Marine Estate Management Strategy
Marine Integrated Monitoring Program

Environmental Condition Framework

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Acknowledgment of Country

We stand on Country that always was and always will be Aboriginal land. We acknowledge the Traditional Custodians of the land and waters, and we show our respect for Elders past, present and emerging. We are committed to providing places in which Aboriginal people are included socially, culturally and economically through thoughtful and collaborative approaches to our work.

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Mangroves, Carama Creek, Jervis Bay NSW - validation of estuarine macrophyte mapping using drone. Cover image: Matt Hammond.

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***Sarcocornia quinqueflora* (saltmarsh).** Image: R. Laird

1 Purpose of this document

The Environmental Condition Framework (ECF) has been prepared to describe how progress towards meeting the environmental goals of the Marine Estate Management Strategy (MEMS) will be evaluated. The Marine Integrated Monitoring Program (MIMP) is the primary process for collecting the relevant information to track progress. The MIMP covers environmental, social, cultural and economic components. This report only addresses the environmental component, and a companion report (Community Wellbeing Framework) addresses social, cultural and economic benefits. An additional process, not described here, will integrate the outputs of these two assessments and describe how the results will be reported.

This Environmental Condition Framework report provides:

- a general overview of the monitoring approach
- links between monitoring and research projects and environmental outcomes of the MEMS
- methods used to assess the condition and trends for assets
- methods for filling priority knowledge gaps
- suggestions for environmental reporting themes and indicators that could be used in MIMP Report Cards, with links back to projects that will provide the knowledge
- detailed information on each of the main projects that contribute data to the Environmental Condition Framework.

2 Marine Estate Management Authority (MEMA)

The marine estate is one of New South Wales (NSW) most significant natural assets and includes estuaries to the tidal limits, the shoreline, seafloor and reefs, and the waters of the NSW coast from the Queensland border to the Victorian border and out to three nautical miles offshore, as well as the offshore area surrounding Lord Howe Island (NSW MEMS 2018). Good water quality, healthy habitats, and diverse and abundant marine life underpin the social, cultural and economic benefits that the NSW community derive from the marine estate.

The Marine Estate Management Authority (MEMA) was established in 2013 as a single authority to oversee and provide strategic advice to government on the management of the NSW marine estate. MEMA is comprised of an independent Chair and four government agencies representing: Regional NSW (represented by Department of Primary Industries Fisheries (DPI-F)), Department of Planning and Environment (represented by Environment & Heritage Group (DPE-EHG) and Department of Planning and Assessment (DPE-PA)), and Transport for NSW (TfNSW). MEMA advises the NSW Government on policies, priorities and the direction of management of the marine estate.

The establishment of MEMA was supported by new legislation, the *Marine Estate Management Act 2014*, and the enactment of an independent panel of social, economic and environmental experts, the Marine Estate Expert Knowledge Panel (MEEKP), to guide MEMA on policies, priorities and direction for the NSW marine estate.

MEMA's vision for the marine estate:

> *'a healthy coast and sea, managed for the greatest wellbeing of the community, now and into the future'.*

This vision promotes managing the marine estate to maintain and enhance the natural assets while allowing access and use in a way that maximises economic, social, cultural, and environmental benefits to the people of NSW, over the long term.

3 NSW Marine Estate Management Strategy (MEMS)

MEMA released the Marine Estate Management Strategy 2018-2028 (MEMS) in 2018. The MEMS articulates how MEMA's vision and management priorities will be delivered over 10 years under the objects of the *Marine Estate Management Act 2014*. The ten-year plan is designed to reduce the major threats to the NSW marine estate and provides for the range of multiple uses and associated benefits that contribute to the wellbeing of the NSW community now and into the future.

The MEMS includes nine management initiatives supported by 53 management actions designed to address priority threats to the marine estate (Table 1). These threats were identified through an evidence-based threat and risk assessment (TARA) for the NSW marine estate (BMT WBM 2017).

The MEMS also outlines high-level roles and responsibilities for each of the Government agencies involved in managing the marine estate. Progress towards delivering the MEMS and achieving success for each management initiative will be measured and reported through the MIMP.

TABLE 1. Marine Estate Management Strategy initiatives and summarised objectives.

Management Initiative		Management Objective
1	Improving water quality and reducing litter	To improve water quality and reduce marine litter for the benefit of marine habitats, wildlife and the community.
2	Delivering healthy coastal habitats with sustainable use and development	To protect coastal and marine habitats and associated species and enhance the health of the marine estate by improving the design, quality and ongoing management of foreshore development, use and waterway infrastructure.
3	Planning for climate change	Understand, adapt and increase resilience, to help mitigate the impacts of climate change on the NSW marine estate.
4	Protecting the Aboriginal cultural values of the marine estate	Work with Aboriginal communities in the management of Sea Country to reduce threats and risks to Aboriginal cultural heritage.
5	Reducing impacts on threatened and protected species	To understand and mitigate threats to threatened and protected species in NSW.
6	Ensuring sustainable fishing and aquaculture	To ensure fishing and aquaculture is managed in a way that is consistent with ecologically sustainable use while providing for the health, heritage and social benefits of fishing and seafood consumption.
7	Enabling safe and sustainable boating	To balance protection of coastal and marine habitats and species with ongoing access and safe and sustainable boating.
8	Enhancing social, cultural and economic benefits	To improve the social, cultural and economic benefits that the NSW community derives from the marine estate by responding to priority threats.
9	Delivering effective governance	To improve governance arrangements across the marine estate to support coordinated, transparent, inclusive and effective decision-making.

4 NSW Marine Integrated Monitoring Program (MIMP)

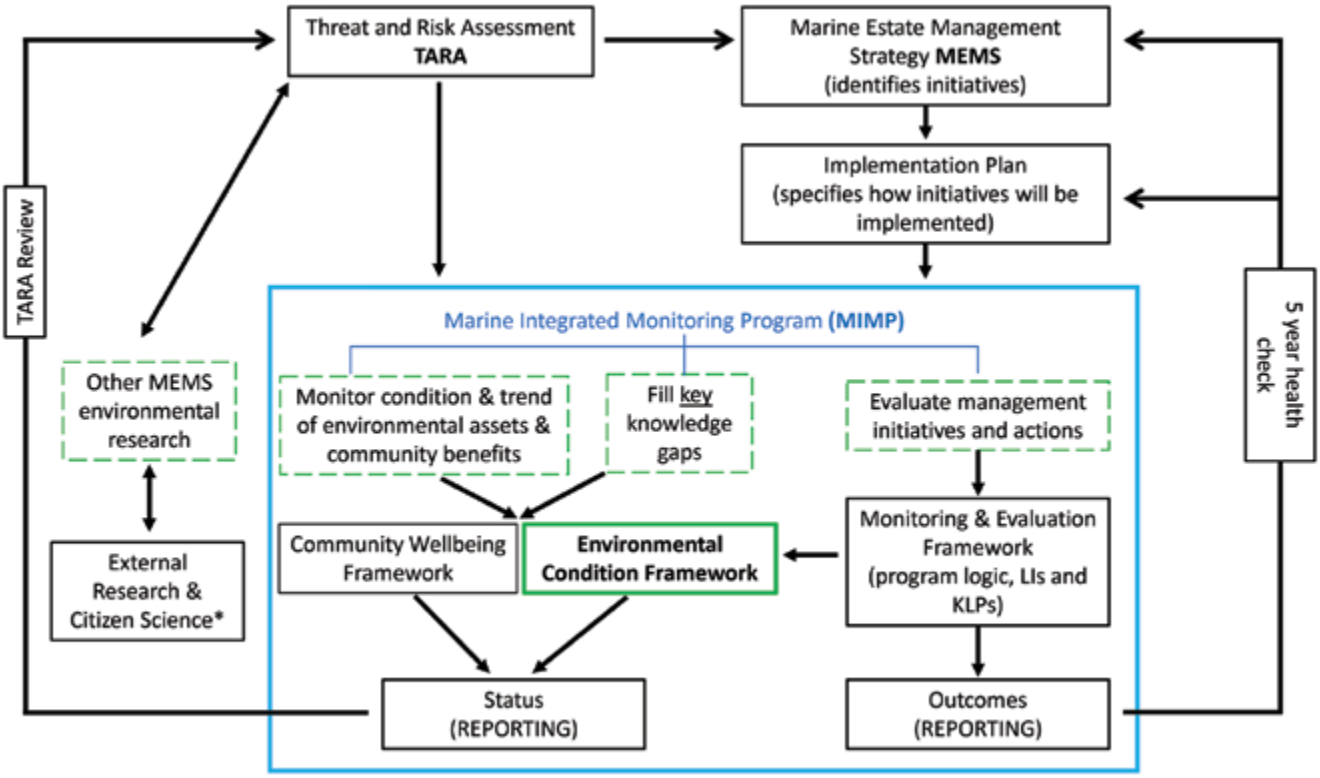
4.1 Background

The MIMP will provide the tools and processes to evaluate whether the MEMS is achieving its environmental, social, economic and cultural goals. It requires the implementation of monitoring and evaluation programs, strategic research to inform management and future directions, and reporting to stakeholders (Figure 1).

The MIMP is an important step in the adaptive management process for marine estate management – to monitor, evaluate and report.

The MIMP supports evidence-based decision-making and adaptive management by addressing knowledge gaps, developing a shared understanding of the benefits derived from the marine estate, tracking the impacts of threats to those benefits, and measuring the effectiveness of management. As data are collected through the monitoring of indicators, this information will be fed back into the adaptive management framework for future iterations of threat and risk assessments, evaluation of selected indicators, development of targeted research projects, the selection and refinements of indicators, and the refinement of management actions and monitoring plans.

FIGURE 1. Relationships between the MIMP, other MEMA actions, and this document (the Environmental Condition Framework). This document refers to research projects being done for a range of reasons (dotted green boxes) and excludes any reference to projects led by external organisations (*), even though some involve collaborations with DPI-F or DPE-EHG. Only core MIMP projects (in blue box) are described in full in Appendix C.



The key purposes of the MIMP are:

1. monitor the condition and trend of environmental assets and community benefits derived from the NSW marine estate
2. evaluate the effectiveness of the MEMS management initiatives and actions that aim to reduce priority threats and risks
3. fill knowledge gaps identified as part of the statewide Threat and Risk Assessment.

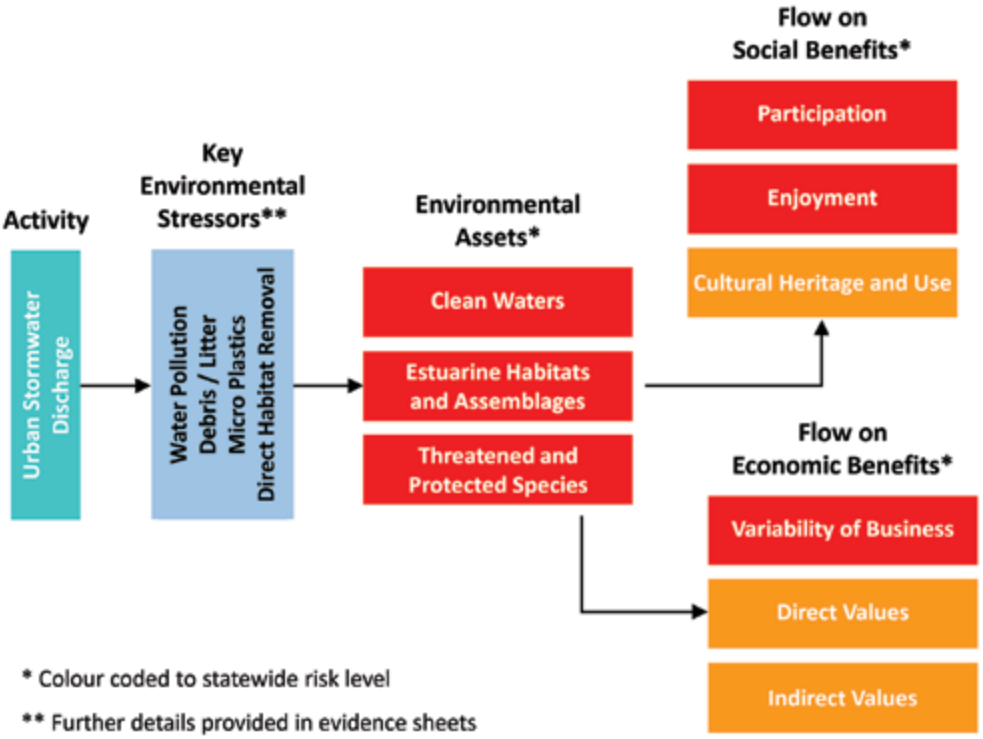
The process to address MIMP Purpose 2 (evaluate the effectiveness of management initiatives and actions) is described in the Integrated Monitoring and Evaluation Framework for the MIMP (Monitoring and Evaluation Framework (Aither 2022)). The Monitoring and Evaluation Framework tracks Leading Indicators (LIs) and Key Performance Indicators (KPIs) that provide quantifiable metrics that are aligned with outcomes. LIs and KPIs related to environmental condition will be included as part of the Environmental Condition Framework (this document).

The Monitoring and Evaluation Framework, with its focus on management effectiveness, does not address the full breadth of needs for the MIMP. This document expands on how the MIMP will address the other two purposes: monitor the condition and trend of *environmental* assets; and, fill key *environmental* knowledge gaps that were identified as part of the statewide TARA (BMT WBM 2017). Monitoring of condition and trend of social, cultural and economic benefits are described in a separate document (Community Wellbeing Framework).

4.2 Relationship of environmental condition to social, cultural and economic benefits

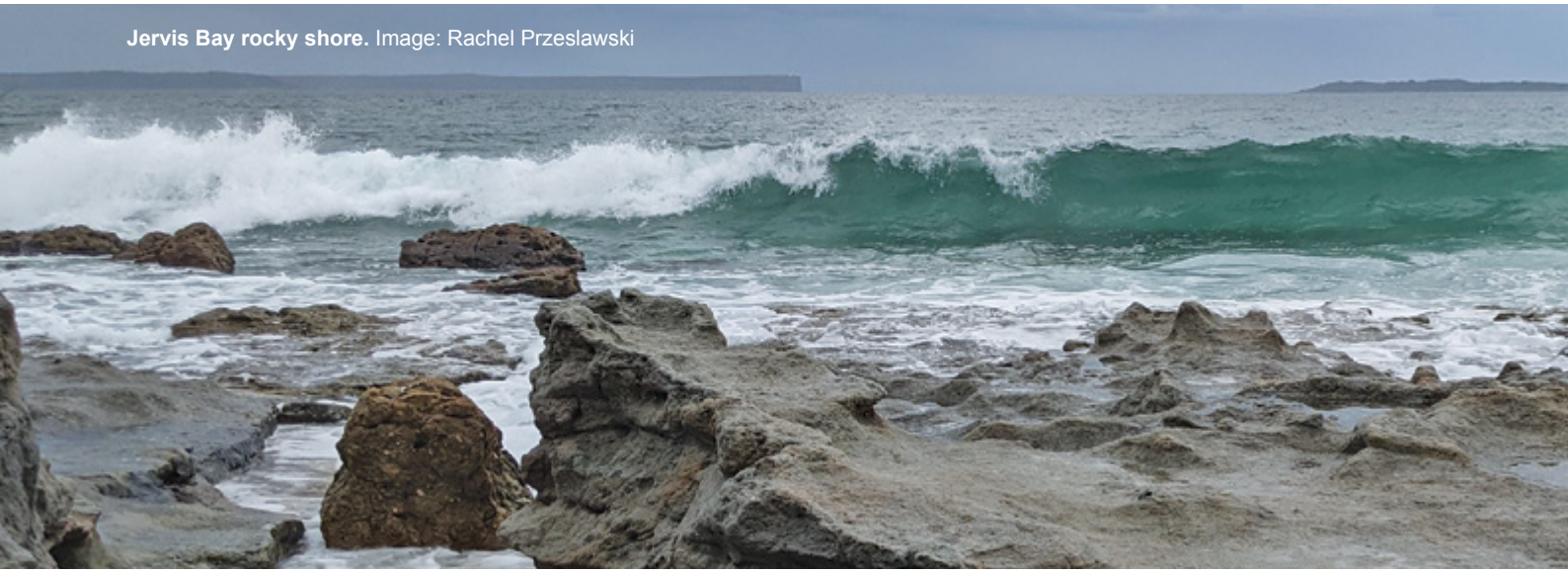
Social, cultural and economic benefits of the marine estate are highly dependent upon environmental assets (Figure 2). There is a very strong interconnection between the condition of environmental assets and the associated social, cultural and economic benefits. Most threats to the social, cultural and economic benefits of the marine estate are environmental (Table ES-1-2 of TARA in BMT WBM (2017)).

FIGURE 2. Example of how social and economic benefits are underpinned by environmental assets (Figure 5-2 from TARA in BMT WBM, 2017).



Outputs from the Environmental Condition Framework are therefore a critical input into ongoing assessment of social, cultural and economic benefits. The data and trends that will be reported as part of the Environmental Condition Framework will allow assessment of the trajectory of the environmental threats and assets that influence social, cultural and economic benefits.

The Environmental Condition Framework will also contribute to assessment of progress towards achievement of a range of KPIs (see Appendix B) all of which are relevant to factors that influence social, cultural and economic benefits.



Jervis Bay rocky shore. Image: Rachel Przeslawski

5 Environmental Condition Framework (ECF) projects

5.1 Environmental Condition Framework project selection

Environmental Condition Framework projects will contribute to reporting on the status of environmental assets and help assess/inform management actions. A set of criteria for selecting environmental research projects for the Environmental Condition Framework has been derived (Table 2).

MEMS funds a wide range of scientific projects, but not all are core components of the Environmental Condition Framework. Therefore, not all MEMS projects have been described in this document. Projects not included in Environmental Condition Framework but which may be used for future monitoring are listed in Table 6, including projects such as: (i) those done to address non-key knowledge gaps (including PhD and externally-funded projects); (ii) experimental projects done at small spatial scales; or (iii) projects involving the development of new techniques. Projects that have been included in Environmental Condition Framework are typically those that cover broad spatial scales and meet at least three of the criteria in Table 2.

This document only describes projects that are led by government agencies, however, relevant data from non-government sources (e.g. universities, NGOs) will be incorporated into Environmental Condition Framework reporting.

TABLE 2. Criteria for categorising environmental research projects in the Environmental Condition Framework. Colours are related to Figure 1: those in blue will be used for MIMP Condition Status and Outcomes monitoring and reporting, those in green indicate specific MEMS research projects led by Agencies, and those in white show external research projects, not detailed in this document. See Tables 4, 5, 6 for lists of projects in each category. Full project descriptions are provided in Appendix C for MIMP projects (blue rows) only.

Project type	Primary purpose of research (MEMS)	Large-scale monitoring of asset condition or pressure	Specifically addresses High or Moderate risk in TARA	Relevant KPI (or LI)	Addresses key knowledge gap	Assess/inform management action	Experimental/ small-scale research	Research by other organisations
MIMP monitoring	Track trends in asset condition or pressure	✓	✓	✓	✓	perhaps	X	✓
MIMP evaluation	Improve management actions	X	✓	✓	perhaps	✓	perhaps	X
MEMS research	Inform next TARA	X	perhaps, or may address L risks	unlikely	perhaps	perhaps	✓	X
External research & citizen science	Inform next TARA	unlikely	perhaps	unlikely	perhaps	perhaps	perhaps	✓

5.2 Addressing key knowledge gaps

Knowledge gaps may be related to the environmental assets, the threats and/or associated stressors, the interaction between the asset and a threat, cumulative impacts or a lack of scientific consensus. Purpose 3 of the MIMP relates to filling knowledge gaps identified in the TARA (BMT WBM 2017), but this statement is considered too broad for the purpose of identifying Environmental Condition Framework projects because it could include any research projects that will address a knowledge gap. This document uses a more specific criterion for inclusion as an Environmental Condition Framework project, that is, it must address a key knowledge gap. Key knowledge gaps are those specific issues that were identified in the TARA (and other documents) and are prioritised based on risk rating and confidence level.

Key knowledge gaps were collated from the TARA (BMT WBM 2017), the Monitoring and Evaluation Framework (Aither 2022), the NSW Marine Estate Management Strategy 2018-2028 (NSW MEMA 2018), and the MEMS Implementation Plan (NSW MEMA 2021). These knowledge gaps can be grouped into eight categories:

1. extent of wildlife disturbance impacts (including noise) on protected species
2. impacts on trophic levels of fish assemblages from recreational and commercial fishing
3. climate change stressors, including adaptation and resilience building actions
4. impacts of sewage, stormwater, agriculture, point discharges, microplastics on estuarine and marine assets
5. threats due to new aquaculture ventures (specific to MEMS)
6. threats due to sea urchin barrens in the southern region (specific to MEMS)
7. techniques to minimise the impact of trained estuary entrances (specific to Implementation Plan)
8. methods for determining marine vegetation resilience (specific to Implementation Plan).

Addressing key knowledge gaps for environmental assets, will be done by specific projects through the MEMS. These may include desktop analysis, targeted field surveys and/or laboratory or field experiments. It is expected to include further analysis of the extent and distribution of stressors, and studies to better understand how these interact with environmental assets. The new knowledge will be incorporated into updated background reports and be reflected in improved certainty in the reporting of condition and trends.

This work will be progressed through a network of organisations that use or generate monitoring data or reporting products, and these will be engaged in the development and implementation of projects that address knowledge gaps. This includes marine management agencies, universities, local government, consultants and the local community who will be encouraged to participate to ensure effective monitoring. However, it is important to coordinate this effort as the time and resources required for effective research are considerable.

Progress in filling knowledge gaps will be monitored, in part, via Leading Indicator 3 of the Monitoring and Evaluation Framework (Aither 2022), 'Knowledge gaps adequately addressed. Knowledge gaps relate to threats, stressors, risks, condition, value and management approaches'. Progress will be measured through the number of knowledge gaps with a confidence level changing from 'inferred' to 'adequate' through the statewide TARA review process (at 5 and 10 years).

5.3 Scientific rigour

Projects underpinning monitoring will adhere to the standards outlined in the DPE-EHG position statement on scientific rigour. Specifically, the science underpinning MIMP projects will meet the following criteria:

- appropriate design including:
  - establishing a clear objective
  - selecting a scientifically sound and appropriate method and scale
  - ensuring the people involved have relevant skills and experience to undertake the work
  - peer review of the design before implementation.
- meticulous implementation including:
  - adhering to the adopted method, and documenting variations
  - ensuring data are reproducible, secure, discoverable and accessible.
- objective analysis and reporting of results, including:
  - ensuring evidence supports results and conclusions
  - peer review prior to publishing data, results and conclusions of published results reported appropriate media. Peer review will consist of the impartial and independent assessment of research by others working in the same or a related field. Peer review may be undertaken by departmental staff or by external reviewers.

Wagonga Inlet. Image: Tim Glasby

6 Monitoring in the marine estate

Marine environments are characterised by large spatial and temporal variation in species abundances and biodiversity driven by variability in factors such as habitat availability, recruitment, regional and local oceanography, physico-chemical conditions and ecological interactions. Spatial and temporal variation in human impacts and climatic changes adds extra complexity to the already difficult task of assessing variable marine environments. Impacts may be episodic (short-lived) or sustained (long term), operate over a range of spatial scales (m's to 100's km), and affect ecosystems in ways that are difficult to predict or detect beyond that of natural variability. Disentangling natural variation from variation due to factors of interest (e.g. anthropogenic impacts) is a key priority for monitoring programs and to underpin meaningful and robust results.

Given the limited amounts of time and money available for effective broad-scale monitoring of environmental assets, it is often useful to identify surrogate (indicator) measures that reflect or underpin patterns of assets or values over large, continuous areas. Moreover, indicators are often necessary because of poor knowledge of some marine and estuarine species and ecosystem patterns and processes, or due to taxonomic challenges. This will be less relevant for small scale experimental studies where response variables are known precisely.

One of the primary considerations of the *Marine Estate Management Act 2014* is the conservation of marine biodiversity, but there is no explicit definition of biodiversity in the Act. In the Environmental Condition Framework we have endeavoured to align considerations of biodiversity with those from the state Biodiversity Assessment Method (BAM) (OEH 2017)), which was developed to meet the monitoring requirements under the *Biodiversity Conservation Act 2016*. While the focus of the BAM is terrestrial, the general concepts are directly transferrable to aquatic systems.

The BAM states that biodiversity indicators need to:

- be inclusive of all levels of biological organisation, that is, diversity within and between species and diversity of ecosystems
- represent all organisms (algal, plant and animal, vertebrate to microbial) native to NSW, including those yet to be discovered and recorded, and the variety of habitats that support them
- evaluate the rate of loss of living variation and extinction risk of all species, not just species and ecological communities currently listed as threatened
- be sensitive to change in the rate of loss of living variation and the amount of extant (existing) biodiversity over five years.

6.1 Broad-scale monitoring of environmental assets

A number of statewide environmental monitoring programs were initiated in the mid-2000s as part of the now superseded Monitoring, Evaluation and Reporting (MER) program which aimed to assess the condition of the NSW environmental assets, including systematic marine park monitoring programs. Many of these monitoring programs were only partially funded and there were no marine social or economic subprograms. The MER program formally concluded in 2012, but in some cases the monitoring continued. Some of these previous monitoring programs have been modified and integrated into the MIMP, and many of new subprograms have been developed based on threats identified in the TARA (BMT WBM 2017).

Broad-scale environmental monitoring will focus on water quality, biodiversity and habitats, and threatened and protected species indicators. These are the key components of the environmental assets of the marine estate in which risks were assessed. Given the statewide extent of these assets, they will be reported in different ways and at different geographic, taxonomic and temporal scales. It will also include characterisation of natural variations in the patterns of several biological and physical attributes to detect changes influenced by management actions.

Examples of existing broad-scale monitoring data

The existing DPE-EHG long-term estuarine water quality monitoring program provides a broad-scale environmental dataset on water quality condition and pressures. The program identifies trends, issues and risks to water quality condition, targeting both short- and long-term responses to pressures on water quality. Indicators of ecological health reflect the response of a waterway to long-term changes in pressures and threats. Throughout the implementation of the MEMS, water quality monitoring will be ongoing, and the data generated will inform the relevant KPIs and LIs in this Framework.

A second example of environmental assets that are monitored are aquatic macrophytes (seagrasses, mangroves and saltmarshes). This occurs principally through regular analysis of aerial imagery combined with field validation. Seagrass mapping is focused on those estuaries containing endangered seagrass populations, with other species also mapped in the lower reaches of estuaries. Mangroves and saltmarshes are also mapped to examine whether mangroves are displacing saltmarshes in the most heavily disturbed NSW estuaries. A range of attributes of aquatic macrophytes is being calculated and compared over time and among estuary types to monitor extent and the amount of change through time.

Fish assemblages and rocky reef biodiversity have been monitored across the NSW open coast over decadal scales. These studies provide details on algae, invertebrates and fishes on shallow reefs (5-10 m) and intermediate reefs (20-50 m). The sampled sites representatively cover the NSW coastline. These data provide fishery-independent data to assess long-term ecological condition across these key coastal habitats.

Threatened and protected megafauna (cetaceans, pinnipeds, turtles) are generally difficult to sample and only spend part of their life in NSW waters resulting in opportunistic data collection. Data are consistently collected from marine wildlife events such as strandings, entanglements, haul outs and carcasses to maximise our understanding of threats, health, distribution and populations.

Routine monitoring of beach nesting birds, nesting marine turtles and specific penguin populations is captured as part of the NSW threatened species program, Saving Our Species (SOS).

Commercial fisheries where bycatches (or other interactions) with threatened and protected species are either known or likely to be a significant problem or where existing data are out of date, are monitored via methods specific to each fishery (considering timeframes, seasonality, resourcing, capacity and urgency).

Other broad-scale monitoring will be developed during further stages of the MEMS, or is already under way, including the assessment and monitoring of key marine habitats (e.g. kelp forests) and estuarine and rocky reef fish assemblages. The kelp forest monitoring is conducted annually using towed video throughout the state and rocky reef fish are monitored throughout the state as part of the statewide-BRUV program in each bioregion.

The estuarine fish taxa indicator based on eDNA will be progressed based on available funding and progression of relevant methods to allow robust and cost-effective monitoring. Further targeted monitoring of specific stressors identified as moderate or high risks to environmental assets are also expected to be developed.

Local-scale monitoring tends to either be associated with a particular small-scale management action or experimental work to provide more information about cause-and-effect relationships in ecological systems.

In general, local-scale work will not be reported in the MIMP unless it directly addresses a priority knowledge gap. Local-scale work is, however, of great benefit to the MEMS through developing understanding of efficacy of management actions or function of ecological systems.

Stressors

The monitoring of stressors can be valuable in particular cases. It can be an early indicator of the implementation of management actions (e.g. water quality). In some circumstances it will not be feasible to monitor condition and trends of populations (e.g. animals with very large migration ranges for example, whales, turtles, shorebirds) so measures of changes in stressors (e.g. wildlife disturbance, incidental catch of species of conservation concern) can be used as a surrogate for risk.

6.2 Citizen science monitoring

The inclusion of data collected by dedicated and experienced citizens has become recognised as a valuable and fortuitous source of information for long-term monitoring. These data sources can provide data over extensive areas and time scales which professional scientists cannot logistically or cost-effectively cover. These data are collected either by certified citizen members (demonstrating high levels of accuracy) for complex data or any member of the community for easily identifiable species or indicators (usually validated by checks of other contributors, collected imagery verified by a specialist or standardisation processes for physico-chemical data). The simplest citizen scientist datasets report on key and easily identifiable species or simple water quality measures and can consist of the recording species presence or water quality variables at a particular location, date and time. These citizen scientist programs can report on range extensions, un-seasonally high abundances or absences of species and migrations (e.g. RedMap, iNaturalist, NSW DPI Game Fish Tagging Program) or draw attention to areas with poor or abnormal water quality. Other, more complex, citizen scientist programs involve highly specialised volunteers who collect data on species identities, densities and sizes (e.g. Reef Life Survey, Australasian Right Whale Photo-Identification Catalogue) or more complicated measures of water quality. These data could be used to supplement professionally collected datasets in the MIMP to provide wider temporal and spatial context.

Several components of citizen science programs, however, make them difficult to neatly incorporate into a program like the Environmental Condition Framework. Firstly, the data are collected by citizens who are unpaid, so they may not collect data when and where it may be needed, but instead (and understandably) when and where is convenient for them to do so. Secondly, the popularity of the programs can waiver and can even come to an end. Consequently, it is difficult to commit these programs as a core component of the MIMP as they are not driven or directed by MEMA, but obviously, the data these citizen programs can provide may be extremely valuable and highly complementary to the formal MIMP projects.

While we will utilise citizen science data for specific purposes and to value add to our long-term monitoring programs, we will not rely on them as a sole means of monitoring.

6.3 Contextual data

Contextual data are those datasets that are usually third party and therefore out of our direct control, which are relied on for context, or drawn upon to derive outputs for the MIMP. Examples of contextual datasets and monitoring include weather, climate, sea surface temperature, solar radiation, evaporation, air pressure (BOM), tidal information and river/estuary water heights and wave climate (Manly Hydraulic Laboratories, DPE-EHG nearshore wave modelling), land-use (DPE/SEED), current structures (IMOS), climate modelling (NARCliM and IPCC), population and demographics (Census and local government), bathymetry (DPE-EHG and Hydrographer). Individual project plans include examples of contextual data being used for each project.

7 Monitoring condition and trend of environmental assets

Purpose 1 of the MIMP is primarily about assessing the condition of key marine estate assets and how MEMS management actions may or may not be benefiting these assets. It is focused on high-level indicators of condition and trend of assets. Assets are the functional groups of organisms (some of which provide habitat) or physical and chemical condition within specific habitats. Within the MIMP, we have further developed and altered the asset description in the statewide TARA (BMT WBM 2017). We will follow the approach of the TARA and consider estuaries and coastal waters as separate systems, while acknowledging that they do interact.

The primary focus of condition and trend monitoring will either be on direct monitoring of the status of assets, or on projects that inform the status of priority threats that contributed to moderate, high, or cumulative risk levels in the statewide TARA through monitoring of resultant stressors (Table 3). Additionally, unassessed and emerging threats or stressors will also be monitored (pending adequate resourcing) to ensure that management actions can be adaptive.
It is well recognised that ecological variables can have a long lag time in response to management and the monitoring needs to reflect this. Monitoring of the magnitude of stressors allows for demonstration of trends in the level of threat, and monitoring of trends in asset abundance and condition demonstrates the response of the asset to changes in stressors.

The main assets under threat in estuaries are water quality, macrophytes (seagrass, saltmarsh, mangroves), species protected under the *Biodiversity Conservation Act 2016* (BCA) or *Fisheries Management Act 1994* (FMA), estuarine habitats (beaches, mudflats, rocky shores, rocky reefs), fish assemblages and trophic structure (BMT WBM 2017). Similarly, the main assets under threat in coastal waters are fish assemblages and trophic structure, BCA species, and habitats (beaches, shallow and deep reefs, deep sediments).

Monitoring will either assess the asset/stressor directly or via indicators (see Section 6, Principles, above). Condition will be assessed by comparison to reference conditions or a baseline. Links between projects and related assets and threats they address are provided in Appendix A. Project summaries in Appendix C provide details on the use of indicators and baseline/reference conditions.

TABLE 3. Priority Coastal and Marine and Estuarine threats, assets and associated stressors identified in TARA (BMT WBM, 2017). Note: the TARA includes ‘fish assemblages’ within each asset type. It is critical to understand that this is NOT the same as stocks of harvested fish but refers to the presence of a natural range and abundance of all species of fish and a broad spread of sizes within each species, from small to large. BCA = *Biodiversity Conservation Act 2016*; *FMA = Fisheries Management Act 1994*.

Activities/Threats	Assets	Stressors
Coastal and Marine		
Shipping	Deep reefs, Deep soft sediments, Species protected under BCA	Marine debris, Physical disturbance, Wildlife disturbance
Commercial fishing	Fish assemblages, Species and communities protected under FMA and BCA, Deep soft sediments, Beaches	Reductions in abundances of species and trophic levels, Catch of species of conservation concern, Ghost fishing, Marine debris, Physical disturbance, Wildlife disturbance
Shore-based and boat-based recreational fishing	Fish assemblages, Species and communities protected under FMA	By-catch, Reductions in abundances of species and trophic levels, Incidental catch of species of conservation concern
Whale and dolphin watching	Species protected under BCA	Wildlife disturbance
Passive recreational use	Beaches, Rocky shores, Species protected under BCA	Marine debris, Physical disturbance, Wildlife disturbance
Four-wheel driving	Beaches, Species protected under BCA	Physical disturbance, Wildlife disturbance
Shark meshing of swimming beaches	Species and communities protected under FMA and BCA	Incidental catch of species of conservation concern, Physical disturbance
Navigation entrance management and modification	Deep soft sediments	Physical disturbance
Urban stormwater discharge	Beaches, Shallow reefs, Species protected under BCA	Water pollution, Marine debris, Physical disturbance

Table 3 (continued on next page)

Table 3 (continued from previous page)

Activities/Threats	Assets	Stressors
Coastal and Marine		
Foreshore development	Beaches, Rocky shores, Species protected under BCA	Marine debris, Physical disturbance, Wildlife disturbance
Beach nourishment and grooming	Beaches, Species protected under BCA	Physical disturbance, Wildlife disturbance
Clearing riparian and adjacent habitat including wetland drainage	Beaches, Species protected under BCA	Physical disturbance, Wildlife disturbance
Sewage effluent and septic runoff	Deep reefs, Rocky shores	Water pollution
Estuary entrance modifications + breakwaters	Beaches, Species protected under BCA	Physical disturbance, Changes to tidal prism, Sedimentation, Water pollution, Wildlife disturbance
Climate change 20-50 years	Ocean waters, Planktonic assemblages, Rocky shores, Shallow reefs, Species protected under BCA, Beaches, Species and communities protected under FMA, Deep reefs, Deep soft sediments, Shallow soft sediments	Elevated temperatures, Increased acidity, Climate and sea temperature rise, Sea-level rise, Altered storm and cyclone activity, Altered ocean currents and nutrients, Ocean acidification, Reductions in abundances of species and trophic levels, Physical disturbance, Marine debris, Water pollution, Wildlife disturbance
Deliberate introduction of animals and plants (e.g. foxes, dogs, cats, bitou bush)	Species protected under BCA	Physical disturbance, Wildlife disturbance

Table 3 (continued from previous page)

Activities/Threats	Assets	Stressors
Estuarine		
Shipping	Species and communities protected under FMA and BCA, Estuarine waters, Beach and mudflats, Mangroves, Rocky shores, Saltmarsh, Seagrass, Shallow soft sediments	Water pollution, Marine debris, Physical disturbance, Wildlife disturbance
Shore-based and boat-based recreational fishing	Species protected under BCA, Fish assemblages	Marine debris, Physical disturbance, Wildlife disturbance, By-catch, Catch of species of conservation concern, Ghost fishing, Reductions in abundances of species and trophic levels
Whale and dolphin watching	Species protected under BCA	Physical disturbance, Wildlife disturbance
Recreation - Boating and boating infrastructure	Species and communities protected under FMA and BCA, Estuarine waters, Beach and mudflats, Rocky shores, Seagrass, Shallow soft sediments, Subtidal reefs	Physical disturbance, Water pollution, Marine debris, Wildlife disturbance, Antifouling paints, Bank erosion
Passive recreational use	Species protected under BCA, Beach and mudflats	Marine debris, Physical disturbance, Wildlife disturbance
Four-wheel driving	Species and communities protected under FMA and BCA, Beach and mudflats, Saltmarsh	Physical disturbance, Wildlife disturbance
Oil, gas, minerals, sand, aggregate, mining coal	Species and communities protected under FMA, Seagrass	Physical disturbance
Pipelines, cables, trenching and boring	Species and communities protected under FMA, Mangroves, Saltmarsh, Seagrass	Physical disturbance, Sedimentation, Water pollution
Urban stormwater discharge	Species and communities protected under FMA and BCA, Estuarine waters, Beach and mudflats, Mangroves, Planktonic assemblages, Rocky shores, Saltmarsh, Seagrass, Shallow soft sediments, Subtidal reefs	Water pollution, Physical disturbance, Wildlife disturbance, Marine debris (including microplastics)

Table 3 (continued from previous page)

Activities/Threats	Assets	Stressors
Estuarine		
Foreshore development	Species and communities protected under FMA and BCA, Beach and mudflats, Mangroves, Rocky shores, Saltmarsh, Shallow soft sediments	Physical disturbance, Marine debris, Wildlife disturbance
Beach nourishment and grooming	Species protected under BCA, Beach and mudflats, Seagrass	Wildlife disturbance, Physical disturbance
Clearing riparian and adjacent habitat including wetland drainage	Species and communities protected under FMA and BCA, Estuarine waters, Beach and mudflats, Mangroves, Planktonic assemblages, Saltmarsh, Seagrass, Shallow soft sediments, Subtidal reefs	Changes to tidal flow velocity and patterns, Physical disturbance, Wildlife disturbance, Water pollution
Agricultural diffuse source runoff	Species and communities protected under FMA and BCA, Estuarine waters, Beach and mudflats, Mangroves, Planktonic assemblages, Rocky shores, Saltmarsh, Seagrass, Shallow soft sediments, Subtidal reefs	Sedimentation, Water pollution, Water pollution
Industrial discharges	Species protected under BCA, Estuarine waters, Beach and mudflats, Mangroves, Planktonic assemblages, Shallow soft sediments	Water pollution
Thermal discharges	Estuarine waters, Planktonic assemblages, Seagrass	Thermal pollution
Sewage effluent and septic runoff	Species and communities protected under FMA and BCA, Estuarine waters, Beach and mudflats, Planktonic assemblages, Seagrass, Shallow soft sediments	Marine debris (including microplastics), Water pollution

Table 3 (continued from previous page)

Activities/Threats	Assets	Stressors
Estuarine		
Climate change 20-50 years	Species protected under BCA, Estuarine waters, Planktonic assemblages, Species and communities protected under FMA, Saltmarsh, Beach and mudflats, Mangroves, Seagrass, Subtidal reefs, Rocky shores, Shallow soft sediments	Elevated temperatures, Increased acidity, Climate and sea temperature rise, Sea-level rise, Altered storm and cyclone activity, Altered ocean currents and nutrients, Ocean acidification, Reductions in abundances of species and trophic levels, Physical disturbance, Marine debris, Water pollution, Wildlife disturbance
Deliberate introduction of animals and plants (e.g. foxes, dogs, cats, bitou bush)	Species protected under BCA	Physical disturbance, Wildlife disturbance
Commercial fishing	Species and communities protected under FMA and BCA, Fish assemblages	Catch of species of conservation concern, Ghost fishing, Marine debris, Physical disturbance, Wildlife disturbance, By-catch, Reductions in abundances of species and trophic levels
Oyster aquaculture	Species and communities protected under FMA, Seagrass	Physical disturbance
Navigation entrance management and modification harbour maintenance etc.	Species and communities protected under FMA, Estuarine waters, Beach and mudflats, Planktonic assemblages, Seagrass, Shallow soft sediments, Subtidal reefs	Physical disturbance, Water pollution
Modified freshwater flows	Species and communities protected under FMA and BCA, Estuarine waters, Mangroves, Planktonic assemblages, Saltmarsh, Seagrass, Shallow soft sediments	Changes to tidal flow velocity and patterns, Physical disturbance, Reductions in abundances of species and trophic levels, Sedimentation, Water pollution, Wildlife disturbance
Stock grazing of riparian and marine vegetation	Species and communities protected under FMA, Mangroves, Saltmarsh, Seagrass	Physical disturbance, Water pollution, Sedimentation
Estuary entrance modifications	Species and communities protected under FMA and BCA, Estuarine waters, Beach and mudflats, Mangroves, Planktonic assemblages, Saltmarsh, Seagrass, Shallow soft sediments	Changes to tidal flow velocity and patterns, Changes to tidal prism, Physical disturbance, Sedimentation, Water pollution, Wildlife disturbance

The main datasets that have been identified to inform Purpose 1 (condition and trends) relate to monitoring of estuarine water quality (stressors) and biological responses, marine debris abundance (stressor), catchment condition (stressor), estuarine habitats, rocky reef benthic biota and fish assemblages, harvested fish stocks, climate change stressors, stressors affecting cetaceans, pinnipeds, turtles, Grey Nurse sharks and seabirds (see Table 4 for a more detailed summary, and Appendix C for full project details).

