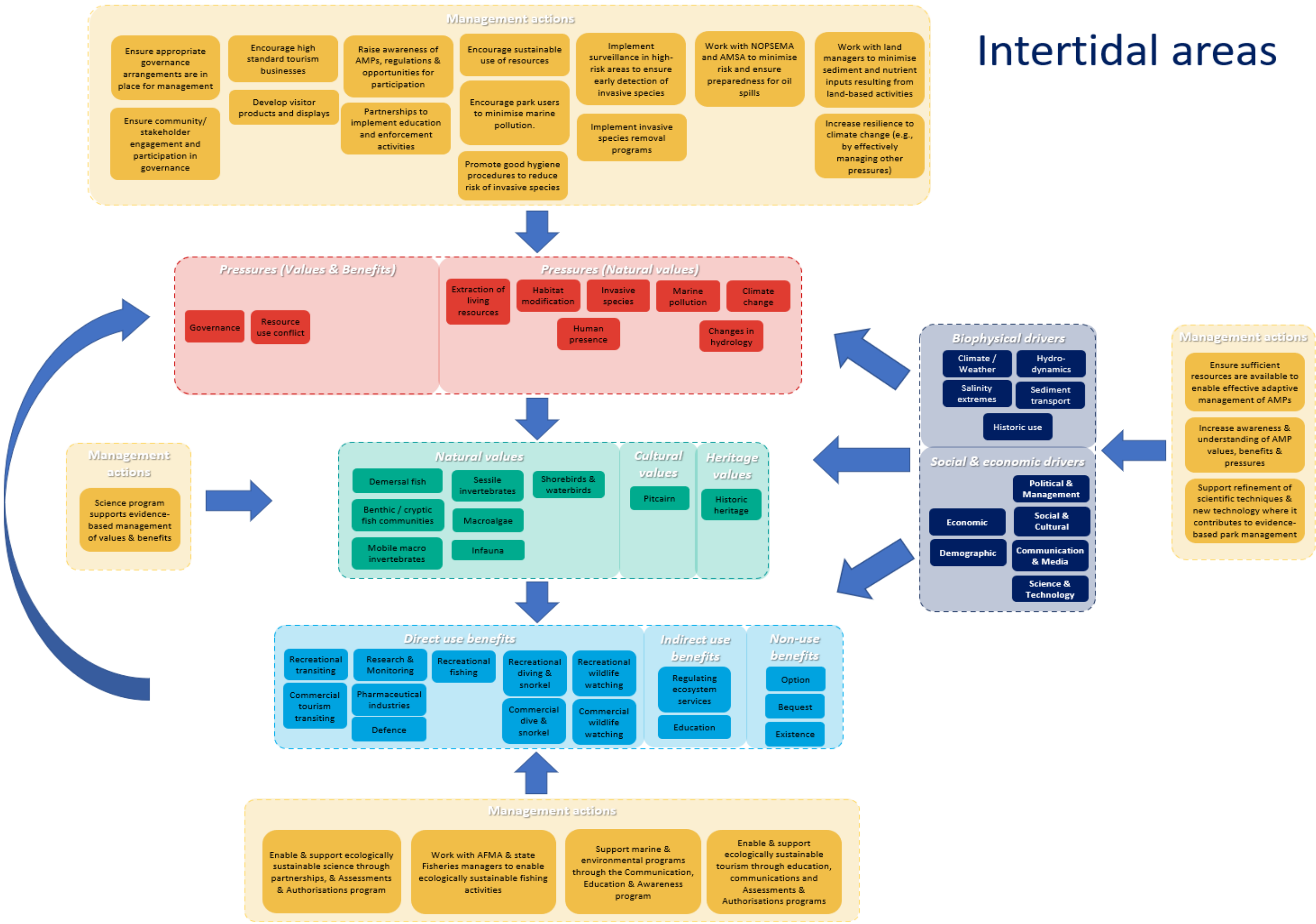

Figure 14.12: Conceptual model for Intertidal areas.