Some projects in the ECF will contribute data towards Purpose 2 of the MIMP (management effectiveness), and these focus on monitoring benefits associated with examples of remediation (e.g. stormwater improvements, agricultural practices, riparian fencing, oyster reefs), assessment of jetty design, large ship anchor scour near ports, marine forest restoration, postmortem assessment of threatened and protected wildlife, disease impacts on threatened wildlife, development of harvest strategies and associated input data (recreational fisheries effort), trawl bycatch mitigation, adaptive management of crab fisheries. Table 5 provides a more detailed summary, and Appendix C has details of these projects.

Many of the projects in Tables 4 and 5 are also contributing significantly towards filling key knowledge gaps (Purpose 3). A list of other MEMS supported research that is contributing to the success of MEMS initiatives or to filling knowledge gaps is provided in Table 6.

Seagrass *Posidonia australis* meadow and luderick *Girella tricuspidata*. Image: J. Gilligan

TABLE 4. Agency-led MIMP projects designed to monitor temporal trends in condition or pressure over large spatial scales. For full details of project methods see Appendix C. Project numbers with an (E) are led by DPE-EHG, with a (F) are led by DPI-F and with an (N) are led by NPWS. See Figure 3 for links between projects and reporting themes and the data needs.

Relevant Initiative	Project name and number	Threats and Stressors creating High or Moderate risk to assets (TARA)	Key knowledge gap (see Section 5.2 for list)	Relevant KPI or LI (Appendix A, B)	Condition indicators being measured	Pressure indicators being measured
1	E1. Monitoring the ecological health of waterways to provide a consistent framework for ecological health assessment of coastal catchments and supports application of the risk-based framework. Incorporated within Clean Coastal Catchments and Estuary Water Quality Monitoring and supports.	Land-use intensification (riparian loss), urban stormwater discharge (on species, biodiversity, habitat)	2, 3	KPI: 1, 4 LI: 1, 3	Chlorophyll *a*, turbidity, DO, bacteria	Nutrients, sediments
1	E2. Monitoring the ecological health of the estuaries in the NSW marine estate: Indicator development. Incorporated within Estuary Water Quality Monitoring.	Land-use intensification (riparian loss), urban stormwater discharge (on species, biodiversity, habitat)	2	KPI:1, 4 LI:1, 3	Fish, invertebrates	Faecal contamination, pests
1	E3. Impacts of bushfire on water quality in NSW estuaries, Included within Appendix C.1.4. See Bushfire affected waterways | NSW Environment and Heritage. Incorporated within Estuary Water Quality Monitoring.	Land-use intensification (riparian loss, on species, biodiversity, habitat)	3	KPI: 1,4 LI: 1, 3	TSS, OSS, turbidity	Nutrients, sediments, TOC, metals, PAH
1	E4. Threats and risks from marine debris	Urban stormwater discharge (on species, biodiversity, habitat)	4	KPI: 2, 5 LI: 1, 3, 29	Volume/0.1 ha	Litter

Bushfire affected waterways | NSW Environment and Heritage

Table 4 (continued on next page)

Table 4 (continued from previous page)

Relevant Initiative	Project name and number	Threats and Stressors creating High or Moderate risk to assets (TARA)	Key knowledge gap (see Section 5.2 for list)	Relevant KPI or LI (Appendix A, B)	Condition indicators being measured	Pressure indicators being measured
2, 3, 7	F1. Monitoring and assessment of estuarine habitats and disturbances	Impacts on macrophytes (incl. threatened species) from shipping & boating, foreshore development, recreation/tourism (4WD impacts on saltmarsh), clearing riparian and adjacent habitats, dredging, climate change, aquaculture	3, 8	KPI: 4, 5 LI: 3	Extent of macrophytes, species composition, fragmentation	Boat moorings, jetties, pontoons, 4WD damage, aquaculture leases, bushfire damage
3	F2. Monitoring impacts of climate change on rocky reefs	Climate change (temperature, nutrients, pH): impacts on algae and calcifying species	3, 8	LI: 3	Per cent cover of kelp, turf, foliose algae, benthic invertebrates, relative urchin abundance, condition, biomass and recruitment of kelp	Sea temperature
5	N1. Cetaceans project	Shipping (vessel strike), commercial fishing (entanglements), recreational fishing (disturbance & bycatch), boating and boating infrastructure (disturbance), recreation & tourism (disturbance), water pollution and sediment contamination (disease/mortality), climate change (migratory dependencies – prey and movement)	1	KPI: 5	Injury, disease, mortality, entanglement of cetaceans	Vessel strike, disturbance, entanglements, bycatch, water pollution

Table 4 (continued from previous page)

Relevant Initiative	Project name and number	Threats and Stressors creating High or Moderate risk to assets (TARA)	Key knowledge gap (see Section 5.2 for list)	Relevant KPI or LI (Appendix A, B)	Condition indicators being measured	Pressure indicators being measured
5	N2. Pinnipeds project	Shipping (vessel strike), commercial fishing (entanglements), recreational fishing (disturbance & bycatch), boating and boating infrastructure (disturbance), recreation & tourism (disturbance), water pollution and sediment contamination (disease/mortality), climate change (migratory dependencies – prey and movement)	1	KPI: 5	Injury, disease, mortality, entanglement of pinnipeds	Disturbance, entanglement, bycatch, vessel strike, water pollution
5	N3. Marine turtles project	Shipping (vessel strike), commercial fishing (entanglements), recreational fishing (disturbance & bycatch), boating and boating infrastructure (disturbance), recreation & tourism (disturbance), water pollution and sediment contamination (disease/mortality), climate change (migratory dependencies – prey and movement)	1	KPI: 5	Injury, disease, mortality, entanglement of marine turtles	Disturbance, entanglement, bycatch, vessel strike, water pollution
5	N4. Shorebirds and seabirds monitoring	Shipping, commercial fishing, recreational fishing, boating and boating infrastructure, recreation & tourism, foreshore and urban development, water pollution and sediment contamination, clearing dredging and excavation activities, estuary openings/modified freshwater flows, deliberate introduction of plants and animals, climate change	1	KPI: 5	Injury, disease, mortality, entanglement of birds	Disturbance, interactions (fishing activities), water pollution
5	F6. Grey Nurse Shark monitoring	Commercial fishing (trawl, Ocean Trap and Line (OTL)), recreational fishing (hooks), recreation/tourism (shark meshing), impacts on GNS	1, 2	KPI: 5 LI: 3	Shark mortality	Number of commercial & recreational catches, shark meshing program, ecotourism interactions

Table 4 (continued from previous page)

Relevant Initiative	Project name and number	Threats and Stressors creating High or Moderate risk to assets (TARA)	Key knowledge gap (see Section 5.2 for list)	Relevant KPI or LI (Appendix A, B)	Condition indicators being measured	Pressure indicators being measured
5, 6	F7. Commercial Fishery Observer Program - Ocean Trawl Fishery	Commercial fishing (Ocean Trawl - OT): impacts on abundances of fish species and trophic levels; incidental catch of species of conservation concern (e.g. FMA; GNS, BCA; Seabirds, Eared Seals).	1, 2	KPI: 5,8	Fish assemblages (harvest and bycatch stressors) and threatened, endangered, or protected species (TEPS) mortality	Rates of discarding and total number & circumstances of interactions (including the life status at the time of the interaction) between commercial fisheries & TEPS
5	F8. Reducing impacts on threatened and protected species (expanded Commercial Fishery Observer Program)	Commercial fishing; OTL: wildlife disturbance, incidental catch of species of conservation concern, physical disturbance, marine debris, ghost fishing. Estuary General Fishery (EGF): reduction in abundances of species and trophic levels, bycatch.	1, 2	KPI: 5,8	TEPS mortality	Total number and circumstances of interactions (including the life status at the time of the interaction) between commercial fisheries & TEPS
6	F9. Status of Australian Fish Stocks (SAFS)	Reduction in abundances of species and trophic levels, bycatch. SAFS program is a national collaboration between all jurisdictions that assesses the biological sustainability of wild-caught fish stocks against a nationally agreed framework.	2	KPI: 8	Fish assemblages (harvest and bycatch stressors)	
6,5,3,2	F5. Statewide monitoring of subtidal reef fishes (BRUVs)	Recreational and commercial fishing impacts on fish assemblages, climate change impacts on fish.	2	KPI: 4 LI: 3	Fish size, abundance & diversity	Fishing effort (P/A)
6,5,3,2	F10. Statewide monitoring of shallow rocky reef biodiversity (UVC)	Recreational and commercial fishing, pollution and climate change impacts on fish, invertebrates and fishes on shallow subtidal reefs.	2	KPI: 4 LI: 3	Fish, invertebrates and macroalgal diversity, abundance, size and covers	Pollution, land use, fishing effort, climate change variables

TABLE 5. Agency-led environmental research projects that directly assess or inform management actions (i.e., fulfill Purpose 2 of the MIMP). For full details of project methods see Appendix C (except for projects E5, E6, F3, N5 and N6). Project numbers with an (E) are led by DPE-EHG, with a (F) are led by DPI-F and with an N are led by NPWS. See Figure 3 for links between projects and reporting themes and the data needs.

Relevant Action	Project name and number	Project purpose	TARA threats addressed	Relevant KPI or LI
1.1 1.2 1.5	E5: Application of the Risk Based Framework in selected areas (refer to project E1 in section C.1.1 for methods)	Support application of the Risk Based Framework in the Northern Beaches LGA, South Creek and Lake Illawarra catchments through targeted field monitoring of water quality, quantity and biological indicators. Establish guideline values, stormwater flow targets and cost–benefit analysis of stormwater controls, develop catchment models and map areas of high ecological value.	Land-use intensification (riparian loss), urban stormwater discharge on species, biodiversity, habitat	KPI: 1,4,5 LI: 1,2,3
1.3 1.5	E6: Tilba Lagoon and catchment – effectiveness of riparian rehabilitation- included within appendix C.1.1 and C.1.4 Water quality at Tilba Tilba lake. Incorporated within Clean Coastal Catchments monitoring	Monitoring water quality, vegetation, saltmarsh, macro-invertebrates, fish, frogs, birds in riparian strip after stock exclusion and tree planting.	Agricultural diffuse source runoff (riparian loss on species, biodiversity, habitat)	KPI: 4 LI: 2
1.1 1.2 1.5	E7: Richmond River Water Quality Monitoring Strategy. Incorporated with Estuary Water Quality Monitoring (E2: refer to section C.1.2 for methods)	Develop coordinated governance structures and strategies for Coastal Management Plans (CMP) and sentinel monitoring of the Richmond River to provide a template for monitoring rural coastal catchments across NSW.	Agricultural diffuse source runoff (riparian loss on species, biodiversity, habitat)	KPI: 1, 5 LI: 2
1.3	F11. Oyster reef restoration and research	Monitoring the effectiveness of newly created oyster reefs within the Port Stephens and Wagonga estuary, and research on oyster reefs in NSW	Agricultural diffuse source runoff, foreshore development, urban stormwater discharge	KPI: 1, 4, 15 LI: 3, 4
2.5	F12. Threats to estuarine fish assemblages	A trial seascape will be used to assess multiple stressors and cumulative impacts within the Greater Sydney estuaries.	Urban stormwater discharge (on several environmental assets)	KPI: 1, 4, 5
2.5	F13. Reviewing jetty designs	Research on jetty design features that contribute to the loss of seagrasses and develop guidelines for estuaries in Greater Sydney (new project).	Recreational boating and boating infrastructure	KPI: 5

Water quality at Tilba Tilba lake

Table 5 (continued on next page)

Table 5 (continued from previous page)

Relevant Action	Project name and number	Project purpose	TARA threats addressed	Relevant KPI or LI
2.5 7	F14. Review offshore anchoring	Assessing social, economic and ecological impacts of merchant ships anchoring on deep habitats in the Hawkesbury Shelf Marine Bioregion.	Shipping (anchor) impacts on deep soft sediments and reefs	KPI: 4
3.5	F3. Building knowledge and capacity to increase resilience to climate change (included under Appendix C3)	Predict change in species distributions related to a range of environmental variables	Climate change (temperature, nutrients, pH) (impacts on algae and calcifying species	LI: 3
3.5 2.5 2.3	F4. Vulnerability and adaptation pathways of intertidal wetlands under sea level rise	Predict future extent of mangroves & saltmarsh under different SLR scenarios; inform management actions such as the Marine Vegetation Strategy	Climate change (SLR, coastal squeeze), estuary entrance modifications (tidal pattern changes)	KPI: 4, 5 LI :3
3.5	F15. Restoration solutions for marine forests undergoing climatic change	Development of new solutions to overcome challenges in marine forest restoration under climate change.	Climate change	LI: 3
5.2	N5. Pinniped, cetacean, turtle Projects - maximise collection of data from stranded, hauled out or dead marine wildlife	Maximise postmortems, genetic sampling and health assessments of stranded and dead marine wildlife	Shipping (vessel strike), commercial fishing (entanglements), recreational fishing (disturbance & bycatch), boating and boating infrastructure (disturbance), water pollution and sediment contamination (disease/mortality),	KPI: 5
5.2	N6. Pinnipeds project - understanding the impact of disease and pollution on New Zealand Fur Seals (*Arctocephalus forsteri*) in NSW	Develop guide for effective post- mortem examination and sample collection, analyse samples for POPs, PFAS, heavy metal exposure	Shipping (vessel strike), commercial fishing (entanglements), recreational fishing (disturbance & bycatch), water pollution and sediment contamination (disease/mortality),	KPI: 5

Table 5 (continued from previous page)

Relevant Action	Project name and number	Project purpose	TARA threats addressed	Relevant KPI or LI
6.1 6.5	F16. Harvest strategy development for NSW fisheries	Introduce harvest strategies and evaluate ecological risk in partnership with stakeholders and shareholders to address the priority threats associated with the reduction in abundance of fish species and trophic levels.	Commercial and recreational fishing (reduction in abundances of species and trophic levels, harvest & bycatch)	KPI: 8
6.2 6.5	F17. Recreational Fisheries Monitoring Program (RFMP). Survey of recreational fishing across NSW	Comprehensive ongoing assessment of recreational fishing in NSW – 2019/2021 – using statewide Diary Surveys	Recreational fishing (reduction in abundances of species and trophic levels, harvest & bycatch)	KPI: 8
5.5 6.2 6.5	F18. Recreational Fisheries Monitoring Program (RFMP): Charter boat monitoring	Statewide implementation of on-board monitoring program for the nearshore charter boat fishery.	Recreational fishing (reduction in abundances of species and trophic levels, harvest & bycatch. Incidental catch of species of conservation concern)	KPI: 5, 8
5.5 6.5	F19. The role of spatial protection measures in mitigating effects of bycatch and increasing yields in the NSW Ocean Trawl Fishery	Experimentation and modelling to evaluate the effectiveness of closures in mitigating effects of bycatch and increasing yields in the NSW Ocean Trawl Fishery.	Commercial fishing (Ocean Trawl) (reduction in abundances of species and trophic levels, harvest & bycatch)	KPI: 5, 8
6.5	F20. Informing adaptive management of portunid fisheries in NSW	Experimentation and modelling to understand the mechanistic processes by which rainfall, estuarine inflow, temperature, and ocean currents can affect cohort strength (through effects on spawning, dispersal, recruitment and migration).	Commercial fishing (estuary general) (reduction in abundances of species and trophic levels, harvest & bycatch)	KPI: 5, 8

TABLE 6. Agency-led and citizen science MEMS environmental research projects addressing specific research questions. Although important to the MEMS for filling general knowledge gaps, these projects are not considered core MIMP projects and as such not described in Appendix C. Note that any relevant university research projects that will help fill additional knowledge gaps are not captured here.

Relevant initiative	Project name and number	Purpose of project	TARA threats addressed
1	Integrated estuary health reporting for NSW estuaries database and website	Informing the community and stakeholders about NSW estuary condition through an online portal and database of all historic and ongoing water quality and ecological health monitoring data	Agricultural diffuse source runoff, urban stormwater discharge, land-use intensification
1	Tidal Rivers Research Program – Richmond River	Develop generic model code for ecosystem response modelling in tidal rivers statewide, calibrate and trial for the Richmond River to guide MEMs actions applying the Risk Based Framework.	Agricultural runoff, urban stormwater
1	Hydrological modifications to estuaries: research support – Tallow Creek Research Project	An estuary entrance management factsheet and decision support tool based on real-time catchment export 3D hydrodynamic modelling.	Estuary entrance modification (impacts on estuarine assets)
1	Terrestrial grazing impacts on water quality pilot study	Assess impacts of grazing activities on farm derived runoff at Kent Farm.	Agricultural diffuse source runoff
2	Subtidal reef monitoring	Research on the diversity, abundance and size of fishes and the distribution of kelp and sessile invertebrates across the Greater Sydney region's deep rocky reefs.	Shipping, commercial and recreational fishing, urban stormwater discharge, sewage effluent and septic runoff
2	Assessment of rocky reefs - functional responses of rocky reef communities across continental scales	Long-term monitoring fishes, invertebrates and algae on shallow rocky reefs across NSW; includes data collected by professional marine biologists (DPI and universities) and also includes citizen science group, Reef Life Survey. Some sites have been frequently sampled since 1996. This study also includes data on macroalgae, barrens and urchins. Other DPI underwater visual census studies can be combined with this study to provide a representative and long-term dataset for the NSW coastline.	Commercial fishing - fish assemblages (including urchin, turban, lobster, abalone, etc.) Recreational fishing - fish assemblages (including urchin, turban, lobster, abalone etc.) Climate change

Table 6 (continued on next page)

Table 6 (continued from previous page)

Relevant initiative	Project name and number	Purpose of project	TARA threats addressed
3	Anticipating and managing impacts of marine heatwaves in NSW	Experiments and genomics to understand impacts and adaptive capacity of kelp forests to marine heatwaves	Climate change
3	Climate change citizen science	Monitoring climate-driven changes to the distributions of key fish and invertebrate species using citizen science observations logged via website and smartphone applications.	Climate change
3	Turfwar - Management solutions for kelp forests	Experimentation and modelling to understand regime shifts from kelp forests to turf and development of solutions.	Climate change
3	Evaluating perturbations to NSW corals between 2002 and 2020	Evaluating how coral communities in northern NSW have responded to large-scale perturbations over an 18-year period including a major coral bleaching event and intense storm events	Climate change
5	Southern Right Whale citizen science project – Right Whale ID	Increase capacity and response to Southern Right Whales in NSW waters to capture photo identification of individuals.	Disturbance (stressor)
5	Analysis of nutritional content and ecotoxicology profiles of seagrasses in NSW	Understand the impact of available diet for turtles in NSW waters affects health	Climate change, agricultural diffuse source runoff, urban stormwater discharge, water pollution and sediment contamination (disease/mortality)
5	The influence of gut microbiota on resilience in a Little Penguin population under stress from climate change	Develop field sampling method for microbiota of little penguins to assess health and fitness	Climate change; agricultural diffuse source runoff, urban stormwater discharge, water pollution and sediment contamination (disease/mortality)
5	Long-term monitoring of endangered Whites Seahorse populations	Monitoring abundances of Whites Seahorse	Commercial fishing (estuary general, prawn trawl)
5	Soft coral conservation research	Monitoring the endangered soft coral and developing methods for soft coral rehabilitation in the wild	Boating (water pollution, physical disturbance) and low resilience of soft corals

Table 6 (continued from previous page)

Relevant initiative	Project name and number	Purpose of project	TARA threats addressed
5	Long-term monitoring of population and size structure of Black Cod	Monitoring the relative and abundance and size of black cod annually at key sites and intermittently at a broader range of sites to assess recovery and population trajectory as part of their recovery plan	Recreational fishing (boat-based line and trap fishing); incidental catch
6	Quantifying movement patterns of ecologically, recreationally and commercially important fishes for better management	Studies to quantify the migration patterns from juvenile to adult habitats to access critical habitat needs and seascape connectivity.	Commercial and recreational fishing
6	Understanding and managing the threats of harvesting on rocky shores in northern NSW	Understanding how differing pressure from intertidal harvesting of molluscs affects Turban shells and periwinkles in northern NSW will inform their management and reduce community conflict	Recreational fishing impacts due to hand collection & trampling on intertidal rocky shore species
6	Detecting patterns of association between fish habitat metrics, variability and condition and fish species catch trends	This project will use long-term mapping data of estuarine habitats and estuarine commercial fisheries' landings data of target, key secondary and by-product species to investigate any patterns of association between the two	Commercial and recreational fishing

8 Addressing cumulative impacts and interactions

The NSW TARA recognised that threats may interact or accumulate in a way that cannot be accurately evaluated with an approach focussed on individual threats or assets. As such, the impact of cumulative stressors and threats was identified as a key knowledge gap, with particular focus on the following environmental aspects:

- estuarine water quality: the cumulative impact of agricultural runoff, urban stormwater, sediment contamination and other threats on estuarine water quality
- threatened and protected species: the cumulative impacts associated with disturbance or interactions with threatened and protected species from fishing, vessels, recreational and land-based activities, as well as climate change
- fish assemblages: the cumulative impact of fishing (commercial, recreational, cultural) on fish assemblages and trophic structures
- climate change: the cumulative impact of multiple stressors related to the threat of climate change.

Although the importance of cumulative impacts was emphasised in the TARA, the way in which to quantify and manage these impacts has yet to be defined. One of the first steps is to define stressors, threats, impacts, and interactions (refer to Glossary in Appendix D) and articulate the relationships between these.

Cumulative impacts arise from a range of activities over time and space, where each individual effect may not be significant if taken in isolation or at a single point in time. Addressing cumulative impacts is a complex exercise because they can result from a single activity repeatedly producing a single stressor, a single threat producing multiple stressors, multiple threats producing a single stressor, or multiple threats producing multiple stressors.

When quantifying the effects of multiple stressors, potential interactions between these stressors should be considered. These interactions can be classified as additive or non-additive, the latter which includes synergistic or antagonistic (compensatory) interactions (Folt et al. 1999; Crain et al. 2008):

- Additive interactions occur when multiple stressors independently affect an organism such that their combined effects are simply the sum of the individual effects
- Synergistic interactions occur when the combined effects of multiple stressors are greater than the sum of their individual effects
- Antagonistic (or compensatory) interactions occur when one stressor offsets the effect of another.

All of these interaction types can be confounded by masking in which the effects of an unconsidered stressor unknowingly mask the effects of another (Morris et al. 2020).

To add further complexity, environmental threats and stressors can sometimes inversely be benefits that contribute to the wellbeing of the NSW community. For example, fishing is an environmental threat, but fishing activities are related to socio-economic and cultural benefits. For the purposes of the Environmental Condition Framework, we focus solely on cumulative impacts as related to threats to environmental assets.

To fully account for the cumulative threats impacting the marine estate, scientists and managers must be able to understand: (1) which activities cause which stressors; (2) the magnitude, frequency, and spatial scale at which the activities occur; (3) what types of interactions among stressors may occur; 4) what the resulting direct and indirect cumulative effects will be on the ecosystem; and (5) how multiple ecological components at different levels of organisation (e.g. individuals, populations, species, communities, and ecosystems) will respond.

A cumulative impact assessment depends on the appropriate quantity and quality of available data on threats and environmental assets, as well as the knowledge of the vulnerability of these environmental assets to the threats. The ideal dataset for cumulative impact assessment integrates historical and recent data, is spatially precise with a high resolution, has spatial coverage consistent with the study area, and has an associated measure of relative intensity. Data limitations are the most frequently cited barrier to conducting multi-stressor analyses (e.g. meta-analyses in Przeslawski et al. 2015; Gissi et al. 2021) and related cumulative impact assessments (Halpern and Fujita 2013; Stelzenmüller et al. 2018).

Within the MEMS program, cumulative impacts are being investigated as part of projects under Initiative 3 (Planning for climate change) and some projects in other initiatives that address various knowledge gaps. The MIMP also has a role regarding cumulative impacts through Purpose 3 which relates to filling knowledge gaps identified in the TARA; this specifically includes addressing cumulative impacts. To achieve this, the MIMP, based on the collaborative efforts across multiple government agencies, research organisations, and community groups, will develop approaches to better understand multiple stressors, their impacts and interactions at an overarching level (across several MEMS initiatives and projects). Approaches will include compiling available data (e.g., data audit), developing case studies that collect additional data (e.g., filling spatiotemporal gaps), and monitoring changes in the condition of the marine estate or in threat levels linked to activities occurring as part of the MEMS.

The selection of these sites will be based on the available data, data quality of both historical and recent data, identification as a key focus area for cumulative impact assessment from the TARA, and ability to monitor the effects of management actions.

9 Data management

Data collected as part of any monitoring program should be stored in appropriate databases accompanied by metadata that complies with the appropriate standard. Metadata for all MIMP projects are being collected and will be included in a MIMP-specific database (currently under development) and added to existing data portals (e.g. NSW Government SEED portal – Sharing and Enabling Environmental Data), where appropriate. A data management strategy for the MIMP is currently under development.

10 Reporting

The Marine Integrated Monitoring and Evaluation Framework (Aither 2022) emphasises that reporting needs to be readily understandable by a wide range of stakeholders and users. It recommends that Report Cards form the basis for reporting and provides guidance on the characteristics of effective report cards.

Examples of report card style reporting for large programs exist (e.g. Great Barrier Reef (GBR) Outlook Report 2019) and most converge on reporting at multiple levels:

- report cards for condition and trend for specified assets (within each of the major marine habitats); habitats (assessed across habitats) at the project level
- aggregated reporting to higher level conceptual topics, often also using report card style presentations of status and trend, for example, climate change responses, human pressure changes, introduced pest changes, pollution/ contamination changes.

It is also often useful to aggregate project level information into themes for reporting. Themes are rarely independent of each other, and the same data are often used for multiple themes. The purpose of themes is to bring information together in a way that engages stakeholders on questions that are relevant to them. Examples of themes from the 2019 GBR Outlook Report are: Biodiversity, ecosystems, heritage (natural, indigenous, historic), large-scale influences, commercial and recreational uses, risks to values.

A five-year health check of the MEMS will review implementation, consider new research and monitoring outputs, and review new evidence for existing and emerging threats requiring a management response. This will include a mid-term review of the statewide TARA. The five-year health check of the MEMS needs to draw together the broad diversity of environmental, social, cultural and economic condition along with trends in the main drivers and associated risks. It should also incorporate new knowledge that may assist understanding of the changes in assets and stressors and threats to these. It is recommended that a MIMP Report Card supports the reporting for this five-year health check. This should be followed by annual report card updates.

The Environment Technical Working Group recommends that there are significant advantages in the five-year Report Card maintaining consistency, as much as possible, with the main themes (chapter headings) for the environmental topics that are common to the GBR Outlook Report and the MIMP's monitoring focuses. The primary benefits are:

- the GBR Outlook Report is an existing mature framework with a proven record of public acceptance
- it allows a consistent east-coast analysis (noting that East Australian Current is a dominant influence in both areas of interest)
- it allows for consistency in interpretation of trends for wide ranging species (e.g. sharks, whales, turtles, birds)
- it establishes a compatibility between the two mega bio-geographical features of the east coast of Australia, the coral dominated GBR in the north and the kelp dominated Great Southern Reef in the south as a context for discussions of ecosystems and habitats
- it facilitates discussion of climate change linkages – primarily poleward movement of species as water temperatures increase.

The themes under consideration for the data collected under the Environmental Condition Framework (ECF) are:

BIODIVERSITY: Biodiversity depends on maintaining the condition of all its habitats, species and the interconnections between them. This theme will report on 'habitats to support species' and 'populations of species and groups of species' including threatened and endangered species nominated under the *Biodiversity Conservation Act 2016* and *Fisheries Management Act 1994*. The idea of 'habitats to support species' links directly back to the assets in the TARA, against which most threats were assessed.

ECOSYSTEM HEALTH: The condition of the NSW marine estate depends on responses to extractive, chemical and physical processes and stressors in connected coastal ecosystems. To understand ecosystem health, an understanding of species diversity, species abundance, habitat resilience and ecosystem processes is required. An ecosystem is considered healthy if it can maintain its structure and function in the face of external pressures. This theme brings together information on external pressures and/or stressors (extractive, physical and chemical) and the condition of collections of habitats (ecosystems) in the face of the pressures/stressors. It introduces ecological processes such as particle feeding, primary production, recruitment, competition, microbial processes, predation, herbivory, but in most cases, we have poor knowledge. It can highlight research in these areas.

COMMERCIAL AND NON-COMMERCIAL USE: Use of the marine environment continues to provide significant economic and social benefits. The Community Benefit Framework will provide assessments of benefits, and the Environmental Condition Framework will provide data on the environmental status that underpins the commercial and non-commercial uses.

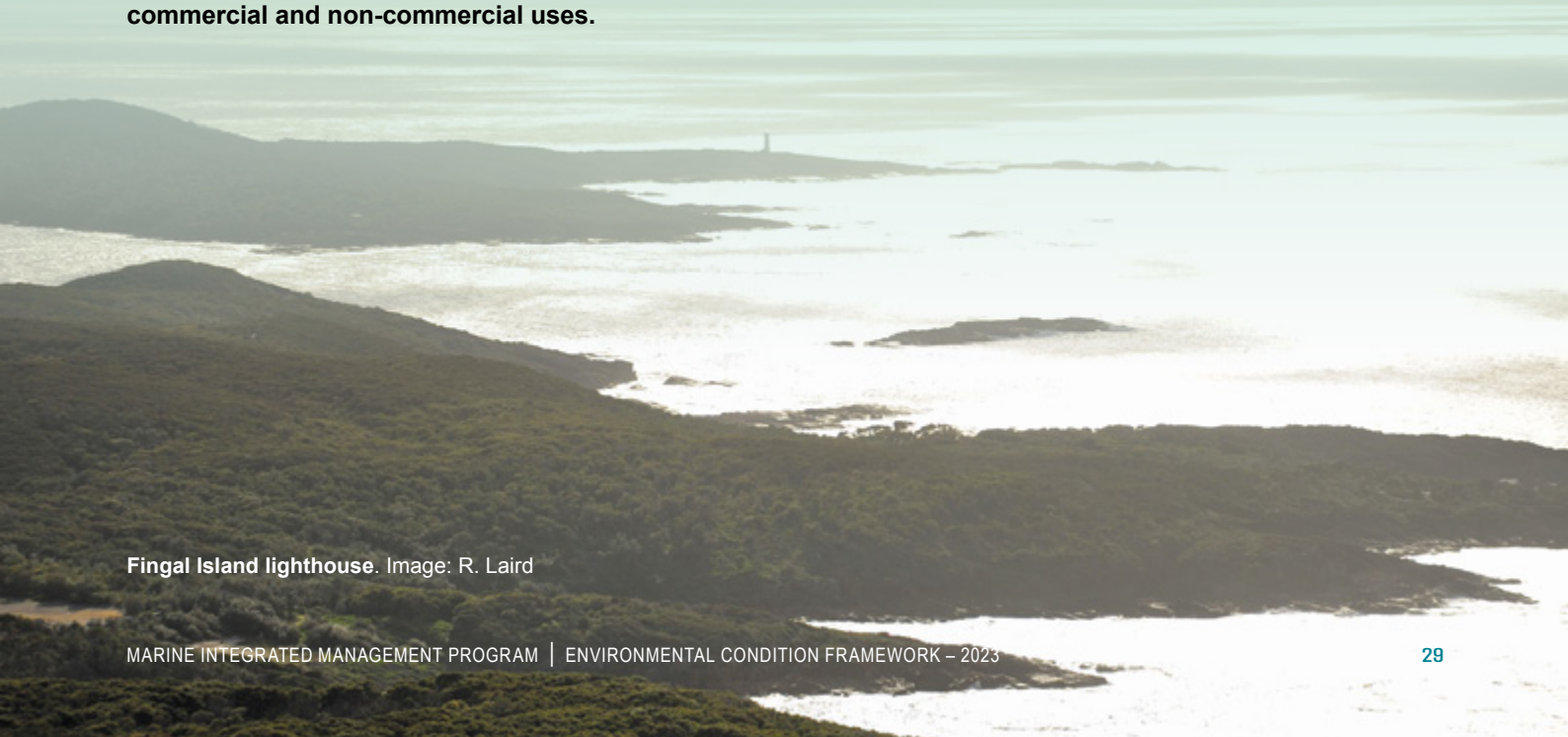
INFLUENCES ON VALUES: The marine estate's values are influenced by four main factors: climate change, coastal development, land-based runoff and direct use (extractive and physical). Many of the resultant stressors are being measured in the Environmental Condition Framework and can be summarised and reported in this theme, as well as the influences of large-scale (regional or global) influences over which we have little direct influence.

RESILIENCE: The resilience of the marine estate's ecosystem and heritage values will be assessed through a series of case studies. Suggestions for potential cases studies include: 'Impacts of ocean warming on the macrophytes that form the Great Southern Reef'; 'Response of estuarine macrophytes to rising sea levels and changing estuarine temperatures'; 'Responses of seals and turtles to increasing ocean temperatures'; 'Influences of ocean temperatures and fisheries management on lobsters in NSW'; and, 'Benefits of no-take zones for ecosystem resilience'.

RESIDUAL RISKS TO VALUES: This theme is mostly about data and management gaps, what risks are not currently being managed, and where are our critical knowledge gaps.

THE COMMUNITY WELLBEING FRAMEWORK, a separate companion report, provides additional themes that complete the assessment of social, cultural and economic aspects of the status of the marine estate.

Figure 3 identifies the reporting themes and the data needs, as well as the projects identified in this report that contribute the necessary data to report on themes.



Fingal Island lighthouse. Image: R. Laird

FIGURE 3. Linkages between reporting themes, data content and data sources (refer to Tables 4 and 5 for details of Agency-led MIMP projects and Table 6 for Agency-led environmental research projects).

Themes

- Biodiversity
- Ecosystems
- Commercial and non-commercial uses
- Influences to values
- Resilience
- Risks to values
- + other social, cultural and economic theme from the Community Wellbeing Framework

Elements	Components	Content	Project Code (see Tables 4 & 5) and other data sources
Habitats	Main (or obvious) broad habitat groups within each ecosystem/ region	Coverage of mangroves, seagrasses, macroalgae (Great Southern Reef), soft sediments, corals, sessile invertebrates including coverage/biomass, biological diversity. We may also want to identify important places related to specific issues or biological parameters. For example, Port Stephens and Jervis Bay for dolphins; Byron Bay and Jervis Bay for whales and calves.	Projects F1, F2, N1, N2, N3, N4, N5, N6 Fisheries data, FMA Data, Macro/habitat data
Populations	Main species/ species groups	Populations of mangroves, seagrasses, macroalgae, corals, sessile and mobile invertebrates, plankton and microbes; bony fishes, sharks and rays, marine reptiles, seabirds, shorebirds, whales, dolphins, seals.	Projects F5, F6, F7, F8, F9, F10, F16, F17, F18, F19, F20 BCA/SOS and other data (DPE-EHG), Fisheries data, FMA Data, Macro/habitat data
Large Scale Environmental Features	Pressures/ stressors, contextual forces	Currents = EAC strength, duration, distance, frequency of eddies; cyclones and wind = storms; freshwater inflow = sediment, nutrient, contaminants, turbidity; sediment exposure; sea level, sea temperature, pH, salinity, light. An assessment would be provided for a range of biological, physical and chemical parameters. Specific issues could also be raised and possibly quantified/discussed here. Also identify important places related to contamination, and management actions such as discontinued shoreline sewage discharges, ongoing offshore discharges and contamination hotspots, diseases, invasions. Pressures – fishing pressure, land use, discharges, noise, light	Projects E1, E3, E4, F3, N5, N6 Bureau of Meteorology, Manly Hydraulics Laboratory, EPA licence data, IPCC, IMOS, Relevant surveys (CBF)
Direct Uses		Recreational fishers, commercial fishers, animal-based tourism, shipping, boating	Projects F6, F7, F8, F9, F12, F13, F14, F17, F18, F19, F20 Relevant surveys

Oyster farming racks. Image: NSW DPI, State of New South Wales

11 References

AITHER (2022) *Integrated Monitoring and Evaluation Framework for the Marine Integrated Monitoring Program (MIMP)*, NSW Marine Estate Management Strategy.

ANZECC and ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

BMT WBM (2017) *New South Wales Marine Estate Threat and Risk Assessment Report*, Marine Estate Management Authority, 251 pp.

Community Environment Network (2005) *Watching the Seagrass Grow – a guide for community seagrass monitoring in NSW* (2nd edn), The Community Environment Network, Ourimbah.

Crain CM, Kroeker K and Halpern BS (2008) 'Interactive and cumulative effects of multiple human stressors in marine systems', *Ecology Letters*, 11:1304–1315.

Creese RG, Glasby TM, West G and Gallen C (2009) *Mapping the habitats of NSW estuaries*, Industry & Investment NSW, Fisheries Final Report Series, 113, Port Stephens.

DECCW (2010a) *Guidelines for Preparing Coastal Zone Management Plans*, Department of Environment, Climate Change and Water NSW, Sydney.

DECCW (2010b) *NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010–2015*, Department of Environment, Climate Change and Water NSW, Sydney.

DECCW (2010c) *State of the Catchments, Estuaries and Coastal Lakes, Northern Rivers Region*, Department of Environment, Climate Change and Water NSW, Sydney.

DECCW (2010d) *State of the Catchments, Estuaries and Coastal Lakes, Hunter – Central Rivers Region*, Department of Environment, Climate Change and Water NSW, Sydney.

DECCW (2010e) *State of the Catchments, Estuaries and Coastal Lakes, Hawkesbury–Nepean and Sydney Metropolitan Regions*, Department of Environment, Climate Change and Water NSW, Sydney.

DECCW (2010f) *State of the Catchments, Estuaries and Coastal Lakes, Southern Rivers Region*, Department of Environment, Climate Change and Water NSW, Sydney.

EcoCheck (2011) *Sampling and Data Analysis Protocols for Mid-Atlantic Tidal Tributary Indicators*, Wicks EC, Andreychek ML, Kelsey RH and Powell SL (eds). IAN Press, Cambridge Maryland, USA.

Folt CL, Chen CY, Moore MV and Burnaford J (1999) 'Synergism and antagonism among multiple stressors', *Limnology and Oceanography*, 44:864–877.

Fraser M (2008) *The Development of an Ecosystem Health Monitoring Program for the Estuaries and Coastal Lakes in the Southern Rivers Catchment Management Authority Region*, Southern Rivers Catchment Management Authority, Wollongong.

Gillies CL, McLeod IM, Alleway HK, Cook P, Crawford C, Creighton C, Diggles B, Ford J, Hamer P, Heller-Wagner G and Lebrault E (2018) 'Australian shellfish ecosystems: Past distribution, current status and future direction', *PLoS One*, 13:e0190914.

Gissi E, Manea E, Mazaris AD,Fraschetti S, Almpanidou V, Bevilacqua S, Coll M, Guarnieri G, Lloret-Lloret E, Pascual M, Petza D, Rilov G, Schonwald M, Stelzenmüller V and Katsanevakis S (2021) 'A review of the combined effects of climate change and other local human stressors on the marine environment', *Science of the Total Environment*, 755(1):142564.

Grabowski JH, Brumbaugh RD, Conrad RF, Keeler AG, Opaluch JJ, Peterson CH, Piehler MF, Powers SP, Smyth AR (2012) 'Economic valuation of ecosystem services provided by oyster reefs', *BioScience*, 62:900-909.

Halpern BS and Fujita R (2013) 'Assumptions, challenges, and future directions in cumulative impact analysis', *Ecosphere*, 4:1–11.

Kim SW, Sampayo EM, Sommer B, Sims CA, Gómez-Cabrera MDC, Dalton SJ, Beger M, Malcolm HA, Ferrari R, Fraser N and Figueira WF (2019) 'Refugia under threat: Mass bleaching of coral assemblages in high-latitude eastern Australia', *Global Change Biology*, 25(11):3918-3931.

Morris OF, Loewen CJG, Woodward G, Schäfer RB, Piggott JJ, Vinebrooke RD and Jackson MC (2022) 'Local stressors mask the effects of warming in freshwater ecosystems', *Ecology Letters*, 25:2540–2551.

Muschal M, Turak E, Gilligan D, Sayers J and Healey M (2010) *Riverine ecosystems: Technical report series of the NSW Monitoring, Evaluation and Reporting Program*, NSW Office of Water, Sydney.

NRC (2005) *Recommendations: Statewide standard and targets*, NSW Natural Resources Commission, Sydney.

NSW Government (1999) *NSW Water Quality and River Flow Objectives*, Department of Environment and Conservation, Sydney.

NSW MEMA (2018) *NSW Marine Estate Management Strategy 2018-2028*, Marine Estate Management Authority, 80 pp.

NSW MEMA (2021). *Marine Estate Management Strategy Implementation Plan 2021-2022*, Marine Estate Management Authority. 80 pp.

NWC (2007) *Australian Water Resources 2005: Assessment of river and wetland health – a framework for comparative assessment of the ecological condition of Australian rivers and wetlands*, National Water Commission, Canberra.

OEH (2016) *Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols*, OEH 2016/0250, NSW Office of Environment and Heritage, Sydney.

Pease BC (1999) 'A spatially oriented analysis of estuaries and their associated commercial fisheries in New South Wales', *Australia Fisheries Research*, 42:67-86.

Przeslawski R, Byrne M, Mellin C (2015) 'A review and meta-analysis of the effects of multiple abiotic stressors on marine embryos and larvae', *Global Change Biology*, 21:2122–2140.

Rapport DJ, Costanza R, McMichael AJ (1998) 'Assessing Ecosystem Health', *Trends in Ecology and Evolution*, 13:397-402.

Roper T, Creese B, Scanes P, Stephens K, Williams R, Dela-Cruz J, Coade G, Coates B and Fraser M (2011) *Assessing the Condition of Estuaries and Coastal Lake Ecosystems in NSW: Technical Report – NSW State of the Catchments 2010*, Department of Environment, Climate Change and Water NSW, Sydney.

Roy PS, Williams RJ, Jones AR, Yassini I, Gibbs PJ, Coates B, West RJ, Scanes PR, Hudson JP, Nichol S (2001) 'Structure and function of south-east Australian estuaries', *Estuarine, Coastal and Shelf Science*, 53:351–384.

Ryder D (2011) *Technical Report for Report Card Preparation, Indicators and Calculation of Grades (Bellinger-Kalang Rivers Ecohealth Project Assessment of River and Estuarine Condition 2011 Report Card)*, University of New England, Armidale.

Scanes P, Coade G, Doherty M and Hill R (2007) 'Evaluation of the utility of water quality based indicators of estuarine lagoon condition in NSW, Australia', *Estuarine, Coastal and Shelf Science*, 74:306–19.

Scanes P, Coade G and Dela-Cruz J (2009) *Monitoring, Evaluation and Reporting Sampling Protocols*, Department of Environment, Climate Change and Water NSW, Sydney.

Stelzenmüller V, Coll M, Mazaris AD, Giakoumi S, Katsanevakis S, Portman ME, Degen R, Mackelworth P, Gimpel A, Albano PG and Almpanidou V (2018) 'A risk-based approach to cumulative effect assessments for marine management', *Science of the Total Environment*, 612:1132-1140.

Sun KW, Sampayo EM, Sommer B, Sims CA, Gómez-Cabrera MDC, Dalton SJ, Beger M, Malcolm HA, Ferrari R, Fraser N and Figueira WF (2019) 'Refugia under threat: Mass bleaching of coral assemblages in high-latitude eastern Australia' *Global Change Biology*, 25(11):3918-3931.

Tamburri MN (2006) *Performance Verification Statement for the Wet Labs ECO FLNTUSB Fluorometer*, Alliance for Coastal Technologies VS07–06.

Australian Fairy Terns *Sternula nereis nereis*.
Image: Geoffrey Ross NSW NPWS © State of New South Wales

12 Appendices

Commercial fishing vessel. Image: NSW DPI, State of New South Wales

Appendix A Projects linked to assets and threats they address for estuaries and coastal waters

TABLE A1. Estuaries: moderate-high risk threats for each asset and project(s) providing information on status and trends for those assets. The projects aligned with project codes (e.g. E1, F7 etc.) are expanded upon in Table 4. Threats without project codes have no associated environmental monitoring currently identified.

Estuaries	ENVIRONMENTAL – BIOLOGICAL ASSETS							ENVIRONMENTAL – PHYSICAL & CHEMICAL	
Species / Habitat	Plankton	Algae	Plants	Invertebrates	Fishes	Reptiles & Mammals	Birds	Pollution incl. nutrients	Physico-chemical condition
Waters	Urban stormwater discharge, Agricultural diffuse source runoff, Thermal discharges, Ocean acidification. E1	Urban stormwater discharge		Urban stormwater discharge. E2	Urban stormwater discharge. E2			Modified freshwater flows, Urban stormwater discharge, Agricultural diffuse source runoff, Clearing riparian and adjacent habitat, Industrial discharges, Thermal discharges, Sewage effluent and septic runoff. E4	Modified freshwater flows, Urban stormwater discharge, Agricultural diffuse source runoff, Thermal discharges, Altered storm/cyclone activity. E1
	Recreation and tourism, Dredging, Modified freshwater flows, Clearing riparian and adjacent habitat, Industrial discharges, Sewage effluent and septic runoff, Estuary entrance modification	Dredging		Dredging, Hand gathering	Commercial fishing, Recreatio-nal fishing, Dredging. D8, F17, F20	Shipping; Commercial fishing, Recreational fishing, Boating and boating infrastructure E5, E6, E7, F8	Shipping Dredging, Commercial fishing, Recreational fishing, Boating and boating infrastruc-ture, Altered storm, activity. F8	Shipping, Commercial fishing, Recreational fishing, Boating and boating, infrastructure, Dredging	Altered ocean currents and nutrient inputs, Estuary entrance modification, Sea level rise, Climate and sea temp. rise, Ocean acidification

Table A1 (continued on next page)

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Estuaries	ENVIRONMENTAL – BIOLOGICAL ASSETS							ENVIRONMENTAL – PHYSICAL & CHEMICAL	
Species / Habitat	Plankton	Algae	Plants	Invertebrates	Fishes	Reptiles & Mammals	Birds	Pollution incl. nutrients	Physico-chemical condition
Beaches		Dredging		Urban stormwater discharge, Ocean acidification	Urban stormwater discharge		Foreshore development	Urban stormwater discharge, Foreshore development, Ocean acidification	Boating and boating infrastructure
				Hand gathering, Four-wheel driving, Dredging			Passive recreational use, Four-wheel driving	Shipping, Dredging, Agricultural diffuse source runoff, Industrial discharges, Sewage effluent and septic runoff	Clearing riparian and adjacent habitat, Estuary entrance modification, Four-wheel driving, Dredging, Urban stormwater discharge, Foreshore development, Beach nourishment and grooming, Climate and sea temp. rise, Sea level rise
Mudflats				Urban stormwater discharge, Ocean acidification	Urban stormwater discharge		Foreshore development	Urban stormwater discharge, Foreshore development	Boating and boating infrastructure Ocean acidification
				Hand gathering, Four-wheel driving			Passive recreational use	Shipping, Dredging, Agricultural diffuse source runoff, Industrial discharges, Sewage effluent and septic runoff, Estuary entrance modification	Shipping, Four-wheel driving, Urban stormwater discharge, Foreshore development, Beach nourishment and grooming, Clearing riparian and adjacent habitat, Sea level rise, Climate and sea temp. rise

Table A1 (continued from previous page)

Estuaries	ENVIRONMENTAL – BIOLOGICAL ASSETS							ENVIRONMENTAL – PHYSICAL & CHEMICAL	
Species / Habitat	Plankton	Algae	Plants	Invertebrates	Fishes	Reptiles & Mammals	Birds	Pollution incl. nutrients	Physico-chemical condition
Saltmarsh			Modified freshwater flows; Foreshore development, Clearing habitat, Stock grazing, Estuary entrance modification, Climate and sea temp. rise. F1, F4	Urban stormwater discharge	Urban stormwater discharge		Foreshore development, Clearing adjacent habitat, Sea level rise		
			Shipping Commercial fishing, Four-wheel driving Pipelines, cables, trenching and boring, Sea level rise, Ocean acidification Altered, storm/cyclone activity. F1, F4						Shipping

Table A1 (continued from previous page)

Estuaries	ENVIRONMENTAL – BIOLOGICAL ASSETS							ENVIRONMENTAL – PHYSICAL & CHEMICAL	
Species / Habitat	Plankton	Algae	Plants	Invertebrates	Fishes	Reptiles & Mammals	Birds	Pollution incl. nutrients	Physico-chemical condition
Seagrass			Boating and boating infrastructure, Urban stormwater discharge, Agricultural diffuse source runoff, Stock grazing, Thermal discharges, Estuary entrance modification. F1, F4	Urban stormwater discharge	Urban stormwater discharge		Clearing adjacent habitat		
			Shipping, Commercial fishing, Aquaculture, Dredging, Modified freshwater flows, Pipelines, cables, trenching and boring, Beach nourishment and grooming; Clearing habitat, Sewage effluent and septic runoff, Climate and sea temp. rise, Ocean acidification, Altered storm/cyclone activity. F1, F4		Commercial fishing	Recreational fishing			Shipping

Table A1 (continued from previous page)

Estuaries	ENVIRONMENTAL – BIOLOGICAL ASSETS							ENVIRONMENTAL – PHYSICAL & CHEMICAL	
Species / Habitat	Plankton	Algae	Plants	Invertebrates	Fishes	Reptiles & Mammals	Birds	Pollution incl. nutrients	Physico-chemical condition
Mangroves			Shipping, Modified freshwater flows, Stock grazing. F1, F4	Urban stormwater discharge	Urban stormwater discharge		Foreshore development, Clearing habitat, Sea level rise		
			Shipping, Pipelines, cables, trenching and boring, Urban stormwater discharge, Foreshore development, Agricultural diffuse source runoff, Clearing habitat Industrial discharges, Estuary entrance modification, Sea level rise, Climate and sea temp. rise, Ocean acidification.F1,F4			Recreational fishing			Shipping
Rocky shores		Urban stormwater discharge		Urban stormwater discharge, Ocean acidification	Urban stormwater discharge		Clearing adjacent habitat	Urban stormwater discharge	Urban stormwater discharge
		Shipping, Boating and boating infrastructure		Shipping, Recreational fishing, Hand gathering, Boating and boating infrastructure	Boating and boating infrastruc-ture	Commercial fishing, Recreational fishing		Foreshore development, Agricultural diffuse source runoff	Shipping, Boating and boating infrastructure, Foreshore development, Agricultural diffuse source runoff, Ocean acidification

Table A1 (continued from previous page)

Estuaries	ENVIRONMENTAL – BIOLOGICAL ASSETS							ENVIRONMENTAL – PHYSICAL & CHEMICAL	
Species / Habitat	Plankton	Algae	Plants	Invertebrates	Fishes	Reptiles & Mammals	Birds	Pollution incl. nutrients	Physico-chemical condition
Shallow soft sediments				Urban stormwater discharge	Urban stormwater discharge, Commercial fishing Recreatio-nal fishing		Clearing adjacent habitat	Dredging, Urban stormwater discharge	Dredging, Urban stormwater discharge, Foreshore development
				Hand gathering, Clearing adjacent habitat, Sewage effluent and septic runoff, Ocean acidification		Commercial fishing, Recreational fishing		Shipping, Modified freshwater flows, Industrial discharges, Sewage effluent and septic runoff	Clearing adjacent habitat, Estuary entrance modification
Subtidal reefs		Urban stormwater discharge. F2, F3		Urban stormwater discharge, Ocean acidification. F2, F3	Urban stormwater discharge. F10			Dredging, Urban stormwater discharge	Urban stormwater discharge
		Boating and boating infrastructure, Agricultural diffuse source runoff, Climate and sea temp. rise, F2, F3		Boating and boating infrastructure, Agricultural diffuse source runoff, Climate and sea temp. rise. F2, F3	Commercial fishing, Recreatio-nal fishing. F10	Commercial fishing, Recreational fishing		Boating and boating infrastructure, Agricultural diffuse source runoff	Clearing riparian and adjacent habitat, Climate and sea temp. rise, Altered storm activity

TABLE A2. Coast and marine: moderate-high threats for each asset and project(s) providing information on status and trends for those assets. The projects aligned with project numbers (e.g. E1, F7 etc.) are expanded upon in Table 4. Threats without project codes have no associated environmental monitoring currently identified. The climate change threat is considered over a 20-year time frame as identified in the statewide TARA.

Coastal and Marine	ENVIRONMENTAL – BIOLOGICAL ASSETS							ENVIRONMENTAL – PHYSICAL & CHEMICAL	
Habitat / Species	Plankton	Algae	Plants	Invertebrates	Fishes	Reptiles & Mammals	Birds	Pollution incl. nutrients	Physico-chemical condition
Waters	Climate change				Commercial fishing. F6, F7, F8, F9	Shipping, Commercial fishing, Land-use intensification. N1, N2, N3, F8, F9	Commercial fishing, Land-use intensification, Climate change	Sewage effluent and septic runoff, Climate change. E4, N1, N2, N3, N4, N5, N6 [Beachwatch]	Climate change
					Recreational fishing, Climate change. F6, F17, F18	Recreation and tourism. N1	Recreational fishing, Recreation and tourism		
Beaches				Land-use intensification, Climate change	Commercial fishing, Recreation and tourism. F8, F9	Recreation and tourism, Land-use intensification, Climate change. N1, N2, N3	Recreation and tourism, Land-use intensification, Climate change	Land-use intensification E4, N1, N2, N3, N4	Recreation and tourism, Dredging, Land-use intensification, Estuary entrance modification
					Recreational fishing		Commercial fishing	[Beachwatch]	Climate change
Rocky shores		F2, F3		Climate change. F2, F3, F6	F2, F3, F5	Recreation and tourism. N1, N2, N3	Recreation and tourism	Sewage effluent and septic runoff. E4, N1, N2, N3, N4	Land-use intensification, Climate change. F2
Shallow soft sediments					Commercial fishing. F6, F7, F8, F9				Climate change
					Recreational fishing. F6				

Table A2 (continued on next page)

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Coastal and Marine Species / Habitat	ENVIRONMENTAL – BIOLOGICAL ASSETS							ENVIRONMENTAL – PHYSICAL & CHEMICAL	
	Plankton	Algae	Plants	Invertebrates	Fishes	Reptiles & Mammals	Birds	Pollution incl. nutrients	Physico-chemical condition
Subtidal reefs		Climate change. F2, F3, F5		Commercial fishing, Climate change. F2, F3, F5, F6	Commercial fishing. F5, F6, F8, F9	Commercial fishing. N1, N2, N3			Climate change. F2
Deep soft sediments				Shipping	F7, F8, F9			Dredging	Climate change
				Commercial fishing					
Deep reefs		F5		Shipping, Commercial fishing, Climate change. F5	F5, F8, F9			Sewage effluent and septic runoff	
Seagrass			Climate change. F1			N3			
Wetlands							Land-use intensification. F4		

Appendix B Key Performance Indicators relevant to monitoring the condition and trend of the environmental assets

TABLE B1. Descriptions of selected Key Performance Indicators (KPIs) relevant to condition and trend monitoring. KPIs are headline indicators that generally align with long-term outcomes and tend to be unique to each initiative. Indicator descriptions are from section 4.2.3 of the Integrated Monitoring and Evaluation Framework (Aither, 2022).

KPI	Description
KPI 1 – Waterway health supports community values	This indicator relates to the long-term outcome 1A 'Waterway health in the marine estate aligns with community values' within Initiative 1 '*To improve water quality and reduce marine litter for the benefit of marine habitats, wildlife and the community'*. It also relates to the MEMS outcome *'Enhanced condition of the marine estate, including its habitats, wildlife and natural beauty, in identified regions and maintained elsewhere*'. This indicator focusses on aligning available waterway health data with related community values. The NSW Water Quality and River Flow Objectives highlight the community values for each estuary and catchment in NSW, as well as water quality indicators that reflect those specific community values. Protection of aquatic ecosystems (PAE), primary contact recreation (PCR) and edible seafood (ES) are identified as the primary community values in the NSW marine estate, and are reflected as measures for this indicator. In addition, an ecological health grade is being developed and will be included as a measure in the future.
KPI 2 – Reduction in litter in the marine and estuarine environments in targeted regions	This indicator relates to long-term outcome 1B '*Reduction in input litter to the marine estate in alignment with community values*', and will also be used to measure progress against the intermediate outcome 1I '*Reduction in input litter in target regions*.' It also relates to the MEMS outcome '*Enhanced condition of the marine estate, including its habitats, wildlife and natural beauty, in identified regions and maintained elsewhere*'. Data will be drawn from monitoring programs operated by NSW EPA. Initially, this indicator drew on data from the National Litter Index (NLI), which used a measure of the volume of litter per 1000 square metres published in the quarterly Keep Australia Beautiful National Litter Index. From 2021 onwards, this indicator will instead draw on the Key Litter Item Study, which will provide a measure based on debris items per 1000 square metres (in urban estuarine environments). 'Targeted regions' for the purpose of this indicator will be selected based on the TARA.
KPI 3 – Community wellbeing indicator	This indicator is primarily related to the social and cultural component of long-term outcome 8A *'Improved or maintained social, cultural and economic benefits of the marine estate that contribute to the wellbeing of the NSW community'* within Initiative 8 *'Enhancing social, cultural and economic benefits*'. It also relates to the MEMS outcome '*Greater community appreciation and enhanced sustainable experiences of the marine estate in identified regions, and maintained elsewhere'*. This indicator focuses on the perceptions of the marine estate's contribution to a person's overall quality of life. Quality of life is the individual perception of their position in life, and is a broad ranging concept that can include a person's physical and mental health, values and beliefs, social relations and their dependency on the environment. This indicator captures subjective aspects of quality of life and will be measured through respondents' satisfaction in relation to feelings about themselves and their dependency on the marine estate. Perceptions of the degree to which the marine estate contributes to quality of life will be assessed through the Coastal Residents Survey, Visitors Survey and Sea Country (marine estate) Survey.

Table B1 (continued on next page)

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KPI	Description
KPI 4 – Biodiversity and habitat indicator	This indicator primarily relates to outcomes 1C and 2B '*Maintained or improved biodiversity and marine habitats*'. It also relates to the MEMS outcome '*Enhanced condition of the marine estate, including its habitats, wildlife and natural beauty, in identified regions and maintained elsewhere*'. This indicator incorporates measures of biodiversity and ecological integrity. These themes are consistent with those identified within the broader Biodiversity Indicator Program, which is currently defined for terrestrial environments and is being expanded to cover aquatic environments. It also relates to the monitoring of management responses, stressors, and the status of biodiversity. The measures will be implemented progressively during the MEMS, reflecting resource availability, and readiness of data and technology. Some measures are in developmental and require further research or confirmation of new technologies to confirm their feasibility. Measures may be developed and reported in different ways and at different geographic, taxonomic and temporal scales. Overall, the biodiversity and habitat indicator will also aim to allow improved evaluation of ecosystem resilience in deriving an overall measure of ecological health. The measures for this KPI were developed collaboratively by staff from Initiative 1, Initiative 2 and the Environmental MIMP Technical Working Group.
KPI 5 – NSW contribution to national body of knowledge, approaches and plans for conservation of targeted threatened and protected species	This indicator relates to outcome 5B '*Increased NSW contribution to national conservation of targeted threatened and protected species*' within Initiative 5 '*Reducing impacts on threatened and protected species*'. It also relates to the MEMS outcome '*Enhanced condition of the marine estate, including its habitats, wildlife and natural beauty, in identified regions and maintained elsewhere*'. This indicator seeks to measure NSW's contribution towards and leadership in national conservation of coastal and marine species that are listed as threatened and protected under the *Biodiversity Conservation Act 2016* and threatened under the *Fisheries Management Act 1994*. Measures capture NSW's leadership or involvement in developing new management methods or processes that can be applied elsewhere; preparing national species plans; and publications relating to threatened and protected species. It also includes providing advice to other jurisdictions, and NSW-developed programs, guidelines or codes of practice that are adopted by other jurisdictions.
KPI 8 - Trend in ecological sustainability, economic viability and community wellbeing measures for fishing and aquaculture	This indicator primarily relates to outcome 6A '*Improved ecological sustainability, economic viability and community wellbeing relating to fishing and aquaculture in the marine estate*' within Initiative 6 '*Ensuring sustainable fishing and aquaculture*'. This indicator includes measures for recreational fishing, and commercial fishing and aquaculture. Some measures are still in development. Measures will include a species sustainability index, which will draw on species stock status data; measures of wellbeing for commercial and recreational fishers and aquaculturalists that extend beyond economic wellbeing; participation in and expenditure associated with recreational fishing; satisfaction with the quality of recreational fishing and experiences; and perceptions of sustainability and economic viability of commercial fishing and aquaculture.

Table B1 (continued from previous page)

KPI	Description
KPI 10 - Community and targeted stakeholders demonstrate improved capacity to anticipate and adapt to climate change impacts	This indicator relates to outcome 3A '*Improved capacity of coastal and marine managers and communities to anticipate climate impacts and identify adaptation pathways*' within Initiative 3 '*Planning for climate change*'. It also relates to the MEMS outcome '*Improved incorporation of the likely impacts of climate change in planning for and managing the marine estate*'. Measures and baseline results for this indicator will be established through the implementation of Initiative 3's management actions and sub-actions that relate to climate change engagement. It will draw on data and information gathered through feedback surveys of participants in engagement activities, as well as broader insights collected through surveys of staff from responsible and related agencies and other targeted stakeholders.
KPI 14 - Agency staff report using decision-making and approvals processes for foreshore and coastal land use management, design and development that balances social and economic benefits with enhancing coastal and marine habitats	This indicator relates to outcome 2A '*Improved design and management of foreshore and coastal land use and development, balancing social and economic benefits of development with enhanced coastal and marine habitat*' within Initiative 2 '*Delivering healthy coastal habitats with sustainable use and development'. It also relates to the MEMS outcome 'Increased appropriateness of the built environment with reduced risk to the marine estate*'. Data for measuring against this indicator will be collected through an agency staff survey and will capture the proportion of respondents who report using relevant processes. The specific decision-making and approvals processes that are relevant to this indicator are those relating to foreshore development and use, coastal floodplain and infrastructure management and other relevant coastal systems. Staff to be surveyed include those from DPE-P, NRAR, Crown Lands and others with their roles and responsibilities as outlined in the domestic waterfront structures strategy, marine vegetation strategies, coastal floodplain assessments, and drainage management plans.
KPI 15 - Adoption of best-practice approaches and processes for undertaking activities related to the marine estate among the community and targeted stakeholders	This indicator relates to long-term outcomes 1D '*Improved adoption of best practice land management and compliance with rules and regulations for managing water pollution and litter*' within Initiative 1 '*To improve water quality and reduce marine litter for the benefit of marine habitats, wildlife and the community'*, and 8B '*Increased stakeholder and community adoption of safe and sustainable use of the marine estate*' within Initiative 8 '*Enhancing social, cultural and economic benefits*'. It also relates to intermediate outcome 2E '*Increased adoption of best practice design and management of foreshore and coastal planning, development and use'* within Initiative 2 '*Delivering healthy coastal habitats with sustainable use and development', and the MEMS outcome 'Increased appropriateness of the built environment with reduced risk to the marine estate*'. The indicator is measured through Coastal Residents Survey and Visitors Survey using questions to elicit the prevalence of use of best practice approaches and processes. The relevant best practice approaches and processes vary by outcome, reflecting the focus of each initiative. In Initiative 8, best practice approaches and processes are those relating to the disposal of rubbish, use of fertiliser and garden chemicals, rules and guidelines to minimise disturbance to coastal and marine wildlife, and rules for recreational fishing and recreational boating. Targeted stakeholders include the general community. In Initiative 1, best practice approaches and processes relate to the Diffuse Source Water Pollution Strategy, Oyster Reef Restoration Implementation Guidelines, fertiliser management, Blueberry Nutrition Guidelines, macadamia nut nutrient replacement, farm water and nutrient management, erosion mitigation practices, coastal wetland rehabilitation, and the Risk-based framework. Targeted stakeholders include agricultural industries, the construction industry, landholders / participants in on-ground works, and councils. In Initiative 2, best practice approaches and processes relate the adoption into council/related stakeholder processes, the Risk-based Framework, and estuary specific strategies. Targeted stakeholders include responsible and related agencies.

Appendix C Details of core MIMP projects

NB: At the time of writing this report (October 2022), some projects are more progressed than others which is reflected in varying levels of details in the subsequent project descriptions and tables.

Appendix C.1 Improving water quality and reducing litter (Initiative 1)

Initiative objective: To improve water quality and reduce marine litter for the benefit of marine habitats, wildlife and community.

Water pollution and litter are together a significant contributor to poor water quality in the marine estate. Water quality affects the health of habitats and wildlife as well as the vast social, cultural and economic benefits provided by the marine estate.

The MEMS management actions for Initiative 1 will reduce the impacts of urban and agricultural diffuse-source water pollution including stormwater. Parts of the initiative will provide improved guidance and coordination of land use activities affecting water pollution, including across state government agencies (e.g. DPI, DPE). Other actions propose onground works that will directly reduce the diffuse sources of water pollution. Research and monitoring programs are proposed to fill knowledge gaps. The specific management actions (Table 1) that relate to environmental monitoring are:

- MEMS 1.1 Improve water quality in agricultural and urban catchments using a pilot-based implementation of the Risk Based Framework
- MEMS 1.2 Improve the management of diffuse-source water pollution by:
  a. clarifying NSW Government and local government roles and responsibilities
  b. building capacity to implement the Risk Based Framework
  c. using mechanisms within existing policy, planning and legislative frameworks to improve outcomes
  d. improve minimum requirements for industry standards and ensure compliance with regulations and best practice through social research, education campaigns and compliance programs.
- MEMS 1.3 Facilitate and deliver onground activities that reduce diffuse-source water pollution through investigation and provision of funding programs and financial incentives
- MEMS 1.4 Implement a targeted marine litter campaign and establish a Marine Litter Working Group
- MEMS 1.5 Develop monitoring, reporting and performance indicators for water quality actions and fill key knowledge gaps. This action is integrated into the Monitoring Program.

Projects monitoring water quality, marine litter, and/or the impacts on environmental assets and community wellbeing are outlined in Tables 4 and 5 (with full project descriptions below), and other relevant MEMS research projects are listed in Table 6. Projects that also support Initiative 1 but primarily contribute monitoring information to other MEMS initiatives are presented in Table 6.

C.1.1 Monitoring the ecological health of the estuaries in the NSW marine estate to provide a consistent framework for ecological health assessment of coastal catchments and support Application of the Risk Based Framework in selected areas – E1

C.1.1.1 Overview

This project has established methods, indicators and baseline datasets to assess and monitor waterway health at pilot catchments. These methods provide a consistent framework for monitoring ecological health of coastal catchments and datasets support implementation of the Risk Based Framework for considering waterway health outcomes by:

- assessing and reporting on the current condition of waterway health at pilot catchments (providing context)
- providing datasets at pilot catchments to assist with implementation of additional stages of the Risk Based Framework (effects-based assessment)
- providing methods to guide assessment of waterway health for implementation of the Risk Framework at additional NSW catchments
- develop suites of ecological health indicators to allow rapid stream health assessments and comparable reporting of coastal catchment condition throughout NSW.

This project has also assisted capacity development of NSW government agencies, councils and communities to implement the Risk Framework and achieve waterway health outcomes. The outcome will be greater community involvement in monitoring of waterway health.

This project is led by DPE-EHG. Project partners include Wollongong City Council, Northern Beaches Council, DPI Fisheries, South East Local Land Services, DPE-EHG Place Based Science, INSW, GSC, DPE Planning, EPA (South Creek Partners). Funding sources include MEMS, Wollongong City Council, Northern Beaches Council, DPI Fisheries and DPE-EHG. This project is ongoing throughout MEMS Stages 1 and 2.

C.1.1.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes

C.1.1.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuary waters Seagrass Beach and mudflats Shallow soft sediments Subtidal reefs Rocky shores Planktonic assemblages FMA species BCA species Mangroves Saltmarsh and associated fish and animal assemblages	Enjoyment – enjoying the biodiversity and beauty of the marine estate Participation – safety, health and wellbeing Cultural heritage & use benefits – tangible and intangible Aboriginal cultural heritage	Agricultural diffuse source runoff Urban stormwater discharge Sewage effluent and septic runoff Foreshore development Stock grazing of riparian and marine vegetation Clearing riparian and adjacent habitat including wetland drainage Modified freshwater flows	Water pollution on environmental values - urban stormwater discharge Water pollution on environmental values - agricultural diffuse source runoff Reductions in abundances of species and trophic levels Modified hydrology/hydraulics and flow regime Water pollution on environmental values - septic runoff, point source pollution and sewage overflows (such as outfalls, STPs, etc.) Other water pollution/contamination affecting human health and safety (such as toxic algal blooms, *E. coli* concentrations, etc.)

C.1.1.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Urban stormwater discharge on environmental assets (E5)	Partial (ongoing)
Agricultural diffuse source runoff on environmental assets (E6, E7)	Partial (ongoing)

C.1.1.5 Methods

This project has established methods, indicators and baseline datasets to assess and monitor waterway health at the pilot catchments. These datasets and methods support implementation of the Risk Based Framework for considering waterway health outcomes by:

- assessing and reporting on the current condition of waterway health at pilot catchments (providing context)
- providing datasets at pilot catchments to assist with implementation of additional stages of the Risk Based Framework (effects-based assessment)
- providing methods to guide assessment of waterway health for implementation of the Risk Framework at additional NSW catchments.

The measurement of chlorophyll *a* and water clarity (turbidity; as a proxy for seagrass depth potential) is recommended as condition indicators (Scanes et al. 2007; OEH 2016). They have been demonstrated to be relevant to the two main disturbances generated by diffuse-source pollution – nutrients and suspended sediments. Other water quality indicators will provide useful contextual data to assist in interpreting results for example, salinity/conductivity, temperature, pH, dissolved oxygen, coloured dissolved organic matter (tannins), nutrient concentrations, state of tide. Methods for data collection are described in OEH (2016).

The Estuary Condition and Stressor and Trend Program is a mature program with continuous data back to 2007.

The process for turning the chlorophyll *a* and turbidity data into algal abundance and water clarity indices is described in full in OEH (2016). In summary, it involves comparison of measured data to guideline values (derived for NSW estuaries) and deriving measures of the proportion of data that exceed guideline values and the magnitude of exceedances. These two measures are combined to give a score that ranges between 0 and 1. This score can than then be turned into a report card type grade if desired.

Data collection involves structured sampling of a range of variables as shown in the indicators table in Section C.1.1.6. Water quality sampling follows the methods set out in OEH (2016). Details of sampling methods for other variables are provided in project reports.

This project has also assisted capacity development of NSW Government agencies, Councils and communities to implement the Risk Framework and achieve waterway health outcomes. A final outcome will be greater community involvement in monitoring of waterway health.

C.1.1.6 Indicators

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Chlorophyll Index (derived from Chlorophyll *a* concentrations)	Chlorophyll *a*	Northern Beaches, Victoria Creek - Central Tilba, Tilba Tilba Lake and South Creek	Northern Beaches – single spring collection completed 2019/2020 Victoria Creek-Central Tilba – 7 collections completed 2019 to 2020 South Creek – 2 collections spring and autumn 2019/2020 Recommended ongoing monitoring to be at minimum bi-annual (spring and autumn)
Water Clarity Index (derived from turbidity data)	Turbidity (NTU)	Northern beaches, Victoria Creek - Central Tilba, and South Creek	Northern Beaches – single spring collection completed 2019/2020 Victoria Creek-Central Tilba – 7 collections completed 2019 to 2020 South Creek – 2 collections spring and autumn 2019 Recommended ongoing monitoring to be at minimum bi-annual (spring and autumn)

Condition Indicators (continued on next page)

Condition indicators (continued from previous page)

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Dissolved Oxygen Index (derived from DO data)	Dissolved Oxygen	Northern Beaches, Victoria Creek - Central Tilba, South Creek	Northern Beaches – single spring collection completed 2019 Victoria Creek-Central Tilba – 7 collections completed 2019 to 2020 South Creek – 2 collections spring and autumn 2019 to 2020 Recommended ongoing monitoring to be at minimum bi-annual (spring and autumn)
Faecal contamination	Bacteria concentrations (*E. coli*, Enterococci)	Victoria Creek-Central Tilba	*E. coli* (13 samples per site), Enterocci (8 samples per site), 2019 to 2020 Genomic identification of sources of enteric bacteria
Aquatic macro-invertebrate indices	(AUSRIVAS, SIGNAL-2, EPT)	South Creek, Northern Beaches and Victoria Creek - Central Tilba	South Creek 2 times annually 2019 to 2020; Victoria Creek - Central Tilba spring (once) 2019; Northern Beaches spring (once)2019 Recommended ongoing sampling frequency is bi-annual (spring and autumn).
Key fish habitat	Number and type of habitat features	Selected monitoring sites at South Creek and Northern Beaches catchments	Single event monitoring to ground truth Key Fish Habitat Map, 2019
Riparian and in-stream habitat health	Rapid Reach Assessment	Selected monitoring sties at South Creek and Northern Beaches catchments, Victoria Creek - Central Tilba	South Creek, 2019; Victoria Creek-Central Tilba, 2019, Northern Beaches, 2019 Recommended ongoing sampling frequency is bi-annual (spring and autumn).
Fish biodiversity survey	Electrofishing survey, count/species	South Creek	Sites were sampled once in 2019 Recommended repeat interval twice-yearly (to capture seasonal/breeding and/or wet dry period variation)
Surface and groundwater dependent vegetation	Surface and groundwater dependent vegetation extent (ha)	South Creek, Northern Beaches	Single event monitoring to establish baseline dataset and ground truth vegetation mapping Recommended repeat interval 5 -10 years.