Water column

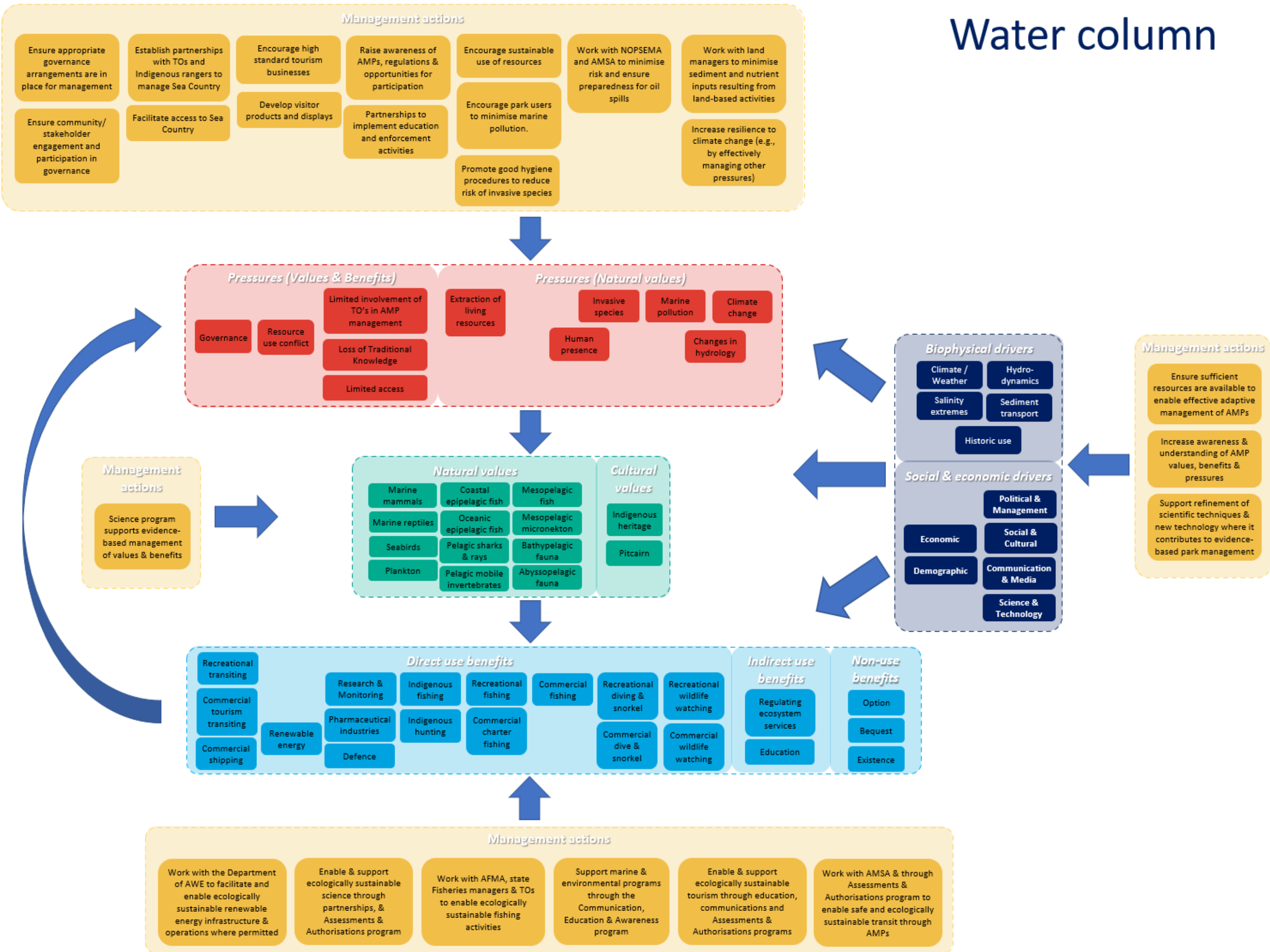

Figure 14.13: Conceptual model for Water column.

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