Condition indicators (continued from previous page)

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Stream geomorphic condition	River Styles and additional measures	South Creek, Lake Illawarra (all metrics), and Northern Beaches (subset of metrics)	Single event monitoring to establish baseline dataset and to ground truth map accuracy (River Styles map) Recommended repeat interval bi-annual (for monitoring sites), 5 -10 years for River Styles map accuracy assessment
Riparian Vegetation Condition	Includes vegetation cover, vegetation floristics (species presence/absence, Wetland Plant Indicators, functional groups), native versus exotic cover, length of fallen timber, tree hollows, and vegetation integrity (BAM method)	South Creek, and Victoria Creek - Central Tilba (subset of metrics)	Single event monitoring to establish baseline Recommended repeat interval twice-yearly (to understand seasonal and wet/dry variations and long-term trend)
Seedbank status	Species count and seed fecundity	Victoria Creek Catchment	Single dataset collection for Seedbank study
Saltmarsh	per cent coverage each species	Tilba Tilba Lake	Quarterly sampling of changes in saltmarsh in fenced parts of lake foreshore

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
pH	pH	Northern Beaches, Victoria Creek - Central Tilba, South Creek	South Creek spring and autumn 2019; Northern Beaches spring (once) 2019; Victoria Creek-Central Tilba 15 samples per site 2019 to 2020
Temperature	Temperature	Northern Beaches, Victoria Creek - Central Tilba, South Creek	South Creek, spring and autumn 2019; Northern Beaches, spring 2019; Victoria Creek-Central Tilba 15 samples per site 2019 to 2020
Nutrient concentrations	TN, TP, NH3, TDP, TDN, NOX, FRP	Northern Beaches, Victoria Creek - Central Tilba, (selected subset)	South Creek, spring and autumn 2019; Northern Beaches, spring 2019; Victoria Creek-Central Tilba 15 samples per site 2019 to 2020
Stormwater flow	Discharge (L)	Northern Beaches, Lake Illawarra.	12 months fortnightly, plus rain events 2019; 1 collection per month
Catchment vegetation	Catchment vegetation cover (tree cover) (desktop assessment)	Lake Illawarra, South Creek, Victoria Creek - Central Tilba	Single dataset collection for each catchment to establish baseline dataset and report current condition
Catchment impervious surfaces	Desktop assessment	South Creek, Lake Illawarra Catchments	Single dataset collection for each catchment to establish baseline dataset and report current condition

C.1.1.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Pelagic chlorophyll				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020
Turbidity				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020
Dissolved oxygen				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020

NSW Estuary Water Quality Data Compilation: 2007 – 2020

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
pH, temperature, salinity, nutrients				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020

NSW Estuary Water Quality Data Compilation: 2007 – 2020

Scientific diver monitoring kelp *Ecklonia radiata*. Image: Meryl Larkin

C.1.1.8 Relevant contextual data

Vegetation mapping (South Creek, Northern Beaches); Lidar derived digital elevation models (DEMs); Satellite imagery including Sentinel 2 Satellite imagery – vegetation indices, SPOT imagery; and additional spatial datasets including SPOT Woody Vegetation mapping; Land use mapping; Seagrass mapping; Fish survey dataset from DPI Fisheries; Key Fish Habitat Map provided by DPI Fisheries; historic macro-invertebrate survey data held by DPE-EHG WWCS; River Styles Mapping provided by DPI Water.

C.1.1.9 Other relevant projects/data

- NSW MEMA Estuary Health program
- LLS MEMA program (Tilba Lake)
- DPE-EHG Biodiversity Indicators Program (monitoring biodiversity outcomes according to NSW Biodiversity Conservation Act 2016)

C.1.1.10 Data storage

Water quality datasets will be added to a dedicated database HERON (under development), accessed through the SEED portal NSW Estuary Water Quality Data Compilation: 2007– 2020. Vegetation floristic survey datasets will be added to the NSW BIONET (vegetation survey data) (in progress). Additional datasets will be made available through the SEED portal.

C.1.1.11 References

OEH (2016) *Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols*, OEH 2016/0250, NSW Office of Environment and Heritage, Sydney.

Scanes P, Coade G, Doherty M and Hill R (2007) 'Evaluation of the utility of water quality based indicators of estuarine lagoon condition in NSW, Australia', *Estuarine, Coastal and Shelf Science*, 74:306–19.

C.1.2 Richmond River Water Quality Monitoring Strategy – E7

C.1.2.1 Overview

The Richmond River Monitoring Strategy (RRMS), has been developed with consideration to NSW Government Legislative requirements, stakeholder needs, the physical and biogeochemical environment, and the principles of good monitoring practices. The RRMS is intended as a guide to the rationalisation of monitoring in the Richmond River and acts as a template for cross-jurisdictional monitoring of large tidal rivers in NSW.

The RRMS will consist of distinct subprograms (Ecosystem Health, Human Health, Drinking Water, Environmental Protection Licence) that fulfil the stakeholder monitoring requirements. Monitoring will consist of two phases: 1) an initial intensive phase with additional sites and higher frequency sampling to provide data for the MEMS Stage 1 sub-action projects and RR-ERM development; and 2) a subsequent long-term monitoring phase designed to track ecosystem health and assess the cumulative impacts of management and climate change into the future.

The aims of the RRMS are to:

- coordinate and rationalise the collection, analysis and reporting of water quality data across the Richmond River catchment to meet the needs of all stakeholders
- improve the knowledge of the linkages between pressures, stressors and ecosystem health in the Richmond River
- develop a revised Richmond River Ecosystem Response Model (RR-ERM) underpinning the Risk Based Framework
- provide a water quality database that is integrated with the RR-ERM and consistent with the various NSW government programs
- facilitate the interpretation and reporting of water quality data.
- The RRMS proposes a temporal and spatial regime of monitoring that recognises the:
- distinct functional zones within the system
- dynamic nature of the interaction between pressures and water quality stressors
- various current management needs of stakeholders
- long time frame (years to decades) of tracking ecosystem health in response to climate change and the cumulative impacts of catchment interventions.

This project is ongoing throughout MEMS Stages 1 and 2.

C.1.2.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes

C.1.2.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuary waters Seagrass Beach and mudflats Shallow soft sediments Subtidal reefs Rocky shores Planktonic assemblages FMA species BCA species Mangroves Saltmarsh and associated fish and animal assemblages	Enjoyment – enjoying the biodiversity and beauty of the marine estate Participation – safety, health and wellbeing Cultural heritage & use benefits – tangible and intangible Aboriginal cultural heritage	Agricultural diffuse source runoff Urban stormwater discharge Sewage effluent and septic runoff Foreshore development Stock grazing of riparian and marine vegetation Clearing riparian and adjacent habitat including wetland drainage Modified freshwater flows	Water pollution on environmental values - urban stormwater discharge Water pollution on environmental values - agricultural diffuse source runoff Reductions in abundances of species and trophic levels Modified hydrology/hydraulics and flow regime Water pollution on environmental values - septic runoff, point source pollution and sewage overflows (such as outfalls, STPs, etc.) Other water pollution/contamination affecting human health and safety (such as toxic algal blooms, *E. coli* concentrations, etc.)

C.1.2.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Urban stormwater discharge on environmental assets	Partial (ongoing)
Agricultural diffuse source runoff on environmental assets	Partial (ongoing)

C.1.2.5 Methods

Monitoring consists of an initial intensive phase with additional sites and higher frequency sampling providing data for the MEMS Stage 1 sub-action projects and RR-ERM development, and a subsequent long-term monitoring phase to track ecosystem health and assess cumulative impacts of management and climate change into the future.

During the MEMS model development phase, all ecosystem health sampling is boat-based allowing mid-stream sampling. A combination of automated and passive samplers is also used to collect flow-weighted samples during runoff / flood events during the Ecosystem Health phase 1 monitoring period. Sampling will revert to land-based sites during the sentinel phase, requiring the installation of remote sampling devices and multi-probe data loggers.

Chlorophyll *a* and water clarity (turbidity; as a proxy for seagrass depth potential) are recommended as condition indicators (Scanes et al. 2007; OEH 2016). They have been demonstrated to be relevant to the two main disturbances generated by diffuse-source pollution – nutrients and suspended sediments. Other water quality indicators will provide useful contextual data to assist in interpreting results for example, salinity/conductivity, temperature, pH, dissolved oxygen, coloured dissolved organic matter (tannins). Nutrient and microbial (FIB) concentrations will provide direct indication of major stressors effecting ecosystem health and human health risks respectively.

C.1.2.6 Indicators

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Chlorophyll Index (derived from Chlorophyll *a* concentrations)	Chlorophyll *a*	Upper catchment to river mouth, 51 sites Phase 1, 26 sites phase 2	Monthly in 36/18 sites (Phase1/Phase2) Weekly in 2 sites Every 15 minutes in 13/6 sites (Phase1/phase2) Event sampling in 21 sites
Water Clarity Index (derived from turbidity data)	Turbidity (NTU)	Upper catchment to river mouth, 51 sites Phase 1, 26 sites phase 2	Monthly in 36/18 sites (Phase1/Phase2) Weekly in 2 sites Every 15 minutes in 13/6 sites (Phase1/phase2) Event sampling in 21 sites
Dissolved Oxygen Index (derived from DO data)	Dissolved oxygen	Upper catchment to river mouth, 51 sites Phase 1, 26 sites phase 2	Monthly in 36/18 sites (Phase1/Phase2) Weekly in 2 sites Every 15 minutes in 13/6 sites (Phase1/phase2) Event sampling in 21 sites
Faecal contamination	Bacteria concentrations (*E. coli*, Enterococci)	Upper catchment to river mouth, 11 sites	Weekly 2 sites, monthly 9 sites

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
pH	pH	Northern Beaches, Victoria Creek - Central Tilba, South Creek	South Creek spring and autumn 2019; Northern Beaches spring (once) 2019; Victoria Creek-Central Tilba 15 samples per site 2019 to 2020
Temperature	Temperature	Northern Beaches, Victoria Creek - Central Tilba, South Creek	South Creek, spring and autumn 2019; Northern Beaches, spring 2019; Victoria Creek-Central Tilba 15 samples per site 2019 to 2020
Nutrient concentrations	TN, TP, NH3, TDP, TDN, NOX, FRP	Northern Beaches, Victoria Creek - Central Tilba, (selected subset)	South Creek, spring and autumn 2019; Northern Beaches, spring 2019; Victoria Creek-Central Tilba 15 samples per site 2019 to 2020
Water Level	Height (m)	23 sites Upper catchment to upper estuary	15 minutes

C.1.2.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Pelagic chlorophyll				X	X		NSW Estuary Water Quality Data Compilation: 2007 – 2020
Turbidity				X	X		NSW Estuary Water Quality Data Compilation: 2007 – 2020
Dissolved oxygen				X	X		NSW Estuary Water Quality Data Compilation: 2007 – 2020

NSW Estuary Water Quality Data Compilation: 2007 – 2020

Pressure/stressor indicators

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
pH, temperature, salinity, nutrients				X	X		NSW Estuary Water Quality Data Compilation: 2007 – 2020

NSW Estuary Water Quality Data Compilation: 2007 – 2020

C.1.2.8 Relevant contextual data

Population, demographics, catchment land-use, climate records and water level data.

C.1.2.9 Other relevant projects/data

- NSW MEMA Estuary Health program
- NSW Health shellfish monitoring
- Local government monitoring: Ballina Shire Council, Kyogle Council, Rous County Council
- WaterNSW catchment monitoring
- Ecohealth 2013/2014.

C.1.2.10 Data storage

Water quality datasets will be added to a dedicated database HERON (under development), accessed through the SEED portal NSW estuary water quality-data compilation-2007-2020. Additional datasets will be made available through the SEED portal.

C.1.2.11 References

OEH (2016) *Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols*, OEH 2016/0250, NSW Office of Environment and Heritage, Sydney.

Scanes P, Coade G, Doherty M and Hill R (2007) 'Evaluation of the utility of water quality based indicators of estuarine lagoon condition in NSW, Australia', *Estuarine, Coastal and Shelf Science*, 74:306–19.

C.1.3 Threats and risks from marine debris – E4

C.1.3.1 Overview

Implement a targeted marine litter campaign (MEMS 1.4.1)

A Marine litter campaign is scheduled to be delivered in 2020 to raise community awareness of the impact of litter on the marine environment and improve disposal behaviour. The campaign will align with the Statewide *Don't be a Tosser* litter campaign. The campaign will include several key tactics to raise awareness and change behaviour:

- a visual social media campaign that demonstrates how litter impacts marine life
- an immersive community engagement experiences that shows how litter affects the marine environment
- a public relations campaign, working with experts and key social influencers, to educate the community on how litter impacts both the health, and our own enjoyment of, the marine environment.

Establish a Marine (litter) debris working group (MEMS 1.4.2)

Marine Litter (Marine Debris) Working Group composed of agency representatives and academic experts to oversee the application of a marine debris specific threat and risk assessment (MDTARA) for NSW.

The working group and MDTARA will address *knowledge gaps* in the spatial distribution of, severity of and greatest threats from, marine debris on the NSW marine estate (Environmental & 5. urban stormwater discharge on environmental assets).

The MDTARA will provide *baseline data* about the highest risks posed by marine debris.

Key Littered Items Study (KLIS): monitoring marine debris in NSW coastal environments

Ongoing ambient marine debris monitoring program for urban estuaries and remote beaches (indicative of coastal waters). Years 2017 – 2021 and beyond.

It has established a baseline data of debris in NSW and is monitoring accumulation of items over time.

Monitoring is assessing the *management effectiveness* of actions that reduce the use/ provision of key littered items on reducing debris. For example:

- NSW CDS (container deposit scheme)
- VBB (Voluntary single-use plastic bag bans from large supermarkets)

The KLIS provides a fit-for-purpose, accurate KPI and LI using data directly related to marine debris within the marine estate. The study has shown that the National Litter Index – KLI (2) and LI (29) – from terrestrial environments – underestimates the densities of litter and has a varied composition of litter than has been shown in the KLIS.

Supports initiatives MEMS 1.4.1 and 1.4.2, providing information and the ability to monitor the effectiveness of actions.

The Litter Reduction projects are funded by MEMS and NSW EPA. Project partners include NSW EPA, Tangaroa Blue, Southern Cross University, Macquarie University, Australian Microplastic Assessment Project (AUSMAP), UNSW, Hunter Local Land Services, Eurobodalla Council. The projects are ongoing and included in MEMS Stage1 and Stage 2.

C.1.3.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes

C.1.3.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuary waters Seagrass Beach and mudflats Shallow soft sediments Subtidal reefs Rocky shores Planktonic assemblages FMA species BCA species Mangroves Saltmarsh	Enjoyment – enjoying the biodiversity and beauty of the marine estate Participation – safety, health and wellbeing Cultural heritage & use benefits – tangible and intangible Aboriginal cultural heritage	Agricultural diffuse source runoff Urban stormwater discharge Sewage effluent and septic runoff Foreshore development Stock grazing of riparian and marine vegetation Estuary entrance modifications and breakwaters Clearing riparian and adjacent habitat including wetland drainage Modified freshwater flows	Water pollution on environmental values - urban stormwater discharge Water pollution on environmental values - agricultural diffuse source runoff Reductions in abundances of species and trophic levels Modified hydrology/hydraulics and flow regime Water pollution on environmental values - septic runoff, point source pollution and sewage overflows (such as outfalls, STPs, etc.) Other water pollution/ contamination affecting human health and safety (such as toxic algal blooms, *E. coli* concentrations, etc.)

C.1.3.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Urban stormwater discharge on several environmental assets	Partial

C.1.3.5 Methods

The working group (1.4.2) undertake the MDTARA which combines available information on the impacts of marine debris in NSW on the economic, social and environmental benefits of the marine estate and on community wellbeing. It focuses on the relationship between specific debris items and the threat to socio-economic and environmental assets they pose. Subsequently risks and threats will be prioritised for effective management intervention.

The Key Littered Items Study, as a long-term monitoring program, enables the assessment of initiatives that are informed by the MDTARA against their objectives to reduce risk posed by marine debris in the NSW marine estate.

C.1.3.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
KLIS Key Littered Items Study	Marine debris items/sqm	Statewide, regional and local monitoring	Marine debris accumulation surveys Quarterly samples in 9 urban estuaries in 4 coastal regions (North, Mid-North, Sydney, South) Annual surveys at 9 remote beach sites in 3 coastal regions (North, Mid-North, South)
Terrestrial Litter Index for NSW (National Litter Index – completed in June 2020; to be replaced by the Australian Litter Measure in the future)	Litter items/sqm	Summarised for the state for a variety of terrestrial environments	Quarterly counts of litter in terrestrial environments

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
KLIS – Key Littered Item Study	Changes in density and proportion of debris items or types being targeted by awareness campaigns and management actions	Statewide, regional and local monitoring	Marine debris accumulation surveys Quarterly samples in 9 urban estuaries in 4 coastal regions (North, Mid-North, Sydney, South) Annual surveys at 9 remote beach sites in 3 coastal regions (North, Mid-North, South)
Marine debris threat and risk assessment – spatial mapping products	Spatial distribution of threat and co-incidence with environmental and socio-economic asset	Statewide assessment of risks posed by types of marine debris	Baseline data to be used to highlight management issues, that is reassessed as an indicator of success of implemented measures

C.1.3.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Key Littered Item Study		X			X	X	EPA dashboard of data in development Proposal to upload to SEED portal in FY21/22
National Litter Index			X			X	

SEED portal

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Reduction in debris density reducing pressures on all assets (KLIS)		X			X	X	EPA dashboard of data in development Proposal to upload to SEED portal in FY21/22
MDTARA – spatial maps of risk by asset and by debris type		X			X	X	To be reported with the MDTARA outcomes report in FY21/22

SEED portal

C.1.3.8 Relevant contextual data

The Key Littered Items Study (KLIS) provides more accurate and relevant monitoring specifically for marine litter and has continuous data from 2017. The original KPI for marine litter related sub-actions was the National Litter Index, a terrestrial count of litter in various environments. This program was disbanded in early 2020. A replacement terrestrial index, the Australian Litter Measure (AusLM), is currently in development.

C.1.3.9 Other relevant projects/data

The AUSMAP is a nationwide science initiative, surveying Australian beaches for microplastic pollution. It is citizen science based while employing a scientifically rigorous methodology to identify hotspots and distribution of microplastic. It is currently being piloted in conjunction with the KLIS.

Tangaroa Blue's Australian Marine Debris Initiative (AMDI) involves a variety of marine debris focused activities including clean ups and monitoring programs. The resulting database creates a comprehensive overview of the marine debris (types and loads) impacting beaches around Australia.

C.1.3.10 Data storage

Dedicated database under development, access through the SEED portal.

C.1.4 Monitoring the ecological health of estuaries in the NSW marine estate: Indicator development – E2

C.1.4.1 Overview

Statewide water quality monitoring of NSW estuaries is being carried out under Stage 1 of the NSW Marine Estate Management Strategy, following the Assessing Estuary Ecosystem Health: Sampling, Data Analysis and Reporting Protocols. The objective of the monitoring is to determine the ecological condition of NSW estuaries focusing on key indicators, using standardised sampling, evaluation and reporting protocols. This is an ambient monitoring program designed to detect long-term trends resulting from the cumulative impacts of multiple management actions. It will provide data to highlight the baseline condition of the NSW marine estate, as well as build capacity to apply the Risk Based Framework for considering waterway health outcomes, which aims to manage diffuse source runoff to maintain the ecological condition of a receiving waterway.

Monitoring is being carried out statewide as part of MEMS Stage 1 and is proposed to continue as part of Stage 2.

High-level description of the program is provided below and full details of NSW Estuary Health Monitoring Program can be found in Office of the Environment and Heritage (2016). This project is led by DPE-EHG with project partners: Mid-coast Council, Lake Macquarie City Council, Central Coast Council and Northern Beaches Council. The project is funded by MEMS and supported by local government funding in select locations.

C.1.4.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes

C.1.4.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuarine waters Estuarine habitats and assemblages	Enjoyment – enjoying the biodiversity and beauty of the marine estate Participation – safety, health and wellbeing Cultural heritage & use benefits – tangible and intangible Aboriginal cultural heritage	Agricultural diffuse source runoff Urban stormwater discharge Sewage effluent and septic runoff Foreshore development Stock grazing of riparian and marine vegetation Estuary entrance modifications and breakwaters Clearing riparian and adjacent habitat including wetland drainage Modified freshwater flows	Water pollution on environmental values - urban stormwater discharge Water pollution on environmental values - agricultural diffuse source runoff Reductions in abundances of species and trophic levels Modified hydrology/hydraulics and flow regime Water pollution on environmental values - septic runoff, point source pollution and sewage overflows (such as outfalls, STPs, etc.) Other water pollution/contamination affecting human health and safety (such as toxic algal blooms, E. coli concentrations, etc.)

C.1.4.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Urban and rural runoff effects on estuarine ecosystems	Partial, ongoing

C.1.4.5 Methods

This project has established methods, indicators and baseline datasets to assess and monitor waterway health at the pilot catchments. These datasets and methods support implementation of the Risk Based Framework for considering waterway health outcomes by:

- assessing and reporting on the current condition of waterway health at pilot catchments (providing context)
- providing datasets at pilot catchments to assist with implementation of additional stages of the Risk Based Framework (effects-based assessment)
- providing methods to guide assessment of waterway health for implementation of the Risk Framework at additional NSW catchments.

The measurement of chlorophyll *a* and water clarity (turbidity; as a proxy for seagrass depth potential) is recommended as condition indicators (Scanes et al. 2007; OEH 2016). They have been demonstrated to be relevant to the two main disturbances generated by diffuse-source pollution – nutrients and suspended sediments. Other water quality indicators will provide useful contextual data to assist in interpreting results for example, salinity/conductivity, temperature, pH, dissolved oxygen, coloured dissolved organic matter (tannins), nutrient concentrations, state of tide. Methods for data collection are described in OEH (2016).

The Estuary Condition and Stressor and Trend Program is a mature program with continuous data back to 2007.

The process for turning the chlorophyll *a* and turbidity data into algal abundance and water clarity indices is described in full in the OEH (2016). In summary it involves comparison of measured data to guideline values (derived for NSW estuaries) and deriving measures of the proportion of data that exceed guideline values and the magnitude of exceedances. These two measures are combined to give a score that ranges between 0 and 1. This score than then be turned into a report card type grade if desired.

In a process of continuous improvement, new indicators are constantly being assessed including the use of eDNA metabarcoding to provide a molecular biodiversity database, faecal indicator bacteria to provide a screening assessment to potentially trigger further investigation of microbial pollution where it is detected and microplastics abundance in the water column as an indicator of more chronic diffuse source pollution and to allow identification of areas requiring remedial management. Targeted trials of bushfire indicators have also been implemented in a subset of affected estuaries throughout the state following the 2019/20 bushfires. In addition to water quality indicators, sediment analysis and incubation experiments are being conducted to assess the ongoing effects of bushfires on estuarine health in fire impacted estuaries on the south coast. Along with this, more intensive targeted water quality monitoring utilising automated and event-based sampling and remote sensing in selected estuaries with differing degrees of burned catchments and differing management responses is being used to monitor estuary health, recovery and the effectiveness of onground mitigation initiatives for bushfire impacts.

TABLE C2. Report card grades, definitions and descriptions.

Grade	Result	Definition (example)	Description
A	Very good	The indicators measured meet all of the benchmark values for almost all of the time period	Equivalent to the best 20% of scores in the state
B	Good	The indicators measured meet all of the benchmark values for most of the time period	Equivalent to the next 30% of good scores
C	Fair	The indicators measured meet some of the benchmark values for some of the time period	Equivalent to the middle 30% of scores
D	Poor	The indicators measured meet few of the benchmark values for some of the time period	Equivalent to the next 15% of poorer scores
E	Very poor	The indicators measured meet none of the benchmark values for almost all of the time period	Equivalent to the worst 5% of scores in the state

C.1.4.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Algal Abundance Index (derived chlorophyll data)	Chlorophyll a	Per estuary, statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every yea
Water Clarity Index (derived from turbidity data)	Turbidity	Per estuary, statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Dissolved Oxygen Index (derived oxygen saturation data)	Dissolved Oxygen	Per estuary, statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Faecal contamination	Bacterial concentrations E. coli	Per estuary, statewide	Pilot in 2020 for 48 estuaries recommend: Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Aquatic biodiversity survey eDNA metabarcoding	Species count	Per estuary statewide	Pilot in 2020 for 31 estuaries recommend: Annual index calculated from 2 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Aquatic biodiversity survey with BRUVs.	Proportion of baits taken Time until bait removal	Per estuary statewide	Pilot in 2019 for 40 estuaries recommend: Annual index calculated from 3 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Estuarine riparian vegetation assessment	Native species count % coverage Introduced species count % coverage	Per estuary statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Estuarine avian diversity assessment	Species count	Per estuary statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Estuarine macroalgae diversity and abundance assessment	Species count % coverage	Per estuary statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Temporal pH change	pH	Per estuary, statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Temporal temperature change	Temperature	Per estuary, statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Runoff input	Nutrient concentrations (TN, TP, DIN, DIP, DON, DOP)	Per estuary, statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Catchment land-use	Desktop study, mapped extent % of catchment	Statewide	Infrequent, perhaps decadal
Entrance condition	Desktop assessment open time %	Statewide	Infrequent, perhaps decadal
Bushfire impact	Inorganic and organic total suspended sediments, pilot tests on additional measures	Bushfire impacted estuaries	Dependent on Bushfire seasons
Chronic diffuse source pollution	Microplastic abundance in water column	Per estuary statewide	Annual index calculated from 2 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year
Recent faecal contamination/ acute diffuse source pollution	E. coli and enterococci counts	Per estuary statewide	Annual index calculated from 6 samples per summer, 30-40 estuaries per year from one of 3 regions (north, central south) on rotating basis 9 sentinel estuaries every year

C.1.4.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Pelagic chlorophyll				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020
Turbidity				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020
Dissolved oxygen				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020

NSW Estuary Water Quality Data Compilation: 2007 – 2020

Pressure/stressor indicators

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
pH, temperature, salinity, nutrients				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020

NSW Estuary Water Quality Data Compilation: 2007 – 2020

C.1.4.8 Relevant contextual data

Salinity, CDOM, population

C.1.4.9 Other relevant projects/data

Council projects aligned with this sampling generate data with higher spatial and temporal intensity.

C.1.4.10 Data storage

Dedicated database under development, access through the SEED portal.

C.1.4.11 References

OEH (2016) *Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols*, OEH 2016/0250, NSW Office of Environment and Heritage, Sydney.

Scanes P, Coade G, Doherty M and Hill R (2007) 'Evaluation of the utility of water quality based indicators of estuarine lagoon condition in NSW, Australia', *Estuarine, Coastal and Shelf Science*, 74:306–19.

C.1.5 Oyster reef restoration and research – F11

C.1.5.1 Overview

In NSW, shellfish reefs have declined due to historical overharvesting, disease, sedimentation and water quality (Gillies et al. 2018). Oyster reefs provide ecosystem services including filtering, benthic-pelagic coupling, nutrient dynamics, stabilisation of sediments, and provision of habitat, and are estimated to be worth 5,500-99,000 USD per hectare per year (Grabowski et al. 2012).

Initiative 1 of the Marine Estate Management Strategy addresses water quality with a clear management action to facilitate and deliver on-ground works that reduce impacts of diffuse-source water pollution (Action 1.3). Oyster Reef Restoration (Subaction 1.3.1) provides onground works to restore oyster reefs that will improve water quality, biodiversity and fish productivity.

Restoration of oyster reefs is a new practice in NSW, and Oyster Reef monitoring and research is required to evaluate its effectiveness. Much of the emphasis of the process of restoration focuses on the addition of structural elements of habitat (e.g. rock or number of oyster spat seeded), but this project also fills the need to determine whether activities restore the ecological functioning as a productive oyster reef. The project aims to: (1) understand the role of oyster reefs as an important estuarine habitat; (2) determine the best methods for oyster reef restoration; (3) detect ecological impacts of restored oyster reefs in time and space in terms of biodiversity and ecosystem services.

C.1.5.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes

C.1.5 Oyster reef restoration and research – F11

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C.1.5.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes

C.1.5.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuarine waters Subtidal reefs	Enjoyment – enjoying the biodiversity and beauty of the marine estate	Agricultural diffuse source runoff Foreshore development Urban stormwater discharge	Environmental - water pollution on environmental values - agricultural diffuse source runoff Environmental - water pollution on environmental values - septic runoff, point source pollution and sewage overflows (such as outfalls, STPs, etc.) Environmental - water pollution on environmental values - urban stormwater discharge Environmental – water pollution on environmental values – litter, solid waste, marine debris and microplastics

C.1.5.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Best practice for oyster reef restoration Biodiversity and ecosystem services of oyster reefs	Species-specific, Ongoing

C.1.5.5 Methods

Prior to the oyster reef restoration project, an experiment was done in the estuary of Port Stephens, during the peak recruitment period (February/March 2019) for Sydney Rock Oysters, *Saccostrea glomerata*, which generally occurs after the peak recruitment of non-native Pacific Oysters. Plots of locally sourced cleaned Sydney rock oyster shell (cultch) or locally quarried rock was placed on the surface of the sediment at a similar tidal height to where remnant reefs occur. After 12 months, the newly recruited oysters were identified and counted. This experiment was small scale but provided valuable data that the sites were suitable for oyster restoration, and the importance of rock and shell for establishment of oyster reefs.

In Port Stephens (on-ground works commencing in November 2019), two types of oyster restoration were tested: (1) augmentation of historic rock leases in the western basin, and (2) creation of new reefs on sandy substrata in the eastern basin. The general monitoring plan included replicated sampling in the eastern and western basins. Within each of these sections Port Stephens, the restoration sites (at the mouth of the Karuah River near Correebah Island and near Pindimar at the mouth of the Myall River) were sampled.

Augmentation of historic rock leases in the western basin was considered as a separate experiment from the creation of new reefs in the eastern basin. In the western basin, the experimental design consisted of historic rock leases that were in-filled with rock and clean oyster shell and compared with two control sites which were historic rock leases but not augmented with additional rock and shell. The eastern restoration site was compared with two reference sites (established natural oyster reefs), and two control sites (sandy/muddy substrata that experiences similar conditions to the sites for restoration).

The extent of the initial oyster reefs and post on-ground works was determined with aerial photography (Nearmap and drones). The sites are intertidal and the existing reef heights were also determined relative to known heights of Australian Height Datum (AHD).

Physico-chemical variables (temperature, pH, salinity, dissolved oxygen, and) were recorded for each site. Loggers are recording temperature and salinity at all study sites in Port Stephens.

Spat recruitment, growth of individual oysters and change in oyster reefs were measured throughout the monitoring project, once a season. At each time of sampling, n = 50 randomly chosen oysters were measured. In addition to measuring the oysters, the presence of Pacific Oysters *Crassostrea gigas* as in invasive species were recorded.

Assemblages of fishes were sampled each season, at all sites. Sampling was done with underwater videos (mini-BRUVs) during high tides. Water samples for environmental DNA (eDNA) analysis were also collected from all sites in the eastern basin.

Assemblages of infauna (e.g. worms, small crustaceans) and epifauna (e.g. snails and barnacles) were sampled once a season at the same restoration, reference and control sites during low tide. *In situ*, gastropods and epifauna at the restoration sites, and infauna were sampled from soft sediments or oysters using 10 cm diameter cores. Infauna (>500 µm) were processed in the laboratory with the aid of a dissecting microscope. Problem species, for example, mudworm, *Polydora* spp. and cornflake worms, Platyhelminthes, were also recorded.

In addition to monitoring oysters and associated biodiversity pre- and post on-ground works, the ecological functioning (measured by filtration) of oyster reefs was evaluated in the eastern basin. Filtration by established oyster reefs was compared with newly recruited oysters on rock at the restoration site.

A similar approach as for the Myall has been used for Wagonga Inlet (completed Sydney Rock Oyster reefs June 2022 and Angasi Oyster Reefs April 2023) and Botany Bay (expected June 2023), but monitoring will occur twice a year (not once a season). All estuaries will be sampled to for at least one year prior to on-ground work.

C.1.5.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Invertebrate assemblages (including species identified to be a problem to oyster aquaculture)	Species and number of individuals	Basin, site, core	Twice a season
Fish assemblages (including species identified as important for recreational and commercial fisheries)	Species and number of individuals	Basin, site, core	BRUVs twice a season eDNA three times before and after restoration
Oysters	Number, size and weight of Sydney Rock Oysters Number and size of oyster spat	Basin, site, core	Once a season
Oyster reef functioning	Water filtration	Site	Before and after restoration
Water quality	Physico-chemical variables (temperature, pH, salinity, dissolved oxygen and turbidity) Temperature and salinity loggers	Basin, site	Twice a season Every 30 minutes

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Oyster reef extent	Aerial extent of oyster reefs	Basin, site	Before and after onground works
Invasive oysters	Aerial extent of oyster reefs	Basin, site, core	Once a season
Problem species (identified to be a problem to oyster aquaculture)	Species and number of individuals	Basin, site, core	Once a season

C.1.5.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Oyster reef presence and				X		X	Gillies et al. 2018, Nearmap
Water quality				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020

NSW Estuary Water Quality Data Compilation: 2007 – 2020

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Oyster reef extent				X		X	Gillies et al. 2018
Invasive species				X		X	Pacific Oyster Survey 2010
Water quality				X		X	NSW Estuary Water Quality Data Compilation: 2007 – 2020

NSW Estuary Water Quality Data Compilation: 2007 – 2020

C.1.5.8 Relevant contextual data

Simultaneous with monitoring, oyster reef restoration managers conducted surveys of the views and knowledge of key stakeholders, oyster farmers and recreational fishers. Managers are also mapping oyster reefs in NSW estuaries and documenting the location of oyster reefs identified by stakeholders online. A historian has also been contracted to provide historic accounts of oyster reefs in NSW. Prioritisation of estuaries and sites in estuaries for future oyster reef restoration is currently being developed. Oyster reef restoration will also engage stakeholder groups to assist in the collection of data to determine locations for future oyster reef restoration.

C.1.5.9 Other relevant projects/data

- Use of environmental DNA to detect changes in fish assemblages associated with oyster reef restoration – research collaboration, University of Newcastle
- Developing a technique for oyster reef restoration – ARC Linkage (administered by UNSW)
- Building with Nature: Using Potato Waste to Restore NSW oyster reefs – Environmental Trust Grant, (administered by Macquarie University)
- Determining the suitability of the leaf oyster, *Isognomon ephippium* for shellfish restoration – PhD and Honours students, Southern Cross University

C.1.5.10 Data storage

Raw data are stored on the PSFI Internal Drive, key milestones are stored in the PVF for the project in CM9.

C.1.5.11 References

Gillies CL, McLeod IM, Alleway HK, Cook P, Crawford C, Creighton C, Diggles B, Ford J, Hamer P, Heller-Wagner G and Lebrault E (2018) 'Australian shellfish ecosystems: Past distribution, current status and future direction', *PLoS One*, 13:e0190914.

Grabowski JH, Brumbaugh RD, Conrad RF, Keeler AG, Opaluch JJ, Peterson CH, Piehler MF, Powers SP and Smyth AR (2012) 'Economic valuation of ecosystem services provided by oyster reefs', *BioScience*, 62:900-909.

Appendix C.2 Delivering healthy coastal habitats with sustainable use and development (Initiative 2)

Initiative objective: To protect coastal and marine habitats and associated species and enhance the health of the marine estate by improving the design, quality and ongoing management of foreshore development, use and waterway infrastructure.

This initiative addresses threats to habitats (and related species) associated with use of the marine estate and adjacent catchments. The threats identified in the statewide TARA that are the primary focus of Stages 1 & 2 of the MEMS include foreshore development, modified freshwater flows (in estuaries), clearing riparian and adjacent including wetland drainage, estuary entrance modifications, navigation and entrance management, beach nourishment and grooming, and four-wheel driving (4WD) impacts.

Environmental monitoring is required to address MEMS Action 2.5. the purpose of which is to 'Undertake research and monitoring to address key knowledge gaps, such as techniques to minimise the impact of trained estuary entrances and methods for determining marine vegetation resilience, and assess the effectiveness of the management actions within this initiative.' There are, however, many other actions in this initiative, and other initiatives, that require environmental monitoring or research to either test the effectiveness of management actions or inform the development of environmental policies. Environmental monitoring supporting Initiative 2 focuses primarily on filling knowledge gaps and monitoring the condition of, and threats to, estuarine macrophytes. Some smaller-scale projects related to impacts of artificial structures on fish assemblages are also in development. Core MIMP projects related to monitoring estuarine habitats and pressures are listed in Tables 4 and 5 (with full project descriptions below), and other relevant MEMS research projects are listed in Table 6.

TABLE C3. Projects contributing monitoring information to Initiative 2 management actions.

Project	MEMS Action(s)	Supports MEMS Action(s)
Monitoring and assessment of estuarine habitats and disturbances (now Initiative 3 "Estuarine habitat monitoring and threat assessment")	2.5	1.3 2.3 3.1 5.7 6.4 7.1

TABLE C4. Other projects supporting Initiative 2 management actions.

Supporting projects	Primary initiative
Climate change threats to mangrove and saltmarsh	3

C.2.1 Monitoring and assessment of estuarine habitats and disturbances – F1

NOTE: This project was recently moved to Initiative 3 and is now entitled Estuarine habitat monitoring and threat assessment.

C.2.1.1 Overview

This research program uses a combination of aerial imagery (drone, aircraft and satellite) and field surveys to map estuarine macrophytes and quantify pressures on these habitats, thereby enabling changes in the extent of habitats and pressures to be identified over time at a range of spatial scales. It will also fill knowledge gaps relating to the extent of impacts from 4WDs on saltmarshes, relationships between agricultural runoff and changes in the abundance of macrophytes, impacts of cattle grazing on saltmarshes and, in the longer term, effects of climate change on estuarine macrophyte distribution.

The primary outputs relevant to the management of estuarine habitats will be updated spatial layers of estuarine habitats and assessments of where these habitats are at threat or have been lost. The effectiveness of some local-scale management initiatives could also be assessed in terms of habitat response.

The project has three main elements:

- map and assess changes in macrophyte areas (estuary-scale)
- map in-water structures that might impact seagrass and document impacts to intertidal macrophytes (estuary-scale)
- develop new techniques for discriminating mangrove and saltmarsh species and assessing their condition (subestuary-scale).
- This project is led by DPI Fisheries and funded from the MEMS and DPI core funds. Work is ongoing from the MEMS Stage 1 to Stage 2.

C.2.1.2 Project type/objectives

- monitoring change in habitat extent
- developing methods for assessing habitat condition
- mapping pressures to habitats
- delivering maps showing changes in habitats within estuaries
- contributes to monitoring progress towards MEMS outcomes.

Wallis Lake. Image: R. Laird

C.2.1.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuarine habitats and assemblages – seagrass, mangrove, saltmarsh Threatened and protected species – Posidonia	Enjoyment benefits Cultural heritage & use benefits Intrinsic & bequest Viability of businesses Direct economic values	Foreshore development Four-wheel driving Stock grazing of riparian and marine vegetation Estuary entrance modifications + breakwaters Agricultural diffuse source runoff Altered storm/cyclone activity Climate and sea temperature rise Sea level rise Flooding, storm surge, inundation from extreme events Clearing riparian and adjacent habitat including wetland drainage Oyster aquaculture Pipelines, cables, trenching and boring Sewage effluent and septic runoff Thermal discharges Urban stormwater discharge Boating and boating infrastructure	Water pollution on environmental values - urban stormwater discharge Water pollution on environmental values - agricultural diffuse source runoff Climate change stressors 20 years Habitat (physical) disturbance

C.2.1.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Many climate change stressors for both 20- and 50-year projections Point discharges and sewage effluent on several environmental assets	Partial

C.2.1.5 Methods

Aerial imagery (drone, aircraft and satellite) is used to map estuarine macrophytes and pressures on these habitats at a range of spatial scales.

Methods for the three main elements of the research program are outlined below.

(1) Macrophyte mapping at the estuary-scale

The specific variables that will be calculated and compared over time and among estuary types include: species composition of seagrasses, areal extent of different macrophyte habitats, variability (coefficient of variation) and habitat fragmentation (patch density, landscape division, area-weighted mean perimeter to area ratio).

The main focus for future seagrass mapping will be the 17 estuaries containing endangered communities of *Posidonia australis* where we will test whether *Posidonia* is declining over time in areas subjected to human impacts. In addition, seagrasses will be mapped in numerous intermittent estuaries, beginning on the south coast where management initiatives will aim to improve water quality and rehabilitate saltmarshes. We will seek to better understand natural temporal variability in *Zostera*-dominated meadows to help discriminate natural from human-induced change in *Zostera* and to characterise the variability of seagrasses in different estuary types. Changes in mapped areas of seagrasses will be assessed relative to depth, estuary type, position in the estuary and proximity to artificial structures and other known disturbances (e.g. stormwater drains).

Mangroves and saltmarshes will also be mapped to test the hypothesis that mangroves are displacing saltmarshes in the most heavily disturbed estuaries. Changes in areas of mangrove and saltmarsh will be correlated with human disturbances and the most recent distribution maps will be used to predict where future impacts due sea level rise are likely to have the greatest impacts on these intertidal habitats.

New maps of macrophytes will be generated using 1 m resolution aerial imagery and Object Based Image Analysis (OBIA) techniques available in using Trimble eCognition software. Rule sets developed within eCognition will incorporate the latest available imagery, previous mapping and detailed field data to enhance mapping speed and accuracy. Habitats will be categorised according to the dominant species (when accounting for ≥70% cover) and mixed habitat categories will be used when species account for ≥ 30% cover. The minimum mapping unit (MMU; smallest identifiable feature) will be 2 x 2 m, but habitat categorisation will be done at a scale of approximately 10 x 10 m. Field data will be collected to inform habitat categorisation. Seagrasses will be sampled using a bathyscope or underwater video to classify mixed habitats at the scale of 10 x 10 m while data on saltmarsh and mangrove habitats will be derived from drone footage of selected 30 x 30 m areas.

The field sampling unit is greater than the size of the MMU, to account for positional inaccuracies when in the field and to account for mixed habitat categories which are mapped at the scale of 20 x 20 m. The accuracy of maps will be assessed in selected areas using a stratified random sampling protocol that will enable the calculation of classification error per habitat category (visual inspections of at least 50 areas per habitat class).

Seagrass *Posidonia australis*. Image: J. Gilligan

(2) Foreshore structure and disturbance mapping

Artificial structures including, jetties, pontoons, slipways, boat ramps and marinas will be mapped using Deep Learning Convolutional Neural networks to automatically extract these features using standard RGB, classified Lidar as well as multispectral data if available. Field validation of foreshore structures will involve visual inspections of at least 50 structures per habitat class. The final classified polygon layer will be exported and incorporated into ArcMAP where the classified polygon attributes will be used to assign the foreshore structure classification to the topographic coastline using spatial intersection tools.

Other pressures to estuarine macrophytes will also be mapped, including 4WD damage to saltmarshes, bushfire damage to mangroves and saltmarshes, boat mooring scars in seagrasses.

(3) Mangrove and saltmarsh species discrimination and condition assessments

Current mapping of mangroves and saltmarshes does not discriminate among species, nor does it include any measure of habitat condition, so this project will investigate methods to address these limitations. Techniques will be developed to estimate the condition of mangroves at small spatial scales using indices such as NDVI (normalised difference vegetation index), LAI (Leaf Area Index) and NDRE (normalised difference red edge). Multispectral imagery will be used at small (drone) and large (WorldView 3 satellite) spatial scales to develop methods for discriminating among saltmarsh and mangrove species, respectively, using Random Forest and Support Vector Machine models, together with elevation data and spectral reflectance values.

There are five large mangrove species in NSW, although one (*Avicennia marina*) dominates in all NSW estuaries. Three species (*Bruguiera gymnorhiza, Rhizophora stylosa*, and *Excoecaria agallocha*) are primarily tropical and occur in some estuaries in northern NSW. As such, it could be predicted that the distribution of these species will shift south with climate change and their abundances within their current ranges will also increase. We will trial multispectral WorldView 3 satellite imagery (cloud-free) for discriminating these species to test for future changes in species distributions. Cloud-free WorldView 3 will be obtained for selected areas where these species are known to occur. Data on known occurrences will be gathered from local experts, publications and databases such as NSW BioNet and Atlas of Living Australia. Species occurrences will be validated and augmented with field inspections as per protocols above.

Similar methods will be trialled to discriminate saltmarsh species, but at much smaller spatial scales, using high-resolution multispectral UAV imagery captured using in-house UAV technologies and a Micasence RedEdge MX multispectral camera.

Species discrimination and condition assessments will utilise a combination of elevation data and spectral reflectance values including short wave infrared bands and vegetative indices, including NDVI, NDRE and LAI. These indices utilise known characteristics of vegetation, for example, healthy leaves reflect more near infrared wavelengths than do stressed leaves. Sites in Port Stephens will be used to test the suitability of multispectral imagery for assessing changes in mangrove condition from before to after a hail storm. Field studies will use standardised methods to sample LAI (using a handheld metre with hemispherical lens) and NDVI in mangroves at the scale of 10 x 10 m (subsampled using multiple replicates). Regressions between field canopy cover and remotely-sensed estimates at the same spatial scale will be used to calibrate the latter.

Rule sets will be developed in eCognition to differentiate species or suites of species using techniques such as the Random Forest classifier and band thresholding. At finer spatial scales (e.g. drone images), contextual (structure and texture) and elevation data will be used to discriminate species. Drone imagery will be processed through Metashape Pro to produce high-resolution orthomosaics, as well as a point cloud, Digital Elevation Model and Digital Surface Models, which will be imported into eCognition.

(Top) **Commercial fishing vessels.**
Image: NSW DPI, State of New South Wales
(Bottom) **Mangroves**. Image: R. Laird

C.2.1.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Changes in habitat extent	Gains or losses (m2)	Statewide	5-10 yrs
Changes in species composition	Number of species	Saltmarsh: Port Stephens & Tilba Lake, Mangroves: northern NSW	5-10 yrs
Fragmentation of habitat	Number of habitat patches; perimeter: area ratio	Statewide	5-10 yrs
Condition of mangrove canopy	Remote sensing measures: NDVI, NDRE and LAI	Local: Port Stephens trial	5-10 yrs
Variability over time	Temporal variance	Statewide	5-10 yrs

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Artificial structures	Number of jetties / pontoons over seagrass	Selected estuaries for trials, then statewide	5-10 yrs
Aquaculture leases	m2 oyster leases over seagrass	Statewide	5-10 yrs
Boat moorings	Number of boat moorings among seagrass	Statewide	5-10 yrs
4WD damage	Area of 4WD damage In saltmarsh or mangrove	Selected estuaries for trials, then statewide	5-10 yrs

C.2.1.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Seagrasses				X		X	DPI Spatial Data Portal; West and Glasby 2022
Mangroves				X		X	DPI Spatial Data Portal; West and Glasby 2022
Saltmarshes				X		X	DPI Spatial Data Portal; West and Glasby 2022

DPI Spatial Data Portal

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Boat moorings			X			X	RMS
Artificial structures	X	X			X		DPI mapping
Stormwater outlets		X			X		Councils
4WD damage	X				X		DPI mapping
Oyster leases				X		X	DPI Spatial Data Portal
Bushfire damage	X						DPI mapping

DPI Spatial Data Portal

C.2.1.8 Relevant contextual data and projects

DPE-EHG bathymetry data; Transport NSW boat mooring GIS data; Crown Lands foreshore structures GIS layers; NSW Land-use layers; Spatial Services Topographic dataset; DPE-EHG saltmarsh quadrat data (Tilba Lake); Lidar derived DEMs; Sentinel 2 Satellite imagery – vegetation indices.

C.2.1.9 Other relevant projects/data

- Environmental Trust project & PhD project with UNSW and DPI investigating methods for restoration of *Posidonia australis*, relationships between seagrass density and community biodiversity, effects of shading from oyster aquaculture on *Posidonia australis*
- ARC Linkage in development with UNSW, UWA & DPI to assess influences of sediment microbes on seagrass growth and condition, effects of nutrient pollution on microbes and seagrasses and how seagrass restoration could be enhanced by manipulating sediments and microbes
- smaller-scale saltmarsh and mangrove rehabilitation studies
- some macrophyte mapping commissioned by local councils, provided methodology is similar.

C.2.1.10 Data storage

All data saved on DPI Fisheries corporate databases, primarily GIS 101. Maps delivered to public via DPI Spatial Data Portal.

C.2.1.11 References

West GJ and Glasby TM (2022) 'Interpreting long-term patterns of seagrasses abundance: How seagrass variability is dependent on genus and estuary type', *Estuaries and Coast*, 45:1393–1408.

C.2.2 Reviewing jetty designs– F13

NOTE: This project was previously entitled Assessing optimal jetty design to minimise seagrass disturbance.

C.2.2.1 Overview

Recreational boating and boating infrastructure (in estuaries) were rated as high risks to seagrasses in NSW estuaries (BMT WBM 2017). Importantly, this rating was based on information was considered 'limited' (BMT WBM 2015). Hence, there is a need to better understand and assess this threat and evaluate possible management actions to reduce the risks associated with this activity.

To provide guidance and specific detail on the various high/medium priority threats and knowledge gaps, MEMA managers wanted to determine whether there were any specific design features or environmental conditions that increased or decreased the risks of jetties damaging seagrass.

The proposed research will attempt to quantify the main design features of jetties that may or may not contribute to the loss of seagrass (e.g. *Posidonia australis, Zostera* spp., *Halophila ovalis*) directly underneath the infrastructure. This will involve measuring a range of potential predictor variables (jetty height, width, orientation, adjacent seagrass species, water depth) and recording the presence or absence of seagrass underneath jetties surrounding areas. Generalised linear mixed models will then be used to determine the key predictors (and parameters) which influence the elimination of seagrass underneath jetties. The results from this study should provide guidelines for each estuary where it is assessed and, if found to be generalisable, across the estuaries of the NSW coastline. The effects of the presence of pontoons and large vessels associated with jetties could also be assessed. Initially, Port Hacking will be used to trial the effectiveness of this modelling approach to support coastal systems management and then assessments across NSW estuaries will be assessed.

This project is led by DPI Fisheries and funded from the MEMS and DPI core funds. Work is ongoing from the MEMS Stage 1 to Stage 2.

C.2.2.2 Project type/objectives

- produce evidenced-based guidelines for environmentally sensitive design
- assess boat infrastructure impacts
- developing methods for assessing habitat condition
- mapping damage to habitats
- contributes to monitoring progress towards MEMS outcomes

C.2.2.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuarine habitats and assemblages – seagrass Threatened and protected species – Posidonia	Enjoyment benefits Cultural heritage & use benefits Intrinsic & bequest Viability of businesses Direct economic values	Foreshore development Boating and boating infrastructure	Habitat (physical) disturbance

C.2.2.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
No knowledge gap from Section 5.2 list addressed	N/A

C.2.2.5 Methods

This research will quantify the main design features of a jetty that may or may not contribute to the loss of seagrass (e.g. *Posidonia australis, Zostera* spp., *Halophila ovalis*) directly underneath jetties, pontoons and moored vessels. This involves measuring a range of potential predictor variables (jetty height, width, orientation, adjacent seagrass species, water depth) and recording the presence or absence of seagrass underneath jetties and also in the surrounding area. Generalised linear mixed models will then be used to determine the key predictors (and parameters) which influence the presence or absence of seagrass underneath jetties. The results from this study should provide guidelines for each estuary where it is assessed and, if found to be generalisable, across the estuaries of the Hawksbury Shelf Marine Bioregion. Initially, Port Hacking will be used to trial the effectiveness of this modelling approach to support coastal systems management. The effects of the presence of pontoons and large vessels associated with jetties will also be assessed.

C.2.2.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Changes in habitat extent	Gains or losses (m2)	Selected estuaries for trials, then statewide	5-10 yrs
Changes in species composition	Species identity	Selected estuaries for trials, then statewide	5-10 yrs
Fragmentation of habitat	Number of habitat patches; perimeter: area ratio; change through time	Selected estuaries for trials, then statewide	5-10 yrs
Condition of seagrass	Biomass; physical structure; shoot density	Selected estuaries for trials, then statewide	1-10 yrs

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Artificial structures	Number of jetties / pontoons / boats over seagrass	Selected estuaries for trials, then statewide	1-10 yrs

C.2.2.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Seagrasses	X			X		X	West et al. 1985; DPI Spatial Data Portal; West and Glasby 2022

DPI Spatial Data Portal

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Artificial structures	X				X		DPI mapping

C.2.2.8 Relevant contextual data and projects

Crown Lands foreshore structures GIS layers; NSW Land-use layers; Spatial Services Topographic dataset.

C.2.2.9 Other relevant projects/data

DPI Monitoring and assessment of estuarine habitats and disturbances (now entitled Estuarine habitat monitoring and threat assessment under the initiative 3)

C.2.2.10 Data storage

All data saved on DPI Fisheries corporate databases.

C.2.2.11 References

BMT WBM (2015) *Threat and Risk Assessment for the Hawkesbury Shelf Marine Bioregion*, Marine Estate Management Authority, 62 pp.

BMT WBM (2017) *New South Wales Marine Estate Threat and Risk Assessment Report*, Marine Estate Management Authority, 251 pp.

West GJ and Glasby TM (2022) 'Interpreting long-term patterns of seagrasses abundance: How seagrass variability is dependent on genus and estuary type', *Estuaries and Coasts*, 45:1393–1408.

C.2.3 Threats to estuarine fish assemblages – F12

Note: this project was formerly named "Seascape assessment of cumulative estuarine threats on fish assemblages"

C.2.3.1 Overview

Recreational boating, boating infrastructure and urban stormwater (in estuaries) were rated as high risks to seagrasses and their biodiversity in NSW estuaries (BMT WBM 2017). Importantly, this rating was based on information was considered limited (BMT WBM 2015). Hence, there is a need to better understand and assess this threat and evaluate possible management actions to reduce the risks associated with this activity.

To provide guidance and specific detail on the various high/medium priority threats and knowledge gaps, MEMA managers wanted to better estimates of this risk of recreational boating, boating infrastructure and urban stormwater to estuarine fish assemblages.

The proposed research will attempt to quantify the effect of multiple stressors and cumulative impacts to estuarine fish assemblages. Specifically, the research will use a 'seascape' approach to measure the effects of multiple threats associated with recreational boating, boating infrastructure and water pollution simultaneously. Key threats that will be examined include the number of moorings, jetties and proximity to stormwater drains. Results from this study should provide guidelines for the effects of these threats on estuarine fishes for each estuary examined.

If results are found to be consistent across estuaries, research findings and management implications should be generalisable to other estuaries along the NSW coastline. Initially, Pittwater will be used to trial the effectiveness of this seascape modelling approach to support coastal systems management and then assessments across NSW estuaries will be undertaken.

This project is led by DPI Fisheries and funded from the MEMS and DPI core funds. Work is ongoing from the MEMS Stage 1 to Stage 2.

C.2.3.2 Project type/objectives

- produce evidenced-based guidelines/ recommendations on the effects of multiple stressors to estuarine fish assemblages
- quantify boating infrastructure influence on fish assemblages
- quantify stormwater influence on fish assemblages
- contributes to monitoring progress towards MEMS outcomes.

C.2.3.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Habitats and assemblages – seagrass, shallow and soft sediments, estuarine waters, rocky shores, subtidal reefs, fish assemblages	Enjoyment benefits Cultural heritage & use benefits Intrinsic & bequest Viability of businesses Direct economic values	Boating and boating infrastructure Foreshore / urban development Water pollution and sediment contamination	Habitat (physical) disturbance

C.2.3.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Urban stormwater discharge on several environmental assets	Partial

C.2.3.5 Methods

A spatially balanced survey design will be created that will representatively survey estuarine sites that vary in density of surrounding jetties, moorings and proximity to pollution sources and natural habitats (e.g. seagrass). Approximately 150 survey sites will be identified and surveyed using baited remote underwater video cameras and/or underwater visual census. These monitoring data will provide information on the abundance, diversity and size of estuarine fishes. Using spatial statistics, models will be built to assess the cumulative effect of threats to estuarine fish assemblages. Model outputs should inform Coastal Managers on the effects of multiple stressors to estuarine fish assemblages. A series of species distribution maps will be produced to visualise changes in the fish assemblage within estuaries in relation the most important threats. Initially, Pittwater will be used as a trial location before extending the study along estuaries of the NSW coast.

C.2.3.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Changes in species composition	Number of species	Selected estuaries for trials, then statewide	1-2 yrs
Changes in the size of species	Number of length of individuals	Selected estuaries for trials, then statewide	1-2 yrs

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Artificial structures	Number of jetties / pontoons in seascape	Selected estuaries for trials, then statewide	1-2 yrs
Stormwater drains	Distance to stormwater drains	Selected estuaries for trials, then statewide	1-2 yrs
Boat moorings	Number of boat moorings in seascape	Selected estuaries for trials, then statewide	1-2 yrs

C.2.3.7 Baseline data

Condition data

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Changes in species composition	Number of species	Selected estuaries for trials, then statewide	1-2 yrs
Changes in the size of species	Number of length of individuals	Selected estuaries for trials, then statewide	1-2 yrs

Pressure/stressor data

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Artificial structures	Number of jetties / pontoons in seascape	Selected estuaries for trials, then statewide	1-2 yrs
Stormwater drains	Distance to stormwater drains	Selected estuaries for trials, then statewide	1-2 yrs
Boat moorings	Number of boat moorings in seascape	Selected estuaries for trials, then statewide	1-2 yrs

C.2.3.8 Relevant contextual data and projects

NSW Fisheries macrophyte maps; DPE-EHG bathymetry data; Transport NSW boat mooring GIS data; Crown Lands foreshore structures GIS layers; NSW Land-use layers; Spatial Services Topographic dataset; Lidar derived DEMs; Sentinel 2 Satellite imagery – vegetation indices.

C.2.3.9 Other relevant projects/data

DPI Monitoring and assessment of estuarine habitats and disturbances (now entitled Estuarine habitat monitoring and threat assessment under the initiative 3)

DPI Assessing optimal jetty design to minimise seagrass disturbance.

C.2.3.10 Data storage

All data will be saved on DPI Fisheries corporate databases and GlobalArchive.

C.2.3.11 References

BMT WBM (2015) *Threat and Risk Assessment for the Hawkesbury Shelf Marine Bioregion*, Marine Estate Management Authority, 62 pp.

BMT WBM (2017) *New South Wales Marine Estate Threat and Risk Assessment Report*, Marine Estate Management Authority, 251 pp.

West GJ and Glasby TM (2022) 'Interpreting long-term patterns of seagrasses abundance: How seagrass variability is dependent on genus and estuary type', *Estuaries and Coasts*, 45:1393–1408.

(Below) ***Sarcocornia quinqueflora* (saltmarsh).** Image: R. Laird;
(Bottom left) **Black Cod *Epinephelus daemelii*,**
(Right) ***Posidonia australis*** and ***Hippocampus whitei.***
Images: D. Harasti

Appendix C.3 Planning for climate change (Initiative 3)

Initiative objective: Understand, adapt and increase resilience, to help mitigate the impacts of climate change on the NSW marine estate.

The impacts of climate change across a 20-year time frame have been identified as a priority threat in the statewide TARA. These impacts are expected to increase as we move towards a 50-year timeframe. Climate change will affect the environmental assets and community benefits derived from the NSW marine estate. Within the next 20 years it is expected that climate change will affect key components of the marine estate by altering or disrupting ecological processes. Climate change will likely affect ocean temperatures, the supply of nutrients, ocean chemistry, food chains, wind systems, ocean currents and extreme events such as east-coast lows. These variables have the potential to affect the distribution, abundance, breeding cycles and migrations of marine plants and animals that people rely on for food, income and enjoyment. By better understanding the impacts of climate change on the marine environment, coastal communities and lifestyles, communities can prepare and adapt for the future. More information and research are needed to understand the severity and extent of future impacts on our marine estate.

The specific MEMS management actions that relate to environmental monitoring indicators are:

- 3.1 Enhance mapping of estuarine communities (such as saltmarsh and mangroves) to identify those communities most at threat from sea level rise under expected climate change scenarios and use this information to model areas of land suitable for retreat and those that should be prioritised for protection. Apply this information in decision making.
- 3.5 Research and monitor the effects of climate change on the marine estate to fill knowledge gaps and inform future management actions, focusing on marine biodiversity and coastal communities. This action will be integrated into the Monitoring Program.

Environmental monitoring supporting Initiative 3 focuses on filling knowledge gaps and monitoring climate change and the impacts on environmental assets in the NSW marine estate. Environmental asset monitoring includes intertidal wetlands, benthic habitats and species and species range extensions. Projects are outlined in Table C5 Projects that also support Initiative 2 but primarily contribute monitoring information to other MEMS initiatives are presented in Table C6.

TABLE C5. Projects contributing monitoring information to Initiative 3 management actions.

Project	MEMS action(s)	Supports MEMS action(s)
Climate change threats to mangrove and saltmarsh (formerly Assessment of vulnerability of intertidal wetlands to sea level rise)	3.1	2.3 2.5
Climate change research (to fill knowledge gaps pertaining to climate change)	3.5 (3.5.1)	
Climate change monitoring	3.5 (3.5.2)	
Climate change citizen science (to monitor species range extensions)	3.5 (3.5.3)	
Restoration solutions for marine forests undergoing climatic change	3.5 (3.5.2)	

TABLE C6. Other projects supporting Initiative 3 management actions.

Supporting projects	Primary initiative
Statewide BRUVs	6
Estuarine habitat monitoring and threat assessment (formerly Monitoring and assessment of estuarine habitats and disturbances)	2 (now in initiative 3)
Evaluating perturbations to NSW corals between 2002 and 2020	3.5

C.3.1 Climate change threats to mangrove and saltmarsh – F4

NOTE: This project was previously entitled Vulnerability and adaptation pathways of intertidal wetlands under sea level rise

C.3.1.1 Overview

As sea levels rise, mangroves and saltmarshes will be lost unless they are able to increase elevation *in situ* or migrate further up the shore. The effects of sea level rise on the loss or migration of estuarine habitats will vary among different types of estuaries and within estuaries according to a range of factors. The first stage of this project will combine existing spatial datasets reflecting these factors into a GIS-model, which will be used to provide a first-pass vulnerability assessment of tidal wetlands to sea level rise across NSW. This underpins the second stage which will (i) expand the vulnerability assessment to include catchment hydrology factors, and ii) develop evaluation and decision support tools to plan for and prioritise adaptation pathways at the intra-estuary scale. This vulnerability assessment and new management tools, together with ongoing monitoring, can reduce the risk of tidal wetland losses across the marine estate.

The project is jointly led by DPI-F and DPE-EHG and funded by MEMS.

C.3.1.2 Project type/objectives

- develop a method for identifying the estuaries with the greatest areas of wetlands at threat from sea level rise (Stage 1)
- develop a method for prioritising estuaries for future protection of intertidal wetlands based on consideration of SLR and changing catchment hydrology under climate change (Stage 1/2)
- identify where monitoring of wetlands should be targeted to test for SLR and climate change impacts (Stage 1/2)
- identify and evaluate potential adaptation pathways for mangroves and saltmarsh in a variety of landscape contexts (Stage 2)
- inform marine vegetation strategies and wetland rehabilitation (Stage 2)
- contributes to monitoring progress against MEMS outcomes (Stage 1/2).

C.3.1.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuarine habitats and assemblages Threatened and protected species – saltmarsh	Enjoyment benefits Cultural heritage & use benefits Intrinsic & bequest Direct economic values	Sea level rise	Climate change stressors 20 years Habitat (physical) disturbance

C.3.1.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Many climate change stressors for both 20- and 50-year projections	Partial

C.3.1.5 Methods

Machine learning techniques will be used to develop a spatial model that accurately represents the current extent of intertidal wetlands (mangroves and saltmarshes) in a subset of NSW estuaries. A subset of the exiting wetland maps will be used to train the model, with the remaining data used to test the model. The model will be based on a range of biophysical predictors including elevation, topography, quaternary geology, inundation, distance to the mouth of the estuary. Inundation models have been developed by DPE-EHG using tidal plane data which have resulted in more spatially accurate models of tidal inundation patterns along estuarine gradients.

Once suitably accurate models have been developed, they will be run under three sea level rise scenarios (+0.5, +1.0, +1.5 m) to predict where wetlands may be able to migrate. Inundation models will be displayed visually in a geodatabase so that they can be combined with macrophyte maps and land use maps. ArcGIS will be used to overlay these spatial layers and identify estuaries that will be most vulnerable under future SLR scenarios based on a multi-criteria decision analysis. Factors to be considered will include per cent of intertidal habitat that is predicted to transition into private land for each SLR scenario and % of intertidal habitat already lost per estuary (based on historical mapping). Results will be presented in a GIS geodatabase that will enable easy identification of vulnerable intertidal wetland.

Stage 2 will refine the statewide first-pass vulnerability assessment by incorporating the potential effects of changes in catchment runoff and sediment delivery to estuary wetlands. This will be achieved by incorporating outputs from catchment hydrology models driven by NARCliM climate projections soon to be available for each estuary in NSW. Stage 2 will also develop high-speed wetland morphodynamic models that can be applied to case study sites for investigating planning and management options for facilitating wetland adaptation.

C.3.1.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Areal extent of habitat		Statewide	Medium & long term

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Modelled sea level rise		Statewide	Medium & long term
NARCliM climate variables		Statewide	Medium & long term
Land use categories		Statewide	Short term

C.3.1.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Mangroves				X		X	DPI Spatial Data Portal
Saltmarshes				X		X	DPI Spatial Data Portal

DPI Spatial Data Portal

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
NARCliM driven estuary hydrology models				X	X	X	DPE-EHG
Land use					X	X	Crown Lands

C.3.1.8 Relevant contextual data

NSW Estuary Tidal Inundation Exposure Assessment Report (DPE-EHG), DPI Fisheries estuarine habitat maps, NSW Land-use layers; Spatial Services Topographic dataset; Lidar derived DEMs; Quaternary geology layers; NARCliM1.5 climate projections.

C.3.1.9 Other relevant projects/data

This project is directly related to MEMS Action 2.5 (Monitoring and assessment of estuarine habitats and disturbances) in that it utilises data from that project and provides pressure data for that action. Results from this project will also be integrated with Action 2.3.2 (marine vegetation management strategies).

C.3.1.10 Data storage

Modelling data stored on DPE-EHG corporate databases and will be made available via SEED portal or the DPI Spatial Data Portal.

C.3.2 Monitoring the impacts of climate change on rocky reefs – F2

C.3.2.1 Overview

Research and monitor the effects of climate change on the marine estate to fill knowledge gaps and inform future management actions, focusing on marine biodiversity and coastal communities. This action will be integrated into the Monitoring Program. Monitoring programs will provide data to highlight the baseline condition of the NSW marine estate. Monitoring is being carried out statewide as part of MEMS Stage 1 and is proposed to continue as part of Stage 2. This project is led by DPI and funded by the MEMS.

C.3.2.2 Project type/objectives

Understand, adapt and increase resilience, to help mitigate the impacts of climate change on the NSW marine estate.

C.3.2.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Habitats and assemblages, including species that dominate the habitat forming component of the seafloor, animals and plants that typically associated with each habitat type and the fish assemblage within the NSW marine estate Threatened and protected species listed under the NSW Biodiversity Conservation Act (BCA) or the Fisheries Management Act (FMA) Threatened and protected species and communities listed under the FMA	Enjoyment benefits derived from recreational fishing, snorkelling, diving and beachcombing	Sea level rise on saltmarsh, mangrove, beaches and mudflats, rocky shores and species and communities protected under the FMA and BCA Ocean acidification on all environmental assets Altered ocean currents and nutrient inputs on shallow reef, species and communities protected under FMA and BCA Altered storm and cyclone activity on water, saltmarsh, seagrass, reefs and species and communities protected under FMA and BCA Climate and sea temperature rise on all environmental assets	Climate change is affecting ocean temperatures, the supply of nutrients, ocean chemistry, food chains, wind systems, ocean currents and extreme events such as cyclones These variables have the potential to affect the distribution, abundance, breeding cycles and migrations of marine plants and animals that people rely on for food, income and enjoyment; this affects business viability Increased sea temperatures and sea level rise could affect the spiritual connections of Aboriginal communities (e.g. culturally significant species, links to Land and Sea Country and food sources)

C.3.2.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Climate change 20 years, climate and sea temperature rise and altered storm and cyclone activity, shallow reefs	Partial

C3.2.5 Methods

The subtidal reefs of NSW are largely dominated by macroalgae and form part of the iconic Great Southern Reef, which provides immense ecological, social and economic value. Key threats to these reefs, identified in the NSW TARA, were climate change (altered nutrients, temperature, currents and storms) and land-based impacts (stormwater discharge/sewage). While we cannot manage climate change, we can monitor change and implement mitigation strategies to boost resilience of populations to change (e.g. rehabilitation and assisted adaptation) and implement management strategies to improve land-based impacts (e.g. improving water quality). Changes in distributions will potentially occur due to anthropogenic impacts (e.g. climate change), extreme weather events (e.g. heat waves, storms) and management actions (e.g. restoration, threat mitigation).

Monitoring, under the MIMP, will be essential for assessing any changes to benthic habitat distributions in NSW. Monitoring is addressed through management Action 3.5, of MEMS Initiative 3, which focuses on research to inform future management actions. Action 3.5 targets collection of baseline data on habitat distributions for NSW subtidal reefs, quantifying the effects of climate change and filling knowledge gaps. This action addresses all two key purposes of the MIMP, namely 1) monitor the condition and trend of environmental assets and 2) fill knowledge gaps that were identified as part of the statewide TARA (BMT WBM, 2017).

Monitoring will address the current lack of statewide baseline data on subtidal habitats from which to measure change. In addition, monitoring will improve our understanding of the mechanisms of change, essential information to design and implement management strategies to mitigate impacts. Finally, monitoring will address knowledge gaps about key issues and provide important information for anticipating and adapting to change and future-proofing management and conservation within the NSW marine estate.

Benthic habitat monitoring – sampling design and locations

A long-term monitoring program has been developed for biota on shallow rocky reefs in NSW which examines the condition and trend of a range of environmental assets, particularly large canopy forming macroalgae (i.e., kelp). The program aims to:

- quantify changes in the distribution and extent of key habitats (e.g. kelp, barrens, turf, sessile assemblages) and fish assemblages across latitudinal gradients. In addition, we will test the hypotheses that areas of upwelling, higher latitudes and depth are refugia from thermal stress
- assess change in the condition of kelp habitats (demography, health, genetic diversity and morphology) as indicators of resilience
- quantify change in physical parameters (principally temperature) on subtidal reefs along the coast.

The program focuses on six locations throughout the state: Cape Byron, Coffs Harbour, Port Stephens, Sydney, Batemans Bay and Eden. These locations span a broad latitudinal temperature gradient and encompass the range edges of dominant taxa, with ranges expected to shift under future climate change. Three sites (km apart) are monitored per location, with each site situated on consolidated rocky reef as identified from swath mapping. In addition, to test hypotheses about upwelling as refugia, an extra location will be added in year 2 (2020) at Smokey Cape, with 4 sites, 2 north and 2 south of this location, and an additional site will be added at Cape Byron (south of the Cape). These additional sites will provide replicated sites to the north (strong East Australian Current (EAC) influence) and south (periodic upwelling) of two known areas of upwelling (i.e., Cape Byron and Smokey Cape).

Sampling at each site consists of replicate transects (~1.5 m wide by 200 m long) conducted using towed video (TOV). At each site 6–7 transects are conducted each year in late summer (Feb – May), to allow quantification of changes in the distribution and extent of key habitats. Transects are conducted using TOV in shallow depths (i.e., 5–20 m) beginning in 2019. Additional data may be collected at greater depths (i.e., 20–40 m) using an autonomous underwater vehicle periodically. Transects are positioned over rocky reef, using downward pointing cameras, ~1 m above the seafloor, to record data on reef biota. The per cent cover of major taxonomic classes (kelp, turf, barrens, sessile invertebrates etc.) will be enumerated and other variables such as kelp condition and urchin abundance will be quantified where possible.

At each of the six locations (as above), an area with at least 50% cover of kelp is also being assessed for potential indicators of kelp resilience, using scuba diving based surveys. On these surveys the density of kelp and levels of kelp recruitment is measured using three 25 m transects. Biomass is measured by harvesting and weighing all plants in three 0.25 m^2 quadrats, with morphology and signs of grazing/fouling/disease quantified for the collected plants. Data on genetic diversity and morphology (already assessed at most locations as part of other projects) will be used to test hypotheses about upwellings and higher latitudes being refugia for genetic diversity and thus adaptive capacity. At all locations (as above) we will collate data on environmental variables including sea surface temperature, chlorophyll, turbidity, photosynthetically available radiation, and pH. These data will be used to develop predictive species distribution models for kelp and other key habitats. In addition, temperature loggers have been deployed at one site per location (same site as diving above) to collect temperature data at depth, thereby identifying any thermal events not apparent from sea surface temperatures.

Analyses will be conducted to test for changes in subtidal habitat distributions among years, across latitudinal temperature gradients, across a range of depths (~5-40 m), and in the vicinity of areas of known upwelling. Species distribution models will be used to determine whether deeper habitats, areas of upwelling, and higher latitudes are potential refugia for kelp. Furthermore, kelp health and condition will be examined to determine whether these are greater and changes in abundance are less at potential refugia sites. Results will be presented as peer reviewed publications, conferences, workshops and via internal communication channels and reports to management that detail key findings.

C.3.2.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Habitat cover	% cover of major habitat types	Statewide	Annually
Relative urchin abundance	Density urchins	Statewide	Annually
Kelp health	Morphology, disease, recruitment	Statewide	Annually
Kelp adaptability	Genetic diversity and structure	Statewide	Periodically
Fish	Abundance, diversity, thermal affinity	Statewide	Annually

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Temperature (in situ)	Degrees Celsius	Statewide	Daily

C3.2.7 Baseline data

There currently exists no long term, systematic monitoring project for kelp cover or urchins at a statewide level in NSW. This project is thus the beginning of a baseline dataset. Historical data to assess baselines from which to measure change can be derived from other one-off sampling events, studies that cover parts of the state or other data sources (e.g. BRUVs footage).

C.3.2.8 Relevant contextual data

This project links to three externally-funded Australian Research Council grants on which NSW DPI are partner investigators. These projects are examining genetic diversity and adaptive capacity of kelp forests along the NSW coast as well as impacts of marine heatwaves. New restoration technologies are being developed to remediate lost kelp forests. Sites in this project also link in with the statewide BRUVs sampling (CONFUND).

C.3.2.9 Other relevant projects/data

Not applicable.

C.3.2.10 Data storage

Metadata will be uploaded into the DPI knowledge base, imagery will be uploaded into Squiddle or temperate reef base.

C.3.2.11 References

BMT WBM (2017) *New South Wales Marine Estate Threat and Risk Assessment Report*, Marine Estate Management Authority, 251 pp.

C.3.3 Restoration solutions for marine forests undergoing climatic change – F15

C.3.3.1 Overview

Pervasive habitat loss driven by environmental change and human activities is necessitating active intervention-based approaches to conservation to restore natural ecosystems. Marine restoration is challenged by the difficulties of working underwater in wave-swept environments combined with complex species life histories and large scales of loss. There is a pressing need to develop innovative marine restoration techniques that overcome these problems, while allowing cost-effectiveness, practical application and flexibility to boost the resilience of natural populations to future stress.

Green gravel is a novel technique for restoring kelp forests that facilitates cost-effective and rapid re-establishment and it represents an exciting avenue to future proof restoration efforts. Gravel seeded with kelp propagules ('green gravel') can be readily scattered from a boat, across areas where algal turfs prevent kelp recruitment, with juvenile kelps overgrowing the gravel and attaching to the underlying reef. Green gravel could, therefore, be applied to large and inaccessible areas without scuba diving or engineered structures, overcoming one of the major hurdles in marine forest restoration. This project will use large-scale field and mesocosm experiments, cutting edge genomics and community engagement to take our novel 'green gravel' technique from concept to application.

Project partners include University of Western Australia, Seaforester.

C.3.3.2 Project type/objectives

Develop solutions to enable restoration of underwater forests undergoing climate mediated declines.

C.3.3.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Habitats and assemblages, including species that that dominate the habitat forming component of the seafloor, animals and plants that typically associated with each habitat type and the fish assemblage within the NSW marine estate	Enjoyment benefits derived from recreational fishing, snorkelling, diving and beachcombing	Climate and sea temperature rise on environmental assets including habitats, assemblages and threatened and protected species	Climate change is affecting ocean temperatures, the supply of nutrients, ocean chemistry, food chains, wind systems, ocean currents and extreme events such as cyclones These variables have the potential to affect the distribution, abundance, breeding cycles and migrations of marine plants and animals that people rely on for food, income and enjoyment; this affects business viability Climate change stressors such as sea level rise and increased sea temperatures can cause the benefit of tangible cultural heritage not being realised as environmental degradation can impact on spiritual connections (e.g. totemic species, culturally significant species, links to Country and food sources)

C.3.3.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Development of restoration solutions to reverse climate mediated kelp declines	Partial

C.3.3.5 Methods

This project will use large-scale field and mesocosm experiments, cutting edge genomics and community engagement to take our novel green gravel technique from concept to application. Specifically, our objectives are to:

- conduct the first *in situ* and at-scale kelp restoration using green gravel across replicate species and coastlines where kelp has been lost
- develop cost-effective and practical green gravel techniques that make kelp restoration achievable for diverse user-groups
- future proof kelp restoration initiatives by testing resilience of green gravel seeded with different genotype and species mixes
- develop a green gravel implementation model applicable from local to global scales through a global green gravel action group, communication and case studies.

C.3.3.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Kelp survival	Number kelp sporophytes on green gravel	Chosen sites	Monthly for 2 years

Pressure/stressor indicators

N/A

C.3.3.7 Baseline data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
No data available at the time of this report							

C.3.3.8 Relevant contextual data

N/A

C.3.3.9 Other relevant projects/data

N/A

C.3.3.10 Data storage

Data will be stored with collaborators at UWA under their data storage protocols and in line with data management set out in the Australian Research Council Agreement under which this project falls.

Appendix C.4 Reducing impacts on threatened and protected species (Initiative 5)

Initiative objective: To understand and mitigate threats to threatened and protected species in NSW.

NSW is home to many threatened and protected species. Some are managed under the *Biodiversity Conservation Act 2016* (BCA): such as species of whales, dugongs, seals, turtles, Little Penguin, seabirds, shorebirds and wader birds and saltmarsh communities. Marine vegetation, aquatic invertebrates and fish are managed under the *Fisheries Management Act 1994* (FMA): such as the Grey Nurse Shark, White Shark, Black Rockcod and endangered populations of the seagrass *Posidonia australis* and marine brown algae *Nereia lophocladia*, which is found in only one location on the north coast of NSW.

The key focus of Initiative 5 is identifying and communicating priority threats and delivering more effective management of threatened and protected species under the BCA and the FMA. The intended outcome is to improve or maintain conservation status and support the health of targeted threatened and protected species in the wild. Initiative 5 is not directly responsible for abating threats to marine wildlife. Monitoring of marine wildlife will assess how actions undertaken under other initiatives are abating the cumulative threats to marine wildlife.

The expansion of the commercial fishing observer program in this initiative will assess bycatch and interactions with threatened and protected species, including sharks such as the Grey Nurse Shark and Black Cod, listed as critically endangered and vulnerable respectively under the FMA.

The specific MEMS management actions that relate to environmental monitoring indicators are:

- 5.5 Expand existing observer programs, including the use of new technologies to high and moderate risk commercial fisheries to better understand threats associated with bycatch and interactions with threatened and protected species.
- 5.6 Understand and reduce the impacts of threatened and protected species habitat modification through mapping of key habitat areas, embedding rehabilitation and conservations actions in planning processes, and collaborating with land owners and the community to protect species and habitats.

Projects monitoring threatened and protected species and associated threats are outlined in Table C7 (and included in this document). Projects that also support Initiative 5 but primarily contribute monitoring information to other MEMS initiatives are presented in Table C8.

TABLE C7. Projects contributing monitoring information to Initiative 5 management actions.

Project	MEMS action(s)	Supports MEMS action(s)
NSW DPI Commercial Fishery Observer Program (CFOP) – Ocean Trawl Fishery	5.5	6.1
Reducing impacts on threatened and protected species	5.5	6.1
Recreational Fisheries Monitoring Program (RFMP): Charter boat monitoring	5.5	6.2
Long-term monitoring of population and size structure of Black Cod	5.5	
Whites Seahorse recovery	5.5	
Grey Nurse Shark monitoring	5.5	
Cetaceans project	Int. 5	
Pinnipeds project	Int. 5	
Turtles project	Int. 5	
Soft corals	5.5	
Shorebirds and seabirds monitoring	Int. 5	
RFMP: Surveys of recreational fishers in NSW waters		6.5

TABLE C8. Other projects supporting Initiative 5 management actions.

Supporting projects	Primary initiative
Harvest strategies	6
Statewide BRUVs	6
Estuarine habitat monitoring and threat assessment (formerly Monitoring and assessment of estuarine habitats and disturbances)	3 (previously in initiative 2)

C.4.1 Commercial Fishery Observer Program (CFOP) – Ocean Trawl Fishery – F7

C.4.1.1 Overview

The Fishery Management Strategy (FMS) for each of the major commercial fisheries operating in NSW (excluding Eastern Rock Lobster and Abalone) require NSW Department of Primary Industries (DPI) to design and implement scientific observer programs for fisheries and methods where bycatches are either known or likely to be a significant problem or where existing data are out of date. Historically, observer-based research priorities in NSW have been determined through a risk-based prioritisation process. Since the early 1990s, a total of 14 observer-based surveys have been completed across five NSW fisheries.

To quantify the level of discarding of unwanted bycatch species in the NSW Ocean Trawl Fishery (OTF), NSW DPI designed and implemented a multi-year observer-based survey of the Southern Fish Trawl (SFT), Northern Fish Trawl Fishery (NFT) and Ocean Prawn Trawl Fishery (OPT – Figure C1). Specifically, these observer programs were designed to: i) document bycatch in the OTF; ii) estimate total annual retained and discarded catches and where possible measure the benefits associated with the introduction of bycatch-mitigation measures via a direct before-after comparison between the current and previous observer surveys; iii) identify extent of regulatory induced discarding of otherwise marketable fish, and iv) describe interactions with protected, threatened and endangered species.

C.4.1.2 Project type/objectives

- condition and trend
- contextual data

C.4.1.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Coastal and marine waters Fish assemblages (harvest and bycatch stressors only) Threatened and protected fish and sharks, marine mammals, reptiles and birds	Enjoyment: consumptive use (North and South only) Enjoyment: enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values Viability of businesses	Threats associated with bycatch and interactions with threatened and protected species in NSW commercial fisheries	Loss or decline of marine industries Reductions in abundances of species and trophic levels

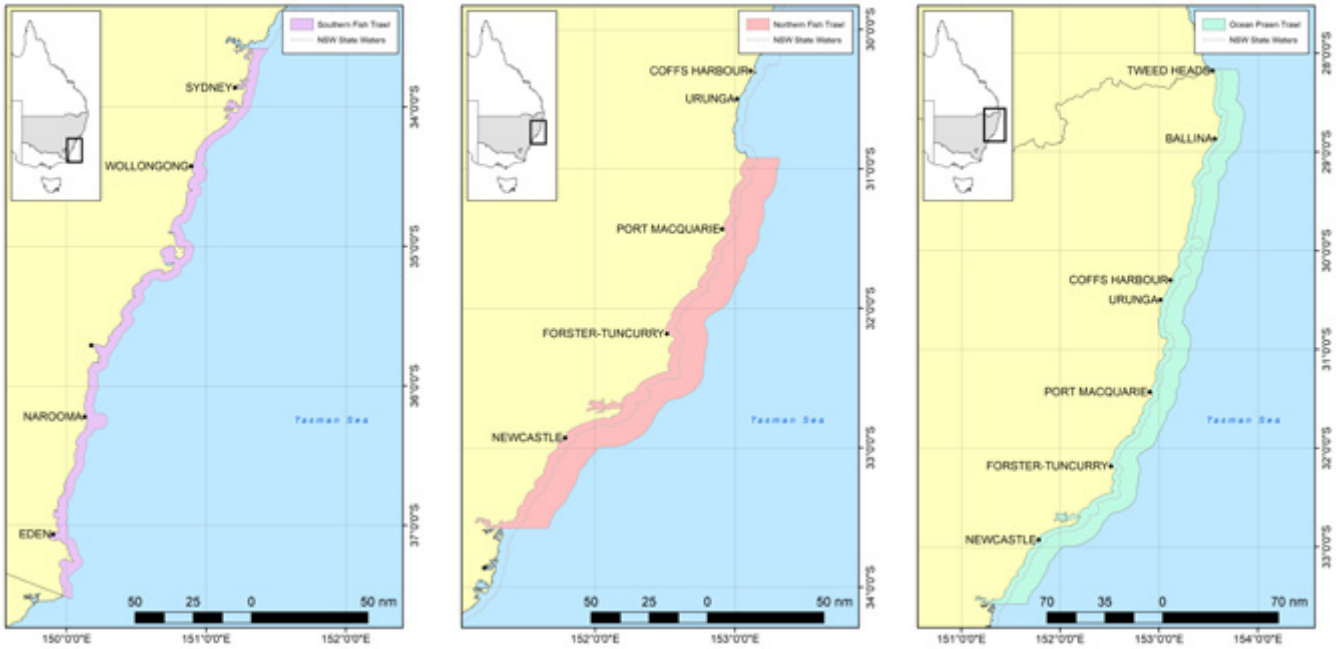
C.4.1.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Reduction in abundances of species and trophic levels, bycatch Incidental catch of species of conservation concern	Partial

C.4.1.5 Methods

In an attempt to tailor the sampling design to the true recently-reported effort, a theoretical, two-factor matrix was generated, allocating the optimum number of observed fishing days (SFT= 100 , NFT = 150, OPT = 430 , target CV 20%) among the fishery/ season combinations, according to a weighting relative to the differences in reported average fishing effort.

FIGURE C1. Map of fishery boundaries for the Southern Fish trawl (SFT), Northern Fish trawl (NFT) and Ocean Prawn Trawl (OPT) fisheries.



Data and samples collected on observed fishing trips can be categorised into five types: operational data; vessel and gear data; catch composition data; biological sample collection; and wildlife abundance/ interaction data.

Generalised Additive Mixed Modelling was used to characterise seabird and vessel interactions, however, due to the extremely low number of potential physical interactions, only a vessel attendance response variable model could be run for all birds (i.e., combined) and Procellaridae, Laridae and Diomedeidae (i.e., family levels). Significant operational and environmental covariates were characterised by the models (e.g. season and fishing activity (net set or haul)).

GAMMs were appropriate for modelling data with potential for autocorrelation and spatio-temporal signals. The voyage unique identifier and year was included as random effects in all models. This allows effects on counts that are common to a given voyage and combine to generate within-voyage correlation between counts to be accounted for as a generic voyage random effect. All models were fitted via a Poisson family and log link to accommodate the count nature of the response data and moderate levels of zero count observations. Numerical fixed effects were fitted with cubic smoothing splines with basis dimension set to 4 for each spline term. Diagnostics plots were checked to ensure conformity with assumptions for generalised models.

Gaussian mixed models will be used to characterise drivers of discards and include a geospatial analysis. To describe species richness and diversity by strata (zone and categorical depth), multivariate analysis will be completed on catch rates standardised for swept area.

Using the observer data collected in combination with: fishing-effort data recorded via fisher-dependent catch returns; species-specific estimates of observed catch rates for the retained and discarded catch components; total annual catches for the fishery; and rates of interaction with rare and threatened species, will be calculated.

C.4.1.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Fish assemblages (Harvest and bycatch stressors)	Abundance, diversity	Statewide	Short term

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Rates of interaction between commercial fisheries and threatened and protected fish and sharks	Total number and circumstances of interactions (including the life status at the time of the interaction)	Statewide	Long term
Rates of interaction between commercial fisheries and threatened and protected marine mammals, reptiles and birds	Total number and circumstances of interactions (including the life status at the time of the interaction)	Statewide	Long term

C.4.1.7 Baseline data

Historically, observer-based research priorities in NSW have been determined through a risk-based prioritisation process. Using this approach, only fisheries with high levels of bycatch or known interactions with threatened endangered and protected species have been opportunistically observed. Historical data to assess baselines from which to measure change can be derived from other one-off sampling events (e.g. Liggins 1996; Kennelly et al. 1998; Gray et al. 2005; Macbeth and Gray 2016).

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Fish assemblages		X		X		X	Barnes et al. 2022; Liggins 1996; Kennelly et al. 1998
Threatened and protected species (FMA, BCA)		X					Liggins 1996; Barnes et al. 2021

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Commercial fishing				X		X	Barnes et al. 2022; Liggins 1996; Kennelly et al. 1998
Interaction (commercial fisheries and threatened, endangered, or protected species (TEPS))				X		X	Barnes et al. 2021; Liggins 1996; Kennelly et al. 1998

C.4.1.8 Relevant contextual data

Observer-based surveys of the OTF have been successfully completed from 2014/15 – 2019/20. Results have been provided and used by DPI scientists in stock assessments (stock status summary reports). Commercial Fisheries Managers have reported key findings in Fishery assessments under the EPBC Act 1999.

C.4.1.9 Other relevant projects/data

Project name: The role of spatial protection measures in mitigating effects of bycatch and increasing yields in the NSW Ocean Trawl Fishery (FRDC 2016/020).

C.4.1.10 Data storage

Data stored on DPI databases and will be made available via Information Asset Register (IAR) portal https://iar.environment.nsw.gov.au/

C.4.1.11 References

Barnes TC, Candy SG, Johnson DD (2021) 'Characterising seabird vessel interactions associated with demersal ocean trawling: vessel attendance depends on intrinsic and extrinsic predictors' *Endangered Species Research*, 44:327-338.

Barnes TC, Candy SG, Morris S and Johnson, DD (2022) 'Understanding discarding in trawl fisheries: A model based demersal case study with implications for mitigating and assessing impacts', *PLoS One*, 17(2):e0264055.

Gray CA, Johnson DD, Broadhurst MK and Young DJ (2005) 'Seasonal, spatial and gear-related influences on relationships between retained and discarded catches in a multi-species gillnet fishery', *Fisheries Research*, 75:56-72.

Kennelly SJ, Liggins GW and Broadhurst MK (1998) 'Retained and discarded by-catch from oceanic prawn trawling in NSW, Australia', *Fisheries Research*, 36:217-236.

Liggins GW (1996) *The interaction between fish trawling (in NSW) and other commercial and recreational fisheries*, Final report to Fisheries Research and Development Corporation, Project No. 92/79, 151 pp.

Macbeth WG and Gray CA (2016) *Observer-based study of commercial line fishing in waters of New South Wales*, NSW DPI Fisheries Report Series No. 148.

C.4.2 Reducing impacts on threatened and protected species (expanded Commercial Fishery Observer Program) – F8

C.4.2.1 Overview

Revised observer sampling designs to provide effective and statistically robust coverage for recording the total number and circumstances of interactions (including the life status at the time of the interaction) with TEP species and sampling designs for estimating the total catch (retained and discarded) have been determined using historic datasets. The line fishing sector of the Ocean Trap and Line Fishery and the trap sector of the Estuary General Fishery are being observed in Stage 1 of the NSW Marine Estate Management Strategy.

The primary objectives of these observer surveys are to describe interactions with protected, threatened and endangered species and the catch characteristics of the commercial line and trap fisheries.

Monitoring is being carried out statewide as part of MEMS Stage 1 and is proposed to continue as part of Stage 2. This project is funded by MEMS, DPI-F, NPWS and DPE-EHG. Project partners include rescue and rehabilitation organisations, commercial tourism operators, commercial fishers, and industry associations/ NGOs.

C.4.2.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes

C.4.2.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuarine waters: Fish assemblages (harvest and bycatch stressors only) Threatened and protected species (macrophytes, fish and shark) Coastal and marine waters: Fish assemblages (harvest and bycatch stressors only) Threatened and protected fish and sharks, marine mammals, reptiles and birds	Enjoyment: consumptive use (North and South only) Enjoyment: enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values Viability of businesses	Threats associated with bycatch and interactions with threatened and protected species in NSW commercial fisheries	Loss or decline of marine industries Reductions in abundances of species and trophic levels

C.4.2.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Incidental catch of species of conservation concern Reduction in abundances of species and trophic levels, bycatch Wildlife disturbance, catch of species of conservation concern, physical disturbance, marine debris, ghost fishing	Partial

C.4.2.5 Methods

The project is designed to prioritise moderate and high-risk fisheries and fisheries with large data gaps identified in the TARA that are a threat to threatened and protected species (bycatch or other interactions) and determine appropriate observation methods specific to each fishery (considering timeframes, seasonality, resourcing, capacity, urgency). The project aims to quantify the nature and extent of discarding (and threatened species interactions) by fishers in the Ocean Trap and Line (OTL) and Estuary General (EG) fisheries in the northern and central bioregions. Observer-based surveys with high levels of replication with respect to the number of fishing days observed within a given spatial, temporal and/or fishing-method category are being implemented.

The project will allow commercial managers to: develop management responses that will further reduce threats associated with bycatch and interactions with threatened and protected species; report validated estimates of interactions to fishery assessments under Parts 13 and 13(A) of the Environment Protection and *Biodiversity Conservation Act 1999*; and address key knowledge gaps outlined in the TARA. Mortality from discards derived from observer-based surveys will be incorporated into the assessment of indicators and resulting decision rules as outlined in NSW Fisheries Harvest Strategy Policy (Initiative 6).

The project has two main elements:

- observer-based survey of NSW Ocean Trap and Line Fishery (Line fishing western zone)
- observer-based survey of NSW Estuary General trap fisheries targeting Blue Swimmer Crabs (*Portunus armatus*) and Giant Mud Crabs (*Scylla serrata*).

(i) Observer-based survey of NSW Ocean Trap and Line Fishery (Line fishing western zone)

To quantify the total number and circumstances of interactions (including the life status at the time of the interaction) between the fishery and threatened and protected species identified as high risk through the ecological risk assessment process (i.e., Grey Nurse Shark), NSW DPI designed and implemented an observer survey in the central and northern bioregions.

The sampling design for the OTL observer survey was optimised for the northern and central bioregions using data from a previous Commercial Fishery Observer Program (CFOP). Capture of threatened, endangered, or protected species (TEPS) in this fishery is characterised by high survivorship. However, interactions were relatively rare, as such the 'hypergeometric' distribution was found to be most appropriate for such a low and skewed count. The effort unit applied to optimisation calculations was fishing days, sampling was further subdivided at the bioregion (using effort proportion) and annual level.

There were two main sources of data used in the calculation of optimal observer sampling level. Historic observer data from the 2007/8 CFOP were collected by the NSW DPI (formerly NSW Fisheries), and previously reported by Macbeth and Gray (2016). The NSW OTL fishing effort and weight of retained catch composition data for years 2015 to 2018 was sourced from the fish-online database (Source NSW DPI). Data in grids equating to the southern bioregion was excluded from the analysis (low risk TARA). Historical CFOP effort data was recorded to the fine scale level (e.g. number of hooks used in a line shot), however, for comparisons to the logbook catch data, effort was scaled to the day (or trip) level. CFOP and logbook data described the line type method used (e.g. handline) as such optimisation considered certain line types, such as handline and setline.

Operational and catch data will be collected by a scientific observer, during randomly selected fishing trips from June 2019 to July 2021. In an attempt to tailor the sampling design to the true recently-reported effort, a theoretical, three-factor matrix was generated, allocating the optimum number of observed fishing days (236 days, target CV 20%) among the bioregion/ method/ season combinations, according to a weighting relative to the differences in reported average fishing effort.

Using the observer data collected in combination with: fishing-effort data recorded via fisher-dependent catch returns; species-specific estimates of observed catch rates for the retained and discarded catch components; total annual catches for the fishery; and rates of interaction with rare and threatened species, will be calculated.

(ii) Observer-based survey of NSW Estuary General trap fisheries targeting Blue Swimmer Crabs and Giant Mud Crabs

Commercial trap fishers will be observed in the Tweed River, Richmond River, Clarence River and Macleay River in the northern bioregion and Wallis Lake and Port Stephens in the central bioregion. Operational and catch data will be collected by a scientific observer, during randomly selected fishing trips from November 2019 to May 2020. In an attempt to tailor the sampling design to the true recently-reported effort, a theoretical, three-factor matrix was generated, allocating the number of available observed fishing days (400 days) among the estuary/method/month combinations, according to a weighting relative to the differences in reported average fishing effort.

Using the observer data collected in combination with: fishing-effort data recorded via fisher-dependent catch returns; species-specific estimates of observed catch rates for the retained and discarded catch components; total annual catches for the fishery; and rates of interaction with rare and threatened species, will be calculated.

C.4.2.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Abundance (fish assemblages)	Trends in species stock status	Statewide	Long term
Diversity (fish assemblages)	Trends in species stock status	Statewide	Long term

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Rates of interaction between commercial fisheries and TEPS	Total number and circumstances of interactions (including the life status at the time of the interaction)	Statewide	Long term

C.4.2.7 Baseline data

Historical data to assess baselines from which to measure change can be derived from other one-off sampling events (e.g. Macbeth et al. 2009; Macbeth and Gray 2016).

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Fish assemblages				X		X	Barnes et al. 2022; Macbeth et al. 2009; Macbeth and Gray 2016

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Commercial fishing				X		X	Barnes et al. 2022; Macbeth et al. 2009; Macbeth and Gray 2016
Interaction (commercial fisheries and TEPS)				X		X	Macbeth et al. 2009; Macbeth and Gray 2016

C.4.2.8 Relevant contextual data

Fishery assessments under the EPBC Act 1999.

C.4.2.9 Other relevant projects/data

- Project name: Commercial Fishing Trust – Observer-based surveys of NSW commercial fisheries (OTF).
- Project name: The role of spatial protection measures in mitigating effects of bycatch and increasing yields in the NSW OTF (FRDC 2016/020).

C.4.2.10 Data storage

Data stored on DPI databases and will be made available via Information Asset Register (IAR) portal https://iar.environment.nsw.gov.au/

C.4.2.11 References

Barnes TC, Broadhurst MK and Johnson DD (2022) 'Disparity among recommended and adopted escape-gap designs and their utility for improving selection in an Australian portunid trap fishery', *Fisheries Research*, 248:106219

Macbeth WG and Gray CA (2016) *Observer-based study of commercial line fishing in waters off New South Wales*. Industry & Investment NSW – Fisheries Final Report Series No. 148, 151 pp.

Macbeth WG, Geraghty PT, Peddemors VM and Gray CA (2009) *Observer-based study of targeted commercial fishing for large shark species in waters off northern New South Wales*, Industry & Investment NSW – Fisheries Final Report Series No. 114, 82 pp.

C.4.3 Recreational Fisheries Monitoring Program (RFMP): Charter boat monitoring – F18

C.4.3.1 Overview

Incorporating the monitoring of the recreational charter fishery into the overall management of NSW fish stocks is a primary objective of the NSW DPI Recreational Fisheries Monitoring Program (RFMP). The licensing of NSW charter fishing operators includes a requirement for mandatory catch and effort information to be collected by industry in the NSW DPI Charter Fishing Monitoring Logbook. Information derived from logbook reporting demonstrates the charter sector to be a significant commercial user of the community-owned fisheries resources and therefore has a potential impact on the stocks of target and bycatch species. Data from the charter sector is valuable in that it provides an ongoing time series of information on important exploited fish stocks spanning the entire NSW coastline. Information from charter operators is therefore critical in not only developing a complete assessment of the entire recreational fishing sector, but also in providing data which can be used in the ongoing monitoring of key exploited fish species in NSW.

Fishery-dependent data sources such as industry logbooks are a commonly used and cost-effective way to obtain catch and effort information for many fisheries worldwide. However, such data are often problematic and can be of limited value in assessments and management due to variable rates of fisher compliance with reporting requirements, accurate species identification and the omission of recording information on discarding. A widely recognised complementary source of cost-effective, independent and reliable data on fishery catch and effort is via the use of trained on-board scientific observers (Cotter and Pilling 2007, Gray and Kennelly 2017). On-board observers travelling on fishing vessels can provide high quality data on catch and effort for all retained and discarded species, along with the collection of other data which may influence catches such as exact spatio-temporal information on the activity of the fishing vessel, gear used, environmental conditions and habitats fished. In addition, there may be opportunities to collect other useful data when using on-board observers, such as demographic information from charter clientele for use in socio-economic analyses and interactions with threatened, endangered or protected wildlife for ecological risk assessment purposes.

A combination of mandatory industry-based logbook and an on-board observer program is therefore used to monitor the nearshore charter fishery as part of the RFMP.

C.4.3.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes

C.4.3.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Coastal and marine waters; Fish assemblages (harvest and bycatch stressors only) Threatened and protected marine mammals, reptiles and birds.	Loss or decline of marine industries Reductions in abundances of species and trophic levels	Threats associated with wildlife disturbance, catch of species of conservation concern, physical disturbance and marine debris	Enjoyment: consumptive use (North and South only) Enjoyment: enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values Viability of businesses

C.4.3.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Reduction in abundances of species and trophic levels, bycatch Incidental catch of species of conservation concern	Partial

C.4.3.5 Methods

Coastal and oceanic waters adjacent to the NSW coastline are divided into ten one-degree-latitude Fisher Reporting Zones (FRZs, Figure 1) which charter fishers are required to report against spatially in their daily catch returns. This is valuable in terms of easily identifying spatial variation in recent historical fishing catch and effort. On-board observer monitoring of the nearshore charter fishery is spatio-temporally stratified according to a hypothetical two-factor matrix which assigns available observer trips (200) across the ten one-degree-latitude FRZs in NSW over four seasons based on reported logbook catch and effort.

Ports for observer monitoring are selected randomly based on the presence of more than one charter fishing vessel. Vessels within ports are then randomly selected for observer coverage with probability of selection based on spatial and temporal variation in catch for several key species (Eastern Bluespotted Flathead, Snapper, Grey Morwong, Yellowtail Kingfish, Teraglin and Pearl Perch) over the previous three years. This monitoring program is ongoing.

Using the observer data collected in combination with: fishing-effort data recorded via fisher-dependent catch returns; species-specific estimates of observed catch rates for the retained and discarded catch components; total annual catches for the fishery; and rates of interaction with rare and threatened species, will be calculated.

C.4.3.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	Measure	Spatial scale	Temporal scale and frequency
Fish assemblages (harvest and bycatch stressors)	Abundance, diversity	Statewide	Long term

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	Measure	Spatial scale	Temporal scale and frequency
Rates of interaction between charter fishing activities and threatened and protected marine mammals, reptiles and birds	Total number and circumstances of interactions (including the life status at the time of the interaction)	Statewide	Long term

C.4.3.7 Baseline data

Historical data to assess baselines from which to measure change can be derived from other one-off sampling events (e.g. Gray and Kennelly, 2017, Hughes et al. 2020).

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Fish assemblages		X				X	Gray and Kennelly 2017; Hughes et al. 2021

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Charter fishing		X				X	Gray and Kennelly 2017; Hughes et al. 2021
Interaction (charter fisheries and TEPS)		X				X	Hughes et al. 2021; Hughes et al. 2022

Observer-based surveys of the charter fishery have been successfully completed in 2015/16 and 2017/18. Results have been provided and used by DPI scientists and Recreational Fisheries Managers.

C.4.3.9 Other relevant projects/data

MEMS 6.2 Conduct an environmental assessment of recreational fishing, periodically review current rules, and act to improve fish stocks and to address threats associated with harvest, bycatch and illegal sale of fish

C.4.3.10 Data storage

Data stored on DPI databases and will be made available via Information Asset Register (IAR) portal https://iar.environment.nsw.gov.au/

C.4.3.11 References

Cotter AJR and Pilling GM (2007) 'Landings, logbooks and observer surveys: Improving the protocols for sampling commercial fisheries', *Fish and Fisheries*, 8:123–152.

Gray CA and Kennelly SJ (2017) 'Evaluation of observer- and industry-based catch data in a recreational charter fishery', *Fisheries Management and Ecology*, 24:126-138.

Hughes JM, Johnson DD, Murphy JJ and Ochwada-Doyle FA (2021) *The NSW Recreational Fisheries Monitoring Program – Charter Fishery monitoring*, 2017/18, NSW DPI – Fisheries Final Report Series No. 159.

Hughes JM, Johnson DD, Collins D, Ochwada-Doyle FA and Murphy JJ (2022) 'Factors affecting seabird abundance and interaction with the nearshore 'for hire' recreational charter fishery in New South Wales, Australia', *Aquatic Conservation-Marine and Freshwater Ecosystems*, 32:385-399.

C.4.4 Grey Nurse Shark monitoring – F6

C.4.4.1 Overview

The Grey Nurse Shark (*Carcharias taurus*) population in the coastal waters of SE Australia has been listed as critically endangered under Part 7A – Threatened species conservation of the *Fisheries Management Act 1994*, federal legislation (i.e., the *Environment Protection and Biodiversity Conservation Act, 1999*), and by the International Union for Conservation of Nature (IUCN). National and state (in draft) recovery plans for the Grey Nurse Shark have been prepared and identify a range of ecological research necessary to assist with the recovery of the species. When the research commenced in 1999, there was little biological information available for the Grey Nurse Shark population off the east coast of Australia. Since that time, various projects have focused on documenting key aspects of the ecology of the species to enable planning and management of the recovery of the species.

Prior to the recent research off eastern Australia, knowledge of the ecology of the Grey Nurse Shark was mainly confined to work carried out off the east coasts of the USA, South Africa and South America.

The overall aim of this research is to fill the substantial knowledge gaps and obtain sufficient ecological information to assist the recovery process and ensure the long-term conservation of the Grey Nurse Shark population along the SE coast of Australia. Indicators of status and trend will be subsequently developed as the knowledge gaps are filled.

C.4.4.2 Project type/objectives

- monitor condition and trend
- fill knowledge gaps
- contextual data

C.4.4.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Threatened and protected species under FMA	Enjoyment: enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values	Commercial fishing Recreational fishing	Environmental – reductions in abundances of species and trophic levels

C.4.4.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Commercial fishing (OTL) impacts on threatened and protected species under FMA Recreational fishing (Boat-based line and trap fishing); incidental catch of species protected species under FMA	Partial

The research methods are focused around five interacting components: (1) necropsies; (2) Underwater Visual Censuses (UVC) and stereo-video photogrammetry; (3) tagging; (4) threatening processes assessment; and (5) population demography. These utilise state of the art techniques based in the field and laboratory and are combined with standard fisheries analytical methods to ensure an efficacious and cost-effective program of work to fill the substantial knowledge gaps that exist with this species.

The main threatening processes and their effects including: the interactions with the recreational scuba diving tourism industry, the number of fishing interactions, the location and timing of these interactions, the types of fishing gear involved and the consequences of capture by the various fishing sectors. Interactions with the recreational scuba diving ecotourism industry have been assessed using: (1) UVC; stereo-video; (2) photogrammetry; and (3) experiments involving acoustically tagged sharks. Fishing-related interactions with Grey Nurse sharks will be quantified using: (1) UVC; (2) stereo-video photogrammetry censuses; (3) the necropsies of shark carcasses; and (4) reports from fishers, scuba divers and members of the public.

Following estimation of all necessary life-history parameters, demographic models will be used quantify the population growth rate and hence an assessment of the degree of population recovery. The age/growth studies will provide a direct input to demographic analyses. Reproductive parameters will be derived from the results of the necropsies. Independent estimates of mortality will be obtained via: (1) the acoustic detections; (2) will also be used to catch curves derived from stereo-video photogrammetry censuses and age/growth data; and (3) life-history techniques.

C.4.4.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Shark meshing program catches	Number and size of male and female Grey Nurse sharks caught	Newcastle to Wollongong	Annually over 8 months per year
Survival	Rate of mortality	Statewide	To be determined
Use of key habitats by Grey Nurse sharks	Usage/presence of Grey Nurse sharks at key habitats	Statewide	Annually with a variable frequency
Number of incidental captures of Grey Nurse sharks	Number and size of male and female Grey Nurse sharks caught Number of Grey Nurse sharks with retained fishing gear	Statewide	Annually over a year Annually over a year
Ecotourism interactions	Behaviour of Grey Nurse sharks when scuba divers present	Statewide	To be determined

Pressure/stressor indicators

N/A

C.4.4.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Grey Nurse Shark population				X		X	Otway and Parker 2000; Otway et al. 2003; Otway et al. 2004; Otway et al. 2009; Otway and Ellis 2011; Smith et al. 2016; Otway et al. 2020

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Shark meshing program catches				X	X		Dalton and Peddemors 2019; NSW DPI 2016
Key habitat usage						X	Otway and Parker 2000; Otway et al. 2003; Otway et al. 2009; Otway and Ellis 2009
Commercial fishing interactions			X			X	Otway et al. 2004; Otway et al. 2009
Recreational fishing interactions			X			X	Otway et al. 2004; Otway et al. 2009; Otway et al. 2020
Ecotourism interactions			X				Otway et al. 2009; Smith et al. 2015; Smith et al. 2016

C.4.4.8 Relevant contextual data

N/A

C.4.4.9 Other relevant projects/data

Monitoring data have also been used in scientific publications listed below.

C.4.4.10 Data storage

Data are stored on the main computer at the Port Stephens Fisheries Institute and backed up on external hard drives.

C.4.4.11 References

Dalton S and Peddemors V (2019) *Shark Meshing (Bather Protection) Program 2018-19 Annual Performance Repor*t, NSW Department of Primary Industries, 46 pp.

NSW DPI (2016) *5-Year Review of the 2009 Joint Management Agreements for the NSW Shark Meshing (Bather Protection) Program*, NSW Department of Primary Industries, 45 pp.

Otway NM and Parker PC (2000) *The biology, ecology, distribution and abundance, and identification of marine protected areas for the conservation of threatened Grey Nurse Sharks in south-east Australian waters*, NSW Fisheries Final Report Series, No. 19. NSWF, 132 pp.

Otway NM, Burke AL, Morrison NS and Parker PC (2003) *Monitoring and identification of NSW critical habitat sites for conservation of Grey Nurse Sharks*, NSW Fisheries Final Report Series, No. 47, NSW Fisheries, 62 pp.

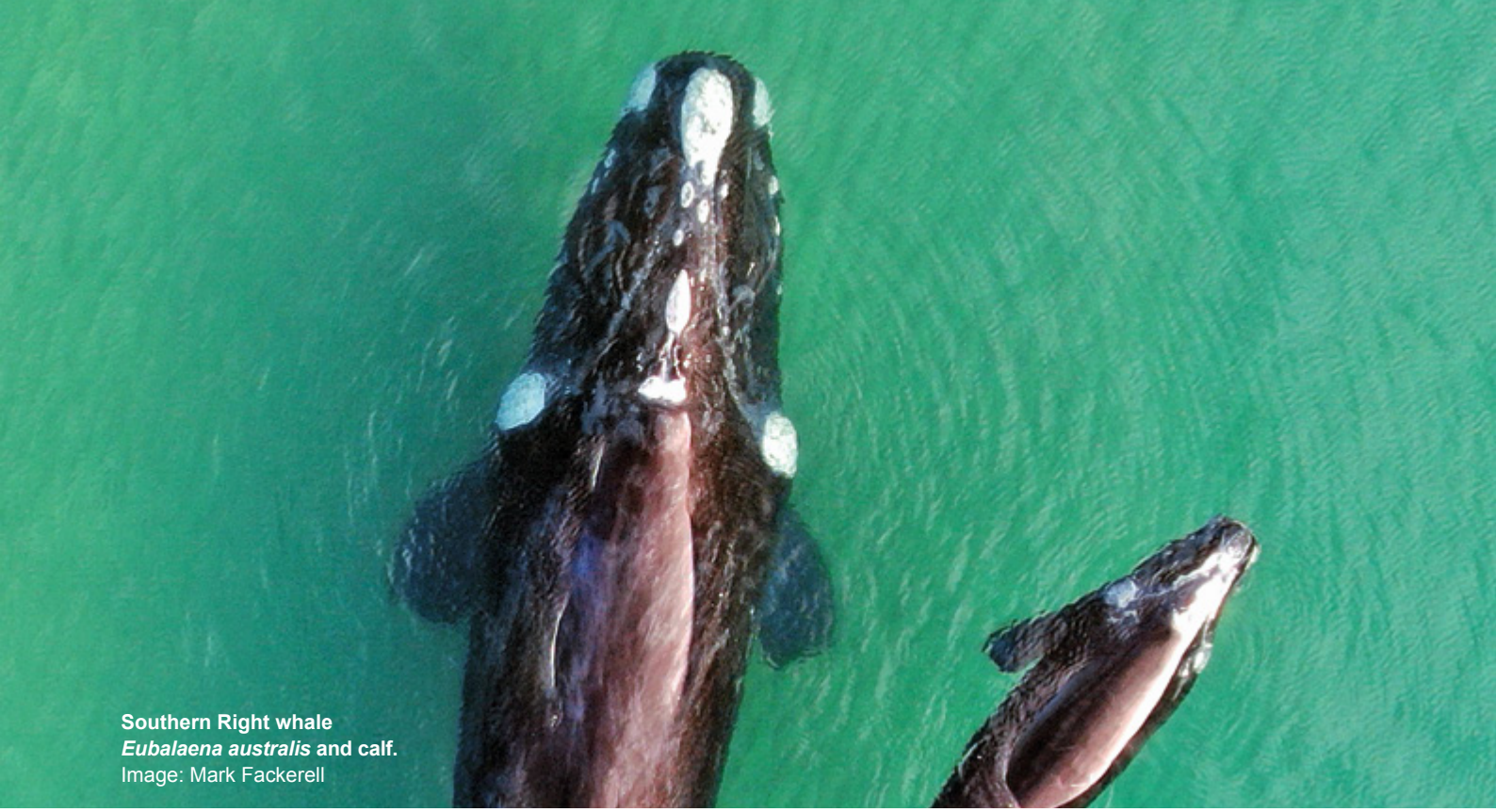
Otway NM, Ellis MT, Louden BM and Gilligan JJ (2009) *Documentation of depth-related migratory movements, localised movements at critical habitat sites and the effects of scuba diving for the east-coast grey nurse shark population*, NSW Fisheries Final Report Series, No. 112. NSW Department of Primary Industries, 90 pp.

Otway NM and Ellis MT (2011) 'Pop-up archival satellite tagging of *Carcharias taurus*: movements and depth/temperature-related use of south-east Australian waters', *Marine and Freshwater Research*, 62:576-582.

Otway NM, West GJ, Gore DB and Williamson JE (2020) 'Hook-shaped enterolith and secondary cachexia in a free-living grey nurse shark (*Carcharias taurus, Rafinesque 1810*)', *Veterinary Medicine and Science*, 7:240– 250

Smith KR, Scarpaci C, Scarr MJ and Otway NM (2014) 'Scuba diving tourism with critically endangered grey nurse sharks (*Carcharias taurus*) off eastern Australia: tourist demographics, shark behaviour and diver compliance' *Tourism Management*, 45:211-225.

Smith KR, Scarpaci C and Otway NM (2016) 'Scuba diving tourism impacts and environmental influences on the patrolling behaviour of grey nurse sharks (*Carcharias taurus*): A preliminary assessment using acoustic telemetry at Fish Rock, Australia', *Tourism in Marine Environments*, 12:17-34.



Southern Right whale *Eubalaena australis* and calf.
Image: Mark Fackerell

C.4.5 Cetaceans project – N1

C.4.5.1 Overview

Impacts on protected species under the BCA are monitored using various data sources. The data are collated annually to understand the rate of impact of the key stressors.

Data are collected from the following sources:

- records of marine wildlife events and incidents captured by NPWS
- National Ship strike database
- annual returns from the NPWS licensed Rescue and Rehabilitation Sector
- Saving Our Species report cards and data (Bionet)
- published whale count data from Point Lookout, Stradbroke Island, Qld.

Data was consolidated in 2019 but some data dates back to 2000. Current monitoring programs are species dependent and are not part of a broad program. Monitoring of some species is funded under Saving our Species (SoS).

Changes to the systems and governance will lead to higher reporting rates.

Wildlife monitored include:

- Southern Right Whale
- Humpback Whale
- Blue Whale
- Sperm Whale
- Minke Whale
- Bryde's Whale
- Common Dolphin
- Pygmy Killer Whale
- Short-Finned Pilot Whale
- Long-Finned Pilot Whale
- Risso's Dolphin
- Pygmy Sperm Whale
- Dwarf Sperm Whale
- Fraser's Dolphin
- Gray's Beaked Whale
- Strap-toothed Beaked Whale
- False Killer Whale
- Pantropical Spotted Dolphin
- Spinner Dolphin
- Rough-Toothed Dolphin
- Bottlenose Dolphin
- Indo-Pacific Bottlenose Dolphin
- Dugong

This project is led by DPE-EHG and funded by the MEMS and SOS. Project partners include: DPI-F; TfNSW; rescue and rehabilitation organisations; veterinarians; Australian Registry of Wildlife Health; Dolphin Marine Rescue Animal Rehabilitation Trust; local government; Australian Museum.

C.4.5.2 Project type/objectives

- condition and trend
- address knowledge gap(s)
- monitor effectiveness of MEMS management
- contextual data

C.4.5.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Species protected under BCA	Enjoyment – enjoying the biodiversity and beauty of the marine estate Participation – safety, health and wellbeing Cultural heritage & use benefits – tangible and intangible Aboriginal cultural heritage	Shipping - Includes large and small commercial vessels i.e., trade ships, cruise ships, major port facilities, ferries, charter boats. Fishing vessels and smaller port facilities Commercial fishing - Includes estuary general, estuary prawn trawl, OT&L, ocean trawl, ocean haul, sea urchin and turban shell, abalone Recreational fishing - Includes shore-based line and trap fishing, boat-based line and trap fishing, hand gathering Boating and boating infrastructure - Recreation and tourism - includes passive use, snorkelling and diving, 4WD, charter activities and shark control measures Foreshore/urban development - includes beach nourishment and grooming Water pollution and sediment contamination - includes urban stormwater, agricultural runoff, industrial discharges, sewage effluent and thermal discharges Clearing, dredging and excavation activities - includes vegetation clearing, dredging, service infrastructure, mining and extraction and cattle grazing Estuary openings/modified freshwater flows - includes hydrological modifications/estuary entrance/modified freshwater flows Climate change - includes all climate change components based on a 20-year projection of impacts only	Wildlife disturbance (shorebirds, turtles, whales) and impacts to ecological health by dog walkers, 4WD, marine vessels etc.

C.4.5.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Extent of wildlife disturbance impacts (including noise) on cetaceans	
Interaction with dredging, aquaculture, mining activities and service infrastructure	
Population modelling and mapping of key habitat in NSW including impacts of climate change on the distribution, abundance and habitat use of cetaceans in NSW waters	Partial
Levels of heavy metals, POC's and other toxins in cetaceans and geographic hot spots in key NSW habitats	Not yet addressed (pending funding)
Impacts of recreational and commercial fishing on species in NSW and effective mitigation techniques	

C.4.5.5 Methods

Sightings data, reports, historical data and present threat information are collected and analysed to determine if Southern Right Whales are being excluded from habitat areas due to threats or if new aggregation areas are likely to emerge.

Implement surveys in collaboration with the National Recovery Plan south-eastern population assessment and contribute photo-ID data to ARWPIC and the National Environment Science Program.

The Cape Solander Whale Migration Study is a citizen science project that annually collects data on the abundance of migrating humpback whales off Cape Solander in Sydney to estimate general humpback whale migration behaviour. Official humpback whale population count data are collected from Point Lookout, Stradbroke Island, coordinated by University of Queensland.

Species incident records are collected from government agencies and licensed rescue groups (e.g. using the Elements database) for analysing trends in threats to the species such as entanglements and vessel strike propeller cuts, entanglements. Vessel strike risk areas are also identified through surveys, historical data and interagency collaboration (e.g. the National Environment Science Program's national ship strike risk project) to inform management actions.

Compliance of whale and dolphin watching operations is also monitored to help address the threat of boat collision and disturbance.

A NSW licensed wildlife rescue and rehabilitation groups provide annual reports to NSW Government for inclusion into Elements. The MEMS is working towards all rescue groups using Elements in real time to monitor threats continually.

Humpback whale *Megaptera novaeangliae*.
Image: NSW DPI, State of New South Wales

C.4.5.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Elements database incidents	Reports of cetacean incidents	Statewide	Ongoing
Wildlife rehabilitation data	Number of cetaceans requiring rescue	Statewide	Ongoing annual reporting cycle
Postmortem results	Cause of death or disease Data from NSW Shark Control Program	Statewide	Ongoing sporadic
Humpback whale counts	Number of Humpbacks migrating	Qld data of East Australia Humpback population data	Sporadic
Bionet data	Bionet records of observations	Statewide	Ongoing

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Vessel strike	Number of vessel strikes per year	Statewide	Ongoing
Recreation and tourism (wildlife disturbance)	Media analysis	Statewide	Incidental, ongoing
Rates of interaction between commercial fisheries and threatened and protected marine mammals, reptiles and birds.	Total number and circumstances of interactions (including the life status at the time of the interaction)	Statewide	Ongoing
Shark meshing program	Total number and circumstances of interactions (including the life status at the time of the interaction)	Statewide	Ongoing
Whale and dolphin watching	Covert and overt compliance and audits	Statewide	Ongoing
Entanglements	Confirmed number of entanglement sightings and source of entanglement	Statewide	Ongoing

C.4.5.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Cetaceans protected under				X		X	Elements, Wildlife rehabilitation data
Dugong protected under the BCA				X		X	Elements, Wildlife rehabilitation data

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Shipping				X		X	Elements and wildlife rehabilitation data
Recreation and tourism				X		X	Elements and wildlife rehabilitation data
Commercial fishing				X		X	Elements
Shark meshing program				X		X	Dalton and Peddemors 2019; NSW DPI 2016
Whale and dolphin watching				X		X	Elements and local file. Audit report

C.4.5.8 Relevant contextual data

- NSW Wildlife Rescue and Rehabilitation annual data reports
- Elements data – NB this data are not comparable over years due to varied effort in collection
- compliance audit reports and operation reports
- media coverage/social media information
- Shark Control Program data
- Australian Registry of Wildlife Health data
- Dolphin Marine Animal Rescue Trust – postmortem analysis
- Wildlife Health Australia – disease monitoring
- Australian Ship Strike register
- UQ humpback whale migration count
- Australian Museum – Genetic analysis.

C.4.5.9 Other relevant projects/data

- SOS
- ORRCA whale census day
- Cape Solander Citizen Science whale monitoring

C.4.5.10 Data storage

- SOS report card (DPE)
- compliance reports (NPWS)
- Elements database (NPWS)
- Wildlife Rescue and Rehabilitation annual data reports (NPWS)
- International Whaling Commission annual report (IWC Portal) https://portal.iwc.int/
- National Ship Strike Register (Aust. Govt) https://data.marinemammals.gov.au/report/shipstrike

C.4.5.11 References

Dalton S and Peddemors V (2019) *Shark Meshing (Bather Protection) Program 2018-19 Annual Performance Report*, NSW Department of Primary Industries, 46 pp.

NSW DPI (2016) *5-Year Review of the 2009 Joint Management Agreements for the NSW Shark Meshing (Bather Protection) Program*, NSW Department of Primary Industries, 45 pp.

C.4.6 Pinnipeds project – N2

C.4.6.1 Overview

Impacts on protected species under the BCA are monitored using various data sources. The data are collated annually to understand the rate of impact of the key stressors.

Data are collected from the following sources:

- records of marine wildlife events and incidents captured in Elements
- annual returns from the NPWS licensed Rescue and Rehabilitation Sector
- SOS Report Cards and data (Bionet).

Data was consolidated in 2019 but some data date back to 2000. Current monitoring programs are species dependent and are not part of broad program.

Changes to the systems and governance will lead to higher reporting rates.

Species include:

- Australian Fur Seal
- Long-nosed Fur Seal
- Subantarctic Fur Seal
- Leopard Seal
- Australian Sea Lion
- Crab-eater Seal
- Southern Elephant Seal.

This project is led by DPE-EHG and funded by the MEMS and SOS. Project partners include: DPI-F; TfNSW; rescue and rehabilitation organisations; veterinarians; LGOV; TAFE; Australian Registry of Wildlife Health; Dolphin Marine Rescue Animal Rehabilitation Trust

C.4.6.2 Project type/objectives

- condition and trend
- address knowledge gap(s)
- monitor effectiveness of MEMS management
- contextual data

Seal colony, Jervis Bay. Image: NSW DPI, Paul Foley

C.4.6.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Species protected under BCA	Enjoyment – enjoying the biodiversity and beauty of the marine estate Participation – safety, health and wellbeing Cultural heritage & use benefits – tangible and intangible Aboriginal cultural heritage	Shipping - includes large and small commercial vessels i.e., trade ships, cruise ships, major port facilities, ferries, charter boats. Fishing vessels and smaller port facilities Commercial fishing - includes estuary general, estuary prawn trawl, OT&L, ocean trawl, ocean haul, sea urchin and turban shell, abalone Recreational fishing - includes shore-based line and trap fishing, boat-based line and trap fishing, hand gathering Boating and boating infrastructure - Recreation and tourism - includes passive use, snorkelling and diving, 4WD, charter activities and shark control measures Foreshore/urban development - includes beach nourishment and grooming Water pollution and sediment contamination - includes urban stormwater, agricultural runoff, industrial discharges, sewage effluent and thermal discharges Clearing, dredging and excavation activities - includes vegetation clearing, dredging, service infrastructure, mining and extraction and cattle grazing Estuary openings/modified freshwater flows - includes hydrological modifications/estuary entrance/modified freshwater flows Deliberate introduction of plants and animals – e.g. foxes, bitou bush Climate change - includes all climate change components based on a 20-year projection of impacts only	Wildlife disturbance (shorebirds, turtles, whales) and impacts to ecological health by dog walkers, 4WD, marine vessels etc.

C.4.6.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Extent of wildlife disturbance impacts (including noise) on protected species Interaction with dredging, aquaculture, mining activities and service infrastructure Population modelling and predicted recovery of seal species in NSW including impacts of climate change Levels of heavy metals, POC's and other toxins in marine species and geographic hot spots in key NSW habitats impacts of recreational and commercial fishing on species in NSW	Partial Not yet addressed (pending funding)

C.4.6.5 Methods

Collaboration occurs with NSW Fisheries to monitor bycatch and entanglement of seals in NSW fisheries for example, through a fisheries observer program. This also includes electronic monitoring and the following is recorded: seal species, sex, age, and animal condition (e.g. alive or dead) and type of interaction (e.g. direct catch, entanglement, feeding off discards).

Incident records from government agencies and licensed rescue groups are collected (e.g. using NPWS Elements system and wildlife rehabilitation data) and analysed for trends in threats to the species, such as disturbance and displacement of seals at haul out and breeding sites.

An agreement with Australian Registry for Wildlife Health maximises data from shark-net bycatch to improve understanding of threats. A bycatch observer monitoring program for the OPT Fishery will address lack of knowledge on the rates of bycatch in NSW fisheries.

Monitoring occurs for evidence of disease impacting population health, including from pollution and poor water quality using a standardised disease assessment protocol. Tissue samples are also collected and archived for ecotoxicological analysis (e.g. for heavy metals and organic pollutants) as a precaution to be analysed if a population level Unusual Mortality Events occurs.

Marine species incident reports are collected and monitored using the NPWS Elements system to assess trends in threats to the species disturbance and displacement of seals at haul out and breeding sites, and to provide data on response rates to animals at risk of harm.

The Elements database is also used to record trends for vessel strikes relating to the threat of shipping, and for entanglements relating to the threat of commercial fishing.

C.4.6.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Elements database Incidents	Reports of pinniped incidents	Statewide	Ongoing
Wildlife rehabilitation data	Number of pinnipeds requiring rescue or dead	Statewide	Ongoing annual reporting cycle
Postmortem results	Cause of death or disease	Statewide	Ongoing sporadic
Bionet data	Bionet records of observations	Statewide	Ongoing

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Recreation and tourism (wildlife disturbance)	Media analysis	Statewide	Ongoing
Fisheries interaction	Number of fisheries interactions	Statewide	Ongoing
Seal watching and swimming	Covert and overt compliance and audits	Statewide	Ongoing
Entanglements	Confirmed entanglement reports/mortality and disentanglement operations	Statewide	Ongoing

C.4.6.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Pinnipeds protected under				X		X	Elements and wildlife rehabilitation data

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Shipping				X		X	Elements and wildlife rehabilitation data
Recreation and tourism				X		X	Elements and wildlife rehabilitation data
Commercial fishing				X		X	Elements and wildlife rehabilitation data
Shark meshing program				X		X	Dalton and Peddemors 2019; NSW DPI 2016
Recreational fishing				X		X	Elements and wildlife rehabilitation data
Whale and dolphin watching				X		X	Elements and local file. Audit report

C.4.6.8 Relevant contextual data

- NSW Wildlife Rescue and Rehabilitation annual data reports
- Elements data – NB this data are not comparable over years due to varied effort in collection
- compliance audit reports and operation reports
- media coverage/social media information
- Australian Registry of Wildlife Health data
- Dolphin Marine Animal Rescue Trust – postmortem analysis
- Wildlife Health Australia – disease monitoring
- Australian Museum – Genetic analysis.

C.4.6.9 Other relevant projects/data

Saving Our Species (SoS): Drones are used to conduct an annual census of the colonies at Montague Island during the breeding season to monitor population trend. Citizen scientists count pups, adults and entangled animals from image data. Automatic processing of images (i.e., artificial intelligence) will be incorporated once the technology is nationally available.

C.4.6.10 Data storage

- SOS report card (DPE)
- Compliance reports (NPWS)
- Elements database (NPWS)
- wildlife rescue and rehabilitation annual data reports (NPWS).

C.4.6.11 References

Dalton S and Peddemors V (2019) *Shark Meshing (Bather Protection) Program 2018-19 Annual Performance Report*, NSW Department of Primary Industries, 46 pp.

NSW DPI (2016) *5-Year Review of the 2009 Joint Management Agreements for the NSW Shark Meshing (Bather Protection) Program*, NSW Department of Primary Industries, 45 pp.

C.4.7 Marine turtles project – N3

C.4.7.1 Overview

Initiative 5 is not directly responsible for abating many of the threats to marine wildlife. Monitoring and maximising data collected from marine wildlife will assess how actions undertaken under other initiatives and by partners are abating the cumulative threats to marine wildlife. Initiative 5 will also work with the community and industry to better understand threats to marine wildlife and how to address them.

NSW is a partner in the delivery of the Recovery Plan for Marine Turtles in Australia (Recovery Plan for Marine Turtles in Australia | Department of Agriculture, Water and the Environment)

Species of marine turtles in NSW:

- Green Turtle (foraging and nesting)
- Loggerhead Turtle (foraging and nesting)
- Hawksbill Turtle (foraging)
- Leatherback Turtle (foraging)
- Flatback Turtle (foraging).

The DPE SoS Program has teamed up with Australian Seabird Rescue to develop the NSW TurtleWatch, a citizen science program involving volunteers to collect valuable data for marine turtles nesting in NSW and their potential threats.

While marine turtles are migratory species and recovery depends primarily on actions largely outside of NSW waters, monitoring of threats to turtles in NSW waters and identification of measures to protect them is a priority. All reported turtle incidents in NSW are recorded in a central emergency database (Elements) for analysis of trends and prioritisation of temporal and spatial threat mitigation. Postmortem reports and observations are also recorded in Elements.

A NSW licensed wildlife rescue and rehabilitation groups provide annual reports to NSW Government for inclusion into Elements. The MEMS is working towards all rescue groups using Elements real time to monitor threats continually.

The marine sea turtles project is led by DPE-EHG and funded by the MEMS and SOS. Project partners include: Australian Seabird Rescue; DPI Fisheries; rescue and rehabilitation organisations; veterinarians; Taronga Conservation Society; SOS; Australian Registry for Wildlife Health; Dolphin Marine Rescue Animal Rehabilitation Trust; LLS; LGOV.

C.4.7.2 Project type/objectives

- condition and trend
- address knowledge gap(s)
- monitor effectiveness of MEMS management
- contextual data.

C.4.7.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	**Social, cultural and economic benefits**	**Environmental**	**Social, cultural and economic**
Species protected under BCA	Enjoyment: Enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values Tangible and intangible Aboriginal cultural heritage (traditions, spiritual values, knowledge, places, items and source of food)	Shipping - includes large and small commercial vessels i.e., trade ships, cruise ships, major port facilities, ferries, charter boats. Fishing vessels and smaller port facilities Commercial fishing - includes estuary general, estuary prawn trawl, OT&L, ocean trawl, ocean haul, sea urchin and turban shell, abalone Recreational fishing - includes shore-based line and trap fishing, boat-based line and trap fishing, hand gathering Boating and boating infrastructure - Recreation and tourism - Includes passive use, snorkelling and diving, 4WD, charter activities and shark control measures Foreshore/urban development - includes beach nourishment and grooming Water pollution and sediment contamination - includes urban stormwater, agricultural runoff, industrial discharges, sewage effluent and thermal discharges Clearing, dredging and excavation activities - includes vegetation clearing, dredging, service infrastructure, mining and extraction and cattle grazing Estuary openings/modified freshwater flows - includes hydrological modifications/estuary entrance/modified freshwater flows Deliberate introduction of plants and animals – e.g. foxes, bitou bush Climate change - Includes all climate change components based on a 20-year projection of impacts only	Wildlife disturbance (shorebirds, turtles, whales) and impacts to ecological health by dog walkers, 4WD, marine vessels etc.

C.4.7.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Extent of wildlife disturbance impacts (including noise) on protected species Interaction with dredging, aquaculture, mining activities and service infrastructure Population modelling and predicted movement of turtles in and through NSW waters due to national population recovery and climate change Levels of heavy metals, POC's and other toxins in marine species and geographic hot spots in key NSW habitats Impacts of recreational and commercial fishing on species in NSW Habitat and food availability along NSW coast and predicted climatic changes Beach preference and suitability for nesting due to climate change	Partial

C.4.7.5 Methods

A partner project involving SOS, DPE-EHG Science and Research and Griffith University aims to better understand and plan for climate impacts on sea turtles uses. It uses sand temperature data loggers along NSW beaches between Tweed Heads and Wollongong to collect data to help understand the effect of present-day temperatures on turtle hatchlings across the latitudinal gradient of current and potential future nesting beaches in northern NSW.

Impacts on protected species under the BCA are monitored using various data sources. The data are collated annually to understand the rate of impact of the key stressors.

Data are collected from the following sources:

- records of marine wildlife events and incidents captured in Elements
- annual returns from the NPWS licensed Rescue and Rehabilitation Sector
- SOS Report Cards and data (Bionet)
- data loggers
- beach monitoring

Data was consolidated in 2019 but some data dates back to 2000. Current monitoring programs are species dependent and are not part of broad program. Monitoring of some species is funded under SOS.

Changes to the systems and governance will lead to higher reporting rates so interpretation of actual numbers of interactions and carcasses is needed.

Catch data from the Shark Control Program will be assessed as well as postmortems and health assessments opportunistically on turtles caught in the shark meshing program to provide valuable baseline turtle health data.

DPI Fisheries will implement a fisheries observer program to address impacts of entanglement and bycatch in priority fisheries.

The DPE SoS Program has teamed up with Australian Seabird Rescue to develop the NSW TurtleWatch, a citizen science program involving volunteers to collect valuable data for marine turtles nesting in NSW and their potential threats.

While marine turtles are migratory species and recovery depends primarily on actions largely outside of NSW waters, monitoring of threats to turtles in NSW waters and identification of measures to protect them is a priority. All reported turtle incidents in NSW are recorded in a central emergency database (Elements) for analysis of trends and prioritisation of temporal and spatial threat mitigation. Postmortem reports and observations are also recorded in Elements.

A NSW licensed wildlife rescue and rehabilitation groups provide annual reports to NSW Government for inclusion into Elements. The MEMS is working towards all rescue groups using Elements real time to monitor threats continually.

C.4.7.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Nesting turtle population count	Number of nesting turtles by species	North Coast NSW	Medium term citizen science beach monitoring
Elements database Incidents	Reports of marine turtle incidents	Statewide	Ongoing
Wildlife rehabilitation data	Number of turtles requiring rescue	Statewide	Ongoing annual reporting cycle
Postmortem results	Cause of death or disease Data from turtles in NSW Shark Control Program	Statewide	Ongoing sporadic
Bionet data	Bionet records of observations	Statewide	Ongoing

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Vessel strike	Number of vessel strikes per year	Statewide	Ongoing
Recreation and tourism (wildlife disturbance)	Media coverage analysis	Statewide	Incidental, ongoing
Sand temperature for nesting turtles	Temperature (Celsius) change	Tweed to Wollongong	30 m intervals continuous

Loggerhead Turtle *Caretta caretta*. Image: D.Harasti

C.4.7.7. Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Marine sea turtles protected under				X		X	Elements, wildlife rehabilitation data

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Shipping				X			Elements and wildlife rehabilitation data
Recreation and tourism				X			Elements and wildlife rehabilitation data
Recreational fishing				X			Elements and wildlife rehabilitation data
Commercial fishing				X			Elements and wildlife rehabilitation data
Water pollution and sediment contamination	X						Postmortem analysis with data captured in Elements
climate change	X						SOS – sand temperature monitoring

C.4.7.8 Relevant contextual data

- NSW Wildlife Rescue and Rehabilitation annual data reports
- media coverage/social media information
- Shark Control Program data
- Australian Registry of Wildlife Health data
- Wildlife Health Australia – disease monitoring
- Dolphin Marine Animal Rescue Trust – postmortem analysis
- Qld Government turtle data.

C.4.7.9 Other relevant projects/data

- SOS Partnership project – Turtle Watch Program

C.4.7.10 Data storage

- SOS report card (DPE)
- Green Turtle – https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/saving-our-species-report-cards
- Loggerhead Turtle – https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/saving-our-species-report-cardscompliance reports (NPWS)
- Elements database (NPWS)
- Wildlife Rescue and Rehabilitation annual data reports (NPWS)
- Turtle watch program officer (Australian Seabird Rescue).

C.4.8 Shorebirds and seabirds monitoring – N4

C.4.8.1 Overview

Impacts on protected species under the BCA are monitored using various data sources. The data are collated annually to understand the rate of impact of the key stressors.

Data was consolidated in 2019 but some data date back to 2000. Current monitoring programs are species dependent and are not part of broad program. Monitoring of some species is funded under SOS.

Changes to the systems and governance will lead to higher reporting rates. Stressors to migratory species interstate.

Wildlife monitored include:

- Penguins
- Seabirds
- Shorebirds

This project is led by DPE-EHG and funded by the MEMS and SOS. Project partners include: DPI-F; SOS; Rescue and rehabilitation organisations; Veterinarians; LGOV.

C.4.8.2 Project type/objectives

- condition and trend
- address knowledge gap(s)
- monitor effectiveness of MEMS management
- contextual data.

C.4.8.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Species protected under BCA	Enjoyment: Enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values Tangible and intangible Aboriginal cultural heritage (traditions, spiritual values, knowledge, places, items and source of food)	Shipping - includes large and small commercial vessels i.e., trade ships, cruise ships, major port facilities, ferries, charter boats. Fishing vessels and smaller port facilities Commercial fishing - includes estuary general, estuary prawn trawl, OT&L, ocean trawl, ocean haul, sea urchin and turban shell, abalone Recreational fishing - includes shore-based line and trap fishing, boat-based line and trap fishing, hand gathering Boating and boating infrastructure Recreation and tourism - includes passive use, snorkelling and diving, 4WD, charter activities and shark control measures Foreshore/urban development - includes beach nourishment and grooming Water pollution and sediment contamination - includes urban stormwater, agricultural runoff, industrial discharges, sewage effluent and thermal discharges Clearing, dredging and excavation activities - includes vegetation clearing, dredging, service infrastructure, mining and extraction and cattle grazing Estuary openings/modified freshwater flows - includes hydrological modifications/estuary entrance/modified freshwater flows Deliberate introduction of plants and animals – e.g. foxes, bitou bush Climate change - includes all climate change components based on a 20-year projection of impacts only	Wildlife disturbance (shorebirds, turtles, whales) and impacts to ecological health by dog walkers, 4WD, marine vessels etc.

C.4.8.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Extent of wildlife disturbance impacts (including noise) on protected species	
Rate of ingestion of marine debris and associated mortality	
Population modelling and predicted recovery of species in NSW including impacts of climate change	Partial
Levels of heavy metals, POC's and other toxins in marine species and geographic hot spots in key NSW habitats	Not yet addressed (pending funding)
Impacts of recreational and commercial fishing on species in NSW on both food availability and entanglement.	

Beach Stone-Curlew *Esacus magnirostris*, Red Cliff Beach. Image: S Ward © NSW DPI

C.4.8.5 Methods

Long-term establishment of shorebird and seabird programs in NSW managed through the SOS program. This includes direct observation of resident pairs, nests, eggs, chicks and fledglings is used to track species abundance / condition over time and long-term trends in the number of breeding pairs is in progress

Surveys are conducted through the Shorebird Recovery Program to set up baseline data on the breeding activities and numbers of priority threatened shorebird species, and monitor suitable coastal habitats to determine the location of nesting sites and the level and types of threats posed at each site.

Information collected at sites includes:

- weather conditions
- a count of adult birds and fledglings
- an estimate or count of new and active nests and egg numbers
- information on the state of protective fences and required maintenance
- information on tracks or other disturbances, including the activity of people at the site
- mangrove incursion into saltmarsh is also monitored.

DPI Fisheries will implement a fisheries observer program to address impacts of entanglement and bycatch in priority fisheries.

Data from the wildlife rescue and rehabilitation sectors annual reporting shows overall reported incidents involving shorebirds and seabirds and where possible identifies cause of injury or death.

Little Tern *Sternula albifrons* with chick. Image: Geoffrey Ross NSW NPWS © State of New South Wales

C.4.8.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Wildlife rehabilitation data	Number of shorebirds and seabirds requiring rescue or dead	Statewide	Ongoing annual reporting cycle
Postmortem results	Cause of death or disease	Statewide	Ongoing sporadic
Bionet data	Bionet records of observations	Statewide	Ongoing

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Recreation and tourism (wildlife disturbance)	Media analysis	Statewide	Incidental, ongoing
Rates of interaction between commercial fishing activities and Beach nesting birds	Total number and circumstances of interactions (including the life status at the time of the interaction)	Statewide	Ongoing
Rates of interaction between recreational fishing activities and Beach nesting birds	Total number and circumstances of interactions (including the life status at the time of the interaction)	Statewide	Ongoing

C.4.8.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Beach nesting birds				X		X	SOS, NPWS google drive
Penguins				X	X		Manly population. Some data from Montague Island
Seabirds				X	X		Bionet data
Shearwaters				X	X		Muttonbird Island – NPWS data and Bionet

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Recreation and tourism							Elements and wildlife rehabilitation data
Commercial fishing		X					Barnes et al. 2021; DAWE 2020
Recreational fishing		X					Hughes et al. 2022

C.4.8.8 Relevant contextual data

- NSW Wildlife Rescue and Rehabilitation annual data reports
- Elements Data
- media coverage/social media information
- Australian Registry of Wildlife Health data
- SOS beach nesting birds and seabird projects.

C.4.8.9 Other relevant projects/data

- SOS
- Birdlife Australia.

C.4.8.10 Data storage

- SOS report card (DPE)
- Wildlife Rescue and Rehabilitation annual data reports (NPWS).

C.4.8.11 References

Barnes TC, Candy SG and Johnson DD (2021) 'Characterising seabird vessel interactions associated with demersal ocean trawling: vessel attendance depends on intrinsic and extrinsic predictors' *Endangered Species Research*, 44:327-338.

Hughes JM, Johnson DD, Collins D, Ochwada-Doyle FA and Murphy JJ (2022) 'Factors affecting seabird abundance and interaction with the nearshore 'for hire' recreational charter fishery in New South Wales, Australia', *Aquatic Conservation-Marine and Freshwater Ecosystems*, 32:385-399.

DAWE (2020) *NPOA–Seabirds Jurisdiction Report 2019*, Department of Agriculture, Water and the Environment, Canberra. CC BY 4.0.

Appendix C.5 Ensuring sustainable fishing and aquaculture (Initiative 6)

Initiative objective: To ensure fishing and aquaculture is managed in a way that is consistent with ecologically sustainable use while providing for the health, heritage and social benefits of fishing and seafood consumption.

This management initiative will enhance the management of high and moderate risk fisheries through an improved understanding of the ecosystem structure and will respond to identified threats. It will foster economically viable, ecologically sustainable commercial, cultural and recreational fishing sectors. This will have flow-on effects to community through enhanced fishing experiences, improved business viability, freshly caught seafood for consumers, and positive health and wellbeing outcomes. The initiative links to the commercial fishing reforms Business Adjustment Program (BAP). The BAP: introduced linkages between commercial fishers' shares and resource access, and catch or fishing effort; capped the total commercial catch or fishing effort by way of catch or effort quotas across a number of fishery share classes; and is streamlining processes such as real-time catch and effort reporting. It also supports the post-harvest sector, including co-operatives, supporting jobs in regional areas. It also supports the post-harvest sector, including co-operatives, supporting jobs in regional areas.

Filling knowledge gaps is an important part of this initiative, which aims to provide an improved understanding to stakeholders of management practices, including data monitoring, assessment and decision making to support fishery objectives. Harvest strategies and ecological risk assessments developed through this initiative for key fisheries will contribute to our understanding and help address and mitigate risks. Stakeholder engagement, through a structured approach to the development of harvest strategies and ecological risk assessments will build capacity and improve social licence.

Other management actions will expand or improve current programs. An environmental assessment of recreational fishing and review of recreational fishing rules will help address identified environmental and social threats, as well as maximise education, advisory and compliance regimes. This management initiative also links to the NSW oyster industry and several land-based sustainable aquaculture strategies. These strategies detail site and operational requirements, best industry practice and water quality protection guidelines. They provide a valuable community resource and include the history and operation of aquaculture in NSW and the legislation in place to monitor and regulate the industry. The threat of marine pests and disease is addressed in this initiative (and linked to MEMS Initiative 7, NSW MEMA 2021) as any outbreak will have significant impacts on seafood consumption. Liaison and cooperation with the Commonwealth to mitigate biosecurity threats, will continue.

A key objective of this initiative is the development and implementation of harvest strategies, which is a framework that specifies predetermined management actions necessary to achieve the agreed ecological, economic and/or social management objectives (from Sloan et al. 2014).

The principal management objective of this initiative is to ensure fishing and aquaculture is managed in a way that is consistent with ecologically sustainable use while providing for the health, heritage and social benefits of fishing and seafood consumption.

The specific MEMS management actions that relate to environmental monitoring indicators are:

- 6.1 Introduce harvest strategies and evaluate ecological risk in partnership with stakeholders and shareholders to address the priority threats associated with the reduction in abundance of fish species and trophic levels
- 6.2 Conduct an environmental assessment of recreational fishing, periodically review current rules, and take action to improve fish stocks and to address threats associated with harvest, bycatch and illegal sale of fish
- 6.4 Apply best-practice guidelines for seagrass protection in the NSW Oyster Industry Sustainable Aquaculture Strategy
- 6.5 Integrate various commercial, recreational and cultural fishing data and new research into the Monitoring Program to address key knowledge gaps associated with harvest and bycatch.

Environmental monitoring supporting Initiative 6 focuses on filling knowledge gaps and monitoring the condition and trends of and threats to fish assemblages. Projects monitoring fish assemblages are outlined in Table C9 (and included in this document). The Estuarine habitat monitoring and threat assessment Project (formerly Monitoring and assessment of estuarine habitats and disturbances) also supports Initiative 6 but primarily contributes monitoring information to other MEMS initiatives.

TABLE C9. Projects contributing monitoring information to Initiative 6 management actions.

Project	MEMS action(s)	Supports MEMS action(s)
Development of harvest strategies	6.1.2	6.2
Informing adaptive management of portunid fisheries in NSW (FRDC 2017/006)	6.1	
Status of Australian Fish Stocks	6.2	
The role of spatial protection measures in mitigating effects of bycatch and increasing yields in the NSW Ocean Trawl Fishery (FRDC 2016/020)	6.1	5.5
Recreational Fisheries Monitoring Program (RFMP): surveys of recreational fishers in NSW waters	6.1, 6.2	
Statewide BRUVs monitoring of reef fishes		2.5
Subtidal reef monitoring		2.5
Importance of offshore islands and headlands as nursery areas for reef fishes		Int. 5

C.5.1 Status of Australian Fish Stocks (SAFS) – F9

C.5.1.1 Overview

The Status of Australian Fish Stocks (SAFS) program is a national collaboration between all jurisdictions that assesses the biological sustainability of wild-caught fish stocks against a nationally agreed framework. DPI-F has adopted the SAFS assessments as the official stock status determinations for NSW. The 2020 will be the fifth iteration of this initiative of the SAFS program and will produce sustainability assessments for more than 80 important species harvested in NSW waters. The assessments will be based on the 2018/19 year for most species.

The SAFS initiative is a national partnership between Fisheries agencies. DPI-F partner with the Fisheries Research and Development Corporation (FRDC) as well as other agencies that jointly manage fish stocks relevant to NSW. Their roles are to contribute to the scientific assessment of species. Co-investigators include: CSIRO Oceans and Atmosphere, WA Department of Agriculture, Fisheries and Forestry (WA); Department of Agriculture and Fisheries (Qld); Department of Economic Development Jobs Transport and Resources (Vic); Department of Primary Industries and Regional Development (WA); Department of Primary Industry and Resources (NT); FRDC; South Australian Research and Development Institute; and University of Tasmania (UTAS).

C.5.1.2 Project type/objectives

- monitor condition and trend
- fill knowledge gaps.

School of Mulloway *Argyrosomus japonicus*. Image: © Gary Bell oceanwideimages.com

C.5.1.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Fish assemblages	Viability of businesses Indirect values	Commercial fishing Recreational fishing Aboriginal cultural fishing (line fishing, spear fishing, hand gathering, traditional fishing methods, related cultural traditions)	Resource use conflict (loss or decline of marine industries) Environmental (reductions in abundances of species and trophic levels)

C.5.1.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Includes some species of lower priority to DPI-F that may be identified as requiring greater investment in monitoring and assessment as a result of potentially being assessed as 'Undefined' within the SAFS framework	Partial

C.5.1.5 Methods

In general, stock status classifications assess whether the current abundance (number or biomass) of fish in a stock is at an adequate level and whether the level of fishing pressure (amount of fish being removed through fishing) is adequately controlled through management. The terminology, criteria and reference points used for stock status classification can vary between species and jurisdictional status reports.

The abundance of a wild fish stock is usually compared with the abundance of that same stock before any fishing had taken place. Abundance is considered to be adequate if there is a large enough proportion of the original adult stock remaining that production of juveniles (recruitment) is not significantly reduced. That is, the abundance of adults has not been reduced to the point where there is increased risk of recruitment failure. This level of adult abundance will vary between different species of fish.

The classification system agreed on by the SAFS reports Advisory Group combines information on both the current stock size and the level of catch into a single classification for each stock. To classify stocks into one of these categories, the current abundance and level of fishing pressure are compared with defined biological reference points. Each stock is then classified as either a sustainable stock, recovering stock, depleting stock or depleted stock. Indicators, measures and monitoring protocols are species specific. Further details are provided at Status of Australian Fish Stocks Reports.

Snapper *Chrysophrys auratus*. Image: © Gary Bell oceanwideimages.com

C.5.1.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Biomass (various species)	Biomass relative to a limit reference point. May be estimated via a population model, or via proxies such as: survey indices; catch per unit of effort; catch trends; age and size composition in catch; spatial distribution	Variable depending on agreed stock structure. Can be jurisdictional, management unit or biological stock.	Variable depending upon data availability. Generally annual frequency

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Fishing pressure	Fishing mortality relative to a limit reference point May be estimated via a population model, or via proxies such as: fishing effort; catch per unit of effort; age and size composition in catch; spatial overlap; mortality estimates	Variable depending on agreed stock structure. Can be jurisdictional, management unit or biological stock	Variable depending upon data availability Generally annual frequency

C.5.1.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Fish stocks				X		X	Status of Australian Fish Stocks Reports

Status of Australian Fish Stocks Reports

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Fishing pressure (harvest and bycatch)				X		X	Status of Australian Fish Stocks Reports

Status of Australian Fish Stocks Reports

C.5.1.8 Relevant contextual data

Data are sourced from commercial and recreational fisheries monitoring, fishery-independent surveys and species-specific research projects.

C.5.1.9 Other relevant projects/data

Sustainable Fish Harvest Program (https://www.dpi.nsw.gov.au/fishing/fisheries-research/fisheries-resource-assessment/harvest-strategiesing-aquaculture/sustainable-fish-harvest-program).

C.5.1.10 Data storage

SAFS assessments are publicly available at: http://fish.gov.au.

C.5.1.11 References

Sloan S, Smith T, Gardner C, Crosthwaite K, Triantafillos L, Jeffries B and Kimber N (2014) *National guidelines to develop fishery harvest strategies*, Fisheries Research and Development Corporation FRDC project no. 2010/061.

C.5.2 Harvest strategy development for NSW fisheries – F16

C.5.2.1 Overview

This project is delivering against management actions described for MEMS Sub-actions 6.1.2-4 and supports outcomes against the objectives of Action 6.1, within Initiative 6 of the MEMS Implementation Plan.

A harvest strategy is a framework that specifies predetermined management actions in a fishery necessary to achieve agreed ecological, economic and social objectives (Sloan et al. 2014). Through collaborative development between fishery stakeholders, including fishery managers and fishers, harvest strategies prescribe management actions in response to different fishery conditions (desirable and undesirable) ensuring all stakeholders understand the reason for and level of a management response before it occurs. This promotes transparent, proactive and precautionary management that avoids ad hoc, reactionary or delayed decisions.

Harvest strategies identify decisions to be made to ensure fishery objectives are met, such as changes to harvest rates or levels (e.g. catches or levels of effort) to ensure sustainable harvest of commercially, recreational and culturally important species. Harvest strategies are considered world's best practice for contemporary fisheries management because they: (1) provide a structured approach to fishery monitoring, assessment and management responses and; (2) provide increased transparency and certainty regarding the status and management of fish stocks and fisheries, respectively.

Development of harvest strategies requires clear articulation of: (1) broad fishery goals; (2) specific operational objectives; (3) performance indicators and reference points (e.g. target and limit reference points), against which the fish stock or fishery can be assessed and; (4) decision rules, designed to influence actions affecting the stock or fishery's performance in relation to the objectives (e.g. pre-agreed actions taken to control the rate or level of fishing to ensure ongoing sustainable harvests). An important consideration during harvest strategy development is that of understanding the relationships between the benefits and costs of different strategies that is, less precautionary decision rules with costs associated with more certain assessments and comprehensive and representative data and monitoring, and vice versa.

This project is developing and evaluating frameworks that guide and support stakeholders through the considerations, complexities and decisions required to be made within each step of building a fishery harvest strategy. It is interrogating current data (fishery-dependent and fishery-independent), identifying aspirational data sources to inform current and improved assessment options and summarising current management controls and potential future arrangements, based on the biological and operational characteristics of individual species and fisheries, respectively. Through these processes, this project supports the goal of developing and implementing harvest strategies to meet the growing needs of NSW Fisheries management, including supporting the sustainable use of fish stocks and meeting broader ecological, economic and social objectives of stakeholders.

This project is being implemented through the development of the NSW Fisheries Harvest Strategy Policy and Guidelines (NSW DPI 2021a and 2021b) as well as staged development of harvest strategies for several case study fisheries (fish stocks), including:

- Eastern Rock Lobster (*Sagmariasus verreauxi*)
- Eastern School Whiting (*Sillago flindersi*) and Stout Whiting (*Sillago robusta*)
- Spanner Crab (*Ranina ranina*)
- Mulloway (*Argyrosomus japonicus*)
- Abalone (*Haliotis rubra*)
- Yellowtail Kingfish (*Seriola lalandi*)
- Snapper (*Chrysophrys auratus*)

These fisheries/fish stocks were selected because harvest or activities associated with it were identified as priority threats within the NSW MEMS Threat and Risk Assessment (TARA), or they contribute to an understanding of the range of fishery scenarios for which harvest strategies need to be developed, including consideration of commercial, recreational and Aboriginal fishing sector representation and management objectives and levels of data quality.

Developing harvest strategies for key stocks will reduce the risk levels identified for NSW environmental assets. The range of issues encompassed by these fisheries will also test and implement of the processes developed to build harvest strategies under the NSW Harvest Strategy Policy and Guidelines.

This work is led by NSW DPI Fisheries and supported through the NSW Marine Estate Management Strategy, with project partners including CSIRO and the UTAS. The work is funded by MEMS and NSW DPI Core Funds.

C.5.2.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Fish assemblages (harvest and bycatch stressors only) Threatened and protected fish and sharks	Viability of businesses Cultural heritage and use Participation (safety, health and wellbeing) Enjoyment (consumptive use) Indirect values	Commercial fishing (Ocean Trawl Fishery) Commercial fishing (Estuary General Fishery) Commercial fishing (OTL Fishery) Recreational fishing (hand gathering) Recreational fishing (boat-based line and trap) Recreational fishing (shore-based line and trap) Aboriginal cultural fishing (line fishing, spear fishing, hand gathering, traditional fishing methods, related cultural traditions)	Resource use conflict (conflict over resource access and use) Resource use conflict (loss or decline of marine industries) Resource use conflict (excessive or illegal extraction) Environmental (reductions in abundances of species and trophic levels) Governance (inadequate, inefficient regulation, over-regulation Governance (lack of or ineffective community engagement or participation in governance)

C.5.2.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Fish assemblages (OTL; Estuary General (Hand Gathering)) Management of fish stocks and potential impacts on trophic structure Governance of the marine estate (community awareness of the marine estate) Monitoring, assessment and decision rule components suitable for harvest strategies of NSW fished stocks Fishery objectives of NSW recreational fishers Data sources and analytical approaches for developing performance indicators within NSW harvest strategies Fish assemblages (OTL; Estuary General (Hand Gathering)) Management of fish stocks and potential impacts on trophic structure Governance of the marine estate (community awareness of the marine estate)	Partial

C.5.2.5 Methods

Principal objective: Deliver processes and provide analytical outcomes in support of management initiatives to deliver harvest strategies for key fisheries, thereby supporting NSW marine estate assets and benefits, addressing their threats and contributing to overcome knowledge gaps.

Specific objectives reflect those within contributing projects and include:

- improve understanding among fishery stakeholders of the structure and function of harvest strategies
- review Australian fisheries management regimes to identify and describe the inclusion of multi-sector fishery components in harvest strategies (to inform objective 1)
- interrogate NSW recreational fishing data sources available to service harvest strategy development
- develop a data monitoring framework and review all available data sources and monitoring activities (within NSW Fisheries) to inform fishery assessments and development of harvest strategies and ecological risk assessment
- utilise the FishPath decision support software to categorise species specific biology, fisheries ecology and fishery operational characteristics of case-study fisheries to short-list data monitoring, assessment and management control options to inform stakeholders and support harvest strategy development
- develop collaborative arrangements, with national and international experts in the fields of fishery assessments and harvest strategies to support harvest strategy development in NSW.

Expert facilitated workshops will introduce the concept, purpose, structure and function of a fishery harvest strategy to stakeholder representatives from all relevant sectors in a fishery (e.g. Aboriginal, commercial, recreational and community stakeholders). The FishPath decision support tool, its structure and function will be presented to these workshops for familiarisation. Preliminary outputs from initial case study fishery characterisations will include monitoring, assessment and decision rule options; these will be provided to formal harvest strategy working groups for consideration in the development of a draft harvest strategy.

Ancillary project work will interrogate available NSW fishing datasets and develop and apply analytical techniques to inform performance measures for fishery harvest strategies.

C.5.2.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Biological stock status	Trends in species stock status (species with harvest strategy)	Statewide/regional (considering population structure)	Long term

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Removal of biomass	Catch (from fishing)	Statewide (considering population structure)	Short term
Fishing pressure	Effort (fishing)	Statewide (considering population structure)	Short term

C.5.2.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Fish stocks				X		X	NSW DPI 2021a; 2021b; 2022a; 2022b

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Commercial Fishing (harvest and bycatch)				X		X	NSW DPI 2021a; 2021b; 2022a; 2022b
Recreational Fishing (harvest and bycatch)				X		X	NSW DPI 2021a; 2021b; 2022a; 2022b
Indigenous cultural fishing				X		X	NSW DPI 2021a; 2021b; 2022a; 2022b

C.5.2.8 Relevant contextual data

- NSW marine estate – Harvest strategies https://www.marine.nsw.gov.au/strategy-implementation/ensuring-sustainable-fishing-and-aquaculture/harvest-strategies
- NSW DPI Fisheries stock assessments and stock status summaries https://www.dpi.nsw.gov.au/fishing/commercial/open-for-comment/stock-status-summary-reports
- National Guidelines to develop fishery harvest strategies http://frdc.com.au/Archived-Reports/FRDC%20Projects/2010-061-DLD.pdf
- FishPath decision support tool – https://www.fishpath.org/
- SAFS Reports (https://www.fish.gov.au/).

C.5.2.9 Other relevant projects/data

- Fisheries Research and Development Corporation (FRDC) project 2019/021 – Integrating Recreational Fishing Information into Harvest Strategies for multi-sector fisheries http://www.frdc.com.au/project/2019-021
- NSW Recreational Fishing Saltwater Trust project (DPISO50)- Integrating Recreational Fishing Information into harvest strategies for multi-sector fisheries
- project (Subaction 6.1.2) is closely integrated with Subaction 6.1.1.

C.5.2.10 Data storage

Data stored on NSW DPI databases and project outputs (i.e., harvest strategies) will be public documents available via NSW DPI Fisheries website https://www.dpi.nsw.gov.au/fishing/harvest-strategies

C.5.2.11 References

NSW DPI (2021a) *NSW Fisheries Harvest Strategy Policy*, NSW Department of Primary Industries, 17 pp.

NSW DPI (2021b) *NSW Fisheries Harvest Strategy Guidelines*, NSW Department of Primary Industries, 13 pp.

NSW DPI (2022a) *NSW Lobster Fishery Harvest Strategy*, NSW Department of Primary Industries, 17 pp.

NSW DPI (2022b) *NSW Trawl Whiting Harvest Strategy*, NSW Department of Primary Industries, 17 pp.

Sloan S, Smith T, Gardner C, Crosthwaite K, Triantafillos L, Jeffries B and Kimber N (2014) *National guidelines to develop fishery harvest strategies*, Fisheries Research and Development Corporation FRDC project no. 2010/061.

C.5.3 Recreational Fisheries Monitoring Program (RFMP): surveys of recreational fishers in NSW waters – F17

C.5.3.1 Overview

Recreational fishing is one of NSW's most popular pastimes with large proportions of the population participating in some type of recreational fishing during a typical year. Recreational fishing also accounts for significant amounts of the total catch for many key species in NSW and indeed for some, recreational fishers account for the majority of the catch.

Due to the significance of the recreational fishery, the NSW Department of Primary Industries (NSWDPI) is committed to providing quality recreational fishing opportunities and ensuring sustainability of the State's fish stocks. To achieve these aims, regular and cost-effective monitoring of the recreational fishery is required to ensure effective management and ongoing health of our fisheries.

Collecting information on the recreational sector is extremely challenging. There are hundreds of thousands of participants, targeting a wide variety of species across a diverse array of waterbodies, with thousands of access points.

Ongoing monitoring is important to provide estimates of recreational fishing effort and catch and to observe changes in these indices through time. For fisheries where recreational fishing provides the only source of data or where the recreational catch is equal to or exceeds the commercial catch, understanding the impact of recreational fishing is essential.

To meet these demands for a cost-effective, high quality and regular monitoring program the NSW DPI developed the Recreational Fisheries Monitoring Program (RFMP). The RFMP is a comprehensive citizen science program that engages with thousands of recreational fishers who voluntarily provide information on their fishing activities within a rigorous scientific framework.

C.5.3.2 Project type/objectives

- condition and trend
- contextual data
- knowledge gaps
- contributes to monitoring progress towards MEMS outcomes.

C.5.3.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Coastal and marine waters: Fish assemblages (this is NOT fish stocks), FMA species Estuarine waters: Fish assemblages (this is NOT fish stocks), FMA species	Reductions in abundances of species and trophic levels Loss or decline of marine industries	Recreational boat-based line and trap fishing Recreational fishing – shore-based line and trap fishing Recreational fishing – hand gathering	Environmental (reductions in abundances of species and trophic levels) Enjoyment: Enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values Governance (lack of or ineffective community engagement or participation in governance)

C.5.3.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Reduction in abundances of species and trophic levels, bycatch	Partial

C.5.3.5 Methods

The RFMP Research Surveys are based on the long-established telephone/diary survey method that has been effectively used for many large-scale recreational fishing surveys both in Australia and overseas. In NSW, a licence is required to fish anywhere in NSW waters and this licensing system provides a comprehensive list of fishers that is used as the sampling frame for the telephone/diary RFMP surveys.

The RFMP surveys are designed to provide data on key indices of recreational fishery performance through time by surveying long-term recreational fishing licence (RFL) holders on a biennial basis that is, 12-month Diary Surveys will be run every second year. Importantly, other members within the household of the selected RFL holder who fish are also included in the survey to optimise the amount of fishing data collected.

High rates of coverage of the fishing population in NSW are achieved by sampling recreational fishers resident within RFL households. For example, a review of survey data from the 2000/01 National Recreational and Indigenous Survey revealed that RFL households would likely represent over 55% of all resident NSW and ACT fishers (aged five years and older) and account for 70% of total fishing effort (fisher days) and close to 80% of the total catch (Stark unpublished data).

A 12-month Diary Survey was held from 1 October 2017 through to 31 September 2018 which collected large amounts of fishing activity data from a robust sample of RFL households.

Prior to the start of the Diary Survey, there were 432,218 current NSW long-term RFL holders (as at 31 March 2017) who resided in the most populous eastern states of Australia (New South Wales, Victoria, Queensland and the ACT). The Sydney region contributed the largest number of licence holders (38%) followed by the Hunter region (10%) and Victoria (10%). To select fishers for the Diary Survey, a Screening Survey of these RFL holders was conducted and 1618 RFL households fully responded. Information on all members of RFL households was collected which profiled past fishing history and any household member's intention to fish in the coming 12-month Diary Survey period. When information on all household members is considered, recreational fishing and demographic profiling was collected for a total of 4335 residents aged five years and older from within the sampled RFL households.

C.5.3.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Fish assemblages (harvest and bycatch stressors).	Abundance, diversity	Statewide	Long term

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Recreational fishing	Harvest and bycatch	Statewide	Long term

C.5.3.7 Baseline data

Results from a subset of data from the 2017/18 survey were compared with a similar survey done in 2013/14. The RFMP surveys are designed to provide comparative statistics on the recreational fishery through time that is, surveys are to be done on a biennial basis beginning with the 2017/18 survey. See Murphy et al. (in prep.) for a complete presentation of results from the 2013/14 and 2017/18 surveys.

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Fish assemblages			X			X	Murphy et al. 2020, Murphy et al. 2022, West et al. 2015

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Recreational fishing (boat-based line and			X			X	Hughes et al. 2021, Murphy et al. 2020, Murphy et al. 2022, West et al. 2015
Recreational fishing (shore-based line and			X			X	Murphy et al. 2020, Murphy et al. 2022, West et al. 2015
Recreational fishing (hand			X			X	Murphy et al. 2020, Murphy et al. 2022, West et al. 2015

C.5.3.8 Relevant contextual data

Surveys of 1- and 3-year licence holders have been successfully completed in 2013/14 and 2017/18. Results have been provided and used by DPI scientists and Recreational Fisheries Managers.

C.5.3.9 Other relevant projects/data

The RFMP also has a charter fishery monitoring component to complement the RFL surveys – see Hughes et al. (in prep) for details.

C.5.3.10 Data storage

Data stored on DPI databases and will be made available via Information Asset Register (IAR) portal https://iar.environment.nsw.gov.au/

C.5.3.11 References

Hughes JM, Johnson DD, Murphy JJ and Ochwada-Doyle FA (2021) *The NSW Recreational Fisheries Monitoring Program – Charter Fishery monitoring*, 2017/18, NSW DPI – Fisheries Final Report Series No. 159.

Murphy JJ, Ochwada-Doyle FA, West LD, Stark KE and Hughes JM (2020) *The NSW Recreational Fisheries Monitoring Program – Survey of Recreational Fishing in NSW, 2017/18*, NSW DPI – Fisheries Final Report Series No. 158.

Murphy JJ, Ochwada-Doyle FA, West LD, Stark KE, Hughes JM and Taylor MD (2022) *Survey of recreational fishing in NSW, 2019/20 – Key Results*, NSW DPI – Fisheries Final Report Series No. 161.

West LD, Stark KE, Murphy JJ, Lyle JM and Ochwada-Doyle FA (2015) *Survey of recreational fishing in New South Wales and the ACT, 2013/14*. Fisheries Final Report Series No. 149. NSW Department of Primary Industries, Wollongong.

C.5.4 The role of spatial protection measures in mitigating effects of bycatch and increasing yields in the NSW Ocean Trawl Fishery – F19

C.5.4.1 Overview

New South Wales has a network of permanent trawling closures along the coast, many of which are present in the inshore areas adjacent to the mouths of estuaries in northern NSW. These closures were initiated collaboratively by DPI Fisheries and industry to improve offshore yields of Eastern King Prawn by limiting harvest on smaller Eastern King Prawn in inshore waters. In the context of the above information, the Professional Fisherman's Association (PFA) and DPI Fisheries managers requested an evaluation of these permanent closures, in terms of: 1) whether they afford protection for juvenile Mulloway during periods when they are flushed from the river; and 2) whether School Prawn occur in these closure areas (without Mulloway) following floods which could be exploited when other areas are closed. Consequently, managers and fishers are seeking this scientific data to: 1) put bycatch levels of juvenile Mulloway into a broader context of potential impact and importance to the stock; and 2) underpin a suite of complementary management arrangements which give regard to both maintaining trawl catches and protecting juvenile Mulloway.

The data collected through the project will be used to generate species distribution maps across the closure and non-closures areas, throughout the sampling periods and under normal and flood conditions. The potential prawn yield that may be lost or derived from the various closure and non- closure areas will be quantified. The potential adult Mulloway yield that may be lost from juvenile mortality associated with trawling will be modelled using data generated from the surveys above, and other data and models available for the species. These estimates will be placed in the context of the broader stock and the contribution of the various juvenile nurseries. All the data will be integrated to recommend a number of potential management responses that balance access to School Prawn against juvenile Mulloway mortality.

C.5.4.2 Project type/objectives

- condition and trend
- contextual data.

C.5.4.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Coastal and marine waters: Fish assemblages (harvest and bycatch stressors only) Threatened and protected fish and sharks, marine mammals, reptiles and birds	Enjoyment: consumptive use (North and South only) Enjoyment: enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values Viability of businesses	Threats associated with bycatch and interactions with threatened and protected species in NSW commercial fisheries	Loss or decline of marine industries Reductions in abundances of species and trophic levels

C.5.4.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Reduction in abundances of species and trophic levels, bycatch	Partial

C.5.4.5 Methods

The trawl survey will focus on closure and non-closure areas off the main juvenile nurseries of the Richmond River, Clarence River and Hunter River. Sampling will occur using 20-minute tows, over the months of January-April (Taylor et al. 2020). Vessels will be triple-rigged with three Florida flyer trawls (14.6 m headline length) made from 45-mm mesh. Sampling will occur three times per month in each region, with an estimated 30-45 x 20-minute tows per region, per month of sampling.

Tows will be stratified across closure and non-closure areas within 12 nautical miles north and south of each river mouth, bounded by the 20-fathom depth contour, with tows randomly assigned to 0.3 x 1 nm grid squares in proportion to the trawlable area within each stratum. Regular sampling will be complemented by irregular field trips targeted in the weeks following flood events at any of the rivers, to evaluate the post-flood abundance of target species within these areas. Regular and post-flood population and error variance estimates for target species will be derived from trawl surveys using conventional methods.

C.5.4.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Fish assemblages	Abundance, diversity, trends in species stock status	Northern and Central Bioregions	Short term

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Fishing pressure (commercial)	Abundance, diversity, trends in species stock status	Northern and Central Bioregions	Short term

C.5.4.7 Baseline data

Historical data to assess baselines from which to measure change can be derived from previous trawl surveys (Graham and Wood 1997) and tagging studies (Montgomery 1990, Montgomery et al. 2007).

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Fish assemblages		X				X	Silburn et al. 2020; Taylor and Johnson 2020; Taylor et al. 2020; Taylor et al. 2020

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Fishing pressure (commercial)		X				X	Camp et al. 2021; Taylor and Johnson, 2020; Taylor et al. 2020; Taylor and Johnson 2021; Taylor et al. 2021a; Taylor et al. 2021b; Taylor et al. 2022

C.5.4.8 Relevant contextual data

Fishery-independent trawl surveys completed from 2017-2020 (Taylor and Johnson, 2020, Taylor et al. 2020, Taylor et al. 2021b))

Fishery assessments under the EPBC Act (http://www.environment.gov.au/marine/fisheries/nsw-managed-fisheries)

C.5.4.9 Other relevant projects/data

Project name: Commercial Fishing Trust – Observer-based surveys of NSW commercial fisheries (Ocean Trawl Fishery).

C.5.4.10 Data storage

Data stored on DPI databases and will be made available Information Asset Register (IAR) portal https://iar.environment.nsw.gov.au/

C.5.4.11 References

Camp EV, Johnson DD and Taylor MD (2023) 'Modelling the potential consequences of adaptive closure management in a penaeid trawl fishery', *Aquaculture and Fisheries*, 8(2):190-201.

Graham KJ and Wood BR (1997) *Kapala Cruise*, Report No. 116, Cronulla: Fisheries Research Institute. 91 pp.

Montgomery SS (1990) 'Movements of juvenile eastern king prawns, *Penaeus plebejus*, and identification of stock along the east-coast of Australia' *Fisheries Research*, 9(3):189-208.

Montgomery SS, Courtney AJ, Blount C, Stewart J, Die DJ, Cosgrove M and O'Neill MF (2007) 'Patterns in the distribution and abundance of female eastern king prawns, *Melicertus plebejus* (Hess, 1865), capable of spawning and reproductive potential in waters off eastern Australia', *Fisheries Research*, 88(1-3):80-87.

Silburn J, Johnson DD, Booth DJ and Taylor MD (2020) 'The effect of subsampling when monitoring bycatch in a penaeid trawl fishery' *Fisheries Research*, 224:105459.

Taylor MD and Johnson DD (2020) 'Evaluation of adaptive spatial management in a multi-jurisdictional trawl fishery', *Regional Studies in Marine Science*, 35:101206.

Taylor MD, Silburn J, Johnson DD and Booth DJ (2020) 'Impact of spatial management on non-target species in an oceanic penaeid trawl fishery' *North American Journal of Fisheries Management*, 40(2):509-520.

Taylor MD and Johnson DD (2021) 'Connectivity between a spatial management network and a multi-jurisdictional ocean trawl fishery' *Ocean and Coastal Management*, 210:105691.

Taylor MD, Hale D and Johnson DD (2021a) 'Biological evaluation of a spatial management network targeted at avoidance of non-optimal size classes of a high-value penaeid species', *Regional Studies in Marine Science*, 47:101924.

Taylor MD, Johnson DD, Hale D and Camp EV (2021b) *Spatial management within the NSW Ocean Trawl Fishery*, Final Report to the Fisheries Research and Development Corporation on project 2016/020, NSW Department of Primary Industries, Port Stephens, 142 pp.

Taylor MD, Hall KC and Johnson DD (2022) 'Effects of spatial management of a penaeid fishery on other target fish species in eastern Australia' *Fisheries Management and Ecology*, 29:575-585.

Prawns at the Newcastle Fishermans Co-Op. Image: NSW DPI, State of New South Wales

C.5.5 Informing adaptive management of portunid fisheries in New South Wales – F20

C.5.5.1 Overview

Portunid crabs are an iconic, high-value species in NSW, but catches are highly variable. This is broadly evident in recent catch statistics which show commercial Blue Swimmer Crab (BSC, *Portunus armatus*) landings ranging between 50 and 200 tonnes (t, p.a.). Also, recent surveys indicate that recreational harvest in NSW has substantially decreased from 153 t in 2000-01 to 27 t in 2013-14. Such variation in the catch of portunid crabs (and other crustaceans) is not unique, and other jurisdictions across Australia have sought to understand this variation by identifying links between environmental variability, recruitment and catch for BSC and Giant Mud Crab (GMC, *Scylla serrata*). These studies examined broad-scale linkages between catch rates, temperature and freshwater inflow, and benthic habitat, but there has been minimal attention given to these issues in NSW. While these linkages derived in other states provide some research context, they are not applicable to NSW waters because NSW is at the southern extent of east-coast distribution for both species. This creates different spawning and recruitment dynamics to those observed in other areas, and the transitional subtropical-temperate climate ultimately exacerbates environmental and oceanographic variability, and the influence of seasonality. Specifically, both the source of larvae and processes responsible for recruitment variability are unknown in NSW, as are the mechanistic processes by which rainfall, estuarine inflow, temperature, and ocean currents can affect cohort strength (through effects on spawning, dispersal, recruitment and migration).

In 2017, the Commercial Fisheries Adjustment Program has seen the NSW Government subsidise the investments of many fishing businesses to access catch quota for BSC and GMC. Quota allocation depends on scientifically based assessment of Total Allowable Catch (TAC). At present the only source of information on which to base TAC is historic catch and effort, but these are highly variable and the mechanistic factors underlying this variation are unclear. The recent NSW Marine Stocking Fishery Management Strategy outlines the development of release programs for both BSC and GMC. Effective implementation of this strategy relies on a thorough knowledge of the requirements of young crabs and the factors affecting their recruitment such that recruitment limitation can be identified, and releases targeted to address it. Through a review of existing work on these species in other states, and consultation with managers and industry, we have identified targeted research questions that will directly enhance the capacity of NSW DPI Fisheries to design and implement effective harvest management, fishery enhancement and restoration programs for BSC and GMC.

C.5.5.2 Project type/objectives

- condition and trend
- contextual data.

C.5.5.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Estuarine waters: Fish assemblages (harvest and bycatch stressors only)	Enjoyment: consumptive use (North and South only) Enjoyment: enjoying the biodiversity and beauty of the marine estate Intrinsic & bequest values Viability of businesses	Threats associated with bycatch and interactions with threatened and protected species NSW commercial fisheries	Loss or decline of marine industries Reductions in abundances of species and trophic levels

C.5.5.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Reduction in abundances of species and trophic levels, bycatch	Partial

C.5.5.5 Methods

The BSC trap survey design targets three estuaries: Wallis Lake, Port Stephens and Lake Macquarie, which are the most important BSC estuaries in NSW for commercial and recreational fisheries. The full survey has run since October 2018, and initially samples were collected from five sites per estuary, monthly, for two nights, in the third quarter of the lunar phase. This has recently been expanded to seven sites in Wallis Lake and Lake Macquarie, and nine sites in Port Stephens (including two closure sites near the mouth of the estuary). Sampling has included 5266 pot lifts, and has captured almost 17,000 BSC, with biometric data collected for all crabs, and detailed biometric data (including reproductive data) collected for about 10% of these. In addition, another two estuaries were incorporated (Botany Bay and Lake Illawarra) over the summer of 2019/20 to increase the latitudinal breadth of sampling locations to study potential effects of temperature on fecundity.

Two forms of modelling will relate BSC and GMC abundance with environmental variables: 1) spatially explicit multiple regression; 2) deterministic population modelling. Multiple regression analysis will build on previous modelling work, with an enhanced focus on detecting lagged relationships between environmental variables and landings and modelling latitudinal dispersal and connectivity which likely controls boom and bust dynamics in NSW estuaries. Deterministic population modelling will explain crab abundance by incorporating the processes driving crab abundance. This deterministic modelling is a more rigorous approach than previous correlative modelling and will give much greater power to forecast abundance to inform a biologically derived TACs. Larval dispersal is key and will be estimated using particle tracking. The core structure of the model is utilising PARCELS v2.0, an open-source Lagrangian particle tracking framework. Particles were advected in velocity fields taken from a free-running 22-year simulation (1994-2016) of the EAC configured using the Regional Oceanographic Modelling System. Initial conditions and boundary forcing for ROMS 3.4 were taken from the most recent Bluelink ReANalysis (BRAN3p5).

The model domain extended from Fraser Island in the north (25.3°S) to south of the NSW/Victoria border (38.5°S) and approximately 980 km offshore. GMC larvae were seeded into the model as larvae, and settlement specified as crablet stage. Growth throughout the larval phase was temperature dependent, and thus the time that each particle was tracked for (i.e., pelagic larval duration, PLD) was expressed as degree-days (DD, otherwise known as the thermal constant), with settlement assumed once the cumulative sum of daily temperatures experienced by a particle equals (or exceeds) the thermal constant (with stage-specific DD estimated by multiplying temperature by the duration [in days] before metamorphosis into the next larval stage). Initial simulations held this value fixed at 535 DD (± 5 SE) which, for example, means that larvae will grow to megalopa and settle after ~22 days, in a constant water temperature of 24°C. Although PARCELS provides the ability to incorporate particle 'behaviour', such as swimming and diel vertical migration within its framework in order to more realistically simulate larval dispersal, however, there is a paucity of information relating to larval swimming ability for GMC so it was ignored. Future work will explore the sensitivity of the model to these variables for GMC, as well as incorporate variability in the thermal constant.

C.5.5.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Biological stock status	Trends in species stock status (BSC, GMC)	Statewide	Short term

Pressure/stressor indicators

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Fishing pressure (Commercial)				X		X	Johnson 2020a; Johnson 2020b; Johnstone et al. 2021; Saunders et al. 2021
Fishing pressure (Recreational)				X		X	Murphy et al. 2020; Murphy et al. 2022

Blue Swimmer Crab *Portunus pelagicus*, cooked and displayed at a fish co-op. Image: NSW DPI, State of New South Wales

C.5.5.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Biological stocks (BSC, GMC)				X		X	Johnson 2020a; Johnson 2020b; Johnstone et al. 2021; Saunders et al. 2021

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Fishing pressure (Commercial)				X		X	Johnson 2020a; Johnson 2020b; Johnstone et al. 2021; Saunders et al. 2021
Fishing pressure (Recreational)				X		X	Murphy et al. 2020; Murphy et al. 2022

C.5.5.8 Relevant contextual data

Fishery-independent trap surveys completed from 2019-2020.

Fishery assessments under the EPBC Act (http://www.environment.gov.au/marine/fisheries/nsw-managed-fisheries).

C.5.5.9 Other relevant projects/data

Project name: Expanded Commercial Fishery Observer Program (MEMS Action 5.5).

C.5.5.10 Data storage

Data stored on DPI databases and will be made available Information Asset Register (IAR) portal https://iar.environment.nsw.gov.au/

C.5.5.11 References

Johnson D (2020a) *NSW Stock Status Summary 2018/19 – Blue Swimmer Crab (Portunus armatus)*, NSW Department of Primary Industries, Fisheries, 8 pp.

Johnson D (2020b) *NSW Stock Status Summary 2018/19 – Giant Mud Crab (Scylla serrata)*, NSW Department of Primary Industries, Fisheries, 8 pp.

Johnston D, Chandrapavan A, Walton L, Beckmann C, Johnson D and Garland A (2021) 'Blue Swimmer Crab *Portunus armatus*', in Toby Piddocke, Crispian Ashby, Klaas Hartmann, Alex Hesp, Patrick Hone, Joanne Klemke, Stephen Mayfield, Anthony Roelofs, Thor Saunders, John Stewart, Brent Wise and James Woodhams (eds) 2021, *Status of Australian fish stocks reports 2020*, Fisheries Research and Development Corporation, Canberra.

Murphy JJ, Ochwada-Doyle FA, West LD, Stark KE and Hughes JM (2020) *Survey of recreational fishing in NSW*, 2017/18 Fisheries Final Report Series, No. 158.

Murphy JJ, Ochwada-Doyle FA, West LD, Stark KE, Hughes JM and Taylor MD (2022) *Survey of recreational fishing in NSW*, 2019/20 – Key Results Fisheries Final Report Series, No. 161.

Saunders T, Johnson D, Johnstone D and Walton L (2021) 'Mud Crabs *Scylla* spp.' in Toby Piddocke, Crispian Ashby, Klaas Hartmann, Alex Hesp, Patrick Hone, Joanne Klemke, Stephen Mayfield, Anthony Roelofs, Thor Saunders, John Stewart, Brent Wise and James Woodhams (eds) 2021, *Status of Australian fish stocks reports 2020*, Fisheries Research and Development Corporation, Canberra.

C.5.6 Statewide monitoring of subtidal reef fishes (BRUVs) – F5

C.5.6.1 Overview

Over the past decade, NSW Department of Primary Industries have implemented an extensive statewide monitoring program to assess rocky reef fish assemblages across the entire NSW coast. This program assesses rock reef fish diversity and associated habitats in depths of 20 – 50 metres with the monitoring program occurring on rocky reef from Cape Byron to Narooma. This monitoring program includes sites within the NSW marine parks as well as sites that are not within marine park boundaries. This long-term monitoring data allows assessment of temporal changes to rocky reef fishes and macroalgae in relation to threats and management arrangements.

This research assesses the long-term trajectory of macroalgae and fish sizes, abundance, and diversity on coastal rocky reefs (20-50 m), providing the only fisheries-independent measure of size and relative abundance of rocky reef fisheries. These data enable the assessment of climate change, recreational and commercial fishing, and estuarine discharges (possibly indicating pollution). This program has also successfully demonstrated the value of no-take areas as long-term scientific reference sites have been established in numerous no-take areas along the NSW coast.

This program was established at a statewide scale in 2010 with studies conducted at four-year intervals, providing comparative benchmarks and producing significant published evidence useful to marine estate management. Further surveys in 2021 and 2022 will inform the MIMP in evaluating the MEMS actions and further assist the NSW Government with evidence-based decision-making in management and marine park planning. A number of journal publications have resulted from this statewide research program (see below).

This monitoring program is reported on a 5-year period: data collection and video analyses in the first two years, statistical analyses in the third year, and reporting (i.e., reports, journal publications and report cards) in the fourth and fifth years.

C.5.6.2 Project type

- monitor condition and trend
- fill knowledge gaps
- contextual data.

C.5.6.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Fish assemblages Shallow reefs Threatened and protected species Marine habitats	Participation (socialising and sense of community) Ecotourism Direct values (individual enjoyment value (consumer surplus))	Commercial fishing Recreational fishing Climate change Pollution Habitat destruction	Governance of the marine estate

C.5.6.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Impacts on trophic levels of fish assemblages from recreational and commercial fishing	High
Climate change stressors, incl. adaptation and resilience building actions	High
Impacts of sewage, stormwater, agriculture, point discharges, microplastics on estuarine and marine assets	High

C.5.6.5 Methods

The primary method to assess rocky reef fish assemblages is Baited Remote Underwater Video systems (BRUVs). BRUVs are a commonly used method to survey fish communities when other methods are unsuitable due to bottom type (e.g. trawl), depth (e.g. SCUBA), or management zone (e.g. no destructive sampling permitted). The non-destructive technique of baited remote underwater video (using stereo-BRUV units) is used on rocky reefs between the depths of 20 – 50 m. Rocky reef fishes at each site are sampled using 4-6 simultaneously deployed BRUV units baited with 500 g of chopped pilchards (*Sardinops sagax*). Each BRUV deployment is for at least 30 min. duration and data are collected from when the BRUV unit reaches the seafloor.

Fish assemblages and macroalgae are sampled on 72 rocky reef sites representatively covering a span of more than 1000 km of NSW coastline and most of the mainland NSW State Marine Park network (four of five marine parks across three bioregions). Sampling occurs using Australian standard operating procedures (Langlois et al. 2018). Representative sections of the NSW coastline outside of the marine park systems are also sampled. Sampling of the NSW rocky reefs occurs is scheduled to occur in winter 2021 and 2022 (as per previous years). These data can be compared to a contemporary baseline/trajectory from the years – 2010/2011 and 2015/2016.

All fish and macroalgae will be analysed within 5 m distance of the camera (Harasti et al. 2015). For each replicate BRUVs deployment, the maximum number of individuals of each particular species in any frame at any point in time is determined (Max N) and the total Max N was the sum of Max N for each species (Cappo et al. 2004). Both are estimates of relative abundance that are considered appropriate for BRUV video analyses because they avoid problems associated with counting the same individual fish more than once and correlate well with fish abundances measured via other methods. Time of first arrival will also be recorded for each species. Measurements of each fish will be made by marking the head and fork (or midpoint) of the tail of each fish.

A generalised additive mixed modelling (GAMMs) is used to analyse the potential patterns among management zones through time (i.e., Periods) and across bioregions. GAMMs are used due to the spatial and temporal structuring of the sampling design, and because of the unbalanced design and the large number of zeros for many species. Models include the factors Zone, Bioregion and Period and also habitat factors (e.g. within video data on macroalgal coverage, reef complexity).

C.5.6.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Abundance (fish)	Size frequency distribution of fishes on rocky reefs (20-40 m)	Statewide	2010/2011, 2015/2016, (planned for every 4-5 years)
Abundance (relative) (fish)	Total maximum N (sum of maximum N for each species)	Statewide	2010/2011, 2015/2016, (planned for every 4-5 years)
Abundance (relative) (fish)	Maximum N of individuals of each species in any frame at any point; total maximum N	Statewide	2010/2011, 2015/2016, (planned for every 4-5 years)
Abundance (macroalgae, sponges, corals)	Per cent cover Presence/ absence	Statewide	2010/2011, 2015/2016, (planned for every 4-5 years)
Abundance (threatened and protected species)	Total maximum N (sum of maximum N for each species) Presence/absence	Statewide	2010/2011, 2015/2016, (planned for every 4-5 years)

Pressure/stressor indicators

N/A

C.5.6.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Rocky reefs				X		X	Knott et al. 2021
Fish assemblages				X		X	Knott et al. 2021

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Human population		X				X	Australian Bureau of Statistics - Australian Population Grid
Pollution						X	NSW Estuary Water Quality Data Compilation: 2007 – 2020
Fishing		X				X	SAFS

Australian Population Grid
NSW Estuary Water Quality Data Compilation: 2007 – 2020

C.5.6.8 Relevant contextual data

In situ temperature measurements (various locations).

C.5.6.9 Other relevant projects/data

N/A

C.5.6.10 Data storage

Data are stored in GlobalArchive which includes metadata derived from Eventmeasure software. Data are also stored on external hard drives at various Fisheries locations.

C.5.6.11 References

Australian Bureau of Statistics (2022) Australian Population Grid 2022, ABS, accessed 11 May 2023.

Coleman M, Bates A, Stuart-Smith R, Malcolm H, Harasti D, Jordan A, Knott N, Edgar G and Kelaher B (2015) 'Functional traits reveal early responses in marine reserves following protection from fishing', *Diversity and Distributions*, 21:876-887.

Davis TR and Harasti D (2020) 'Predictive modelling of illegal recreational fishing in no-take marine protected areas', *Fisheries Management and Ecology*, 27:292–301.

Goetze JS, Wilson S, Radford B, Fisher R, Langlois TJ, Monk J, Knott NA, Malcolm H, Currey-Randall LM, Ierodiaconou D, Harasti D, Barrett N, Babcock RC, Bosch NE, Brock D, Claudet J, Clough J, Fairclough DV, Heupel MR, Holmes TH, Huveneers C, Jordan AR, McLean D, Meekan M, Miller D, Newman SJ, Rees MJ, Roberts KE, Saunders BJ, Speed CW, Travers MJ, Treml E, Whitmarsh SK, Wakefield CB and Harvey ES (2021) 'Connectivity and depth improves the efficacy of no-take marine reserves', *Conservation Letters*, 27:3432-3447.

Langlois T, Goetze J, Bond T et al. (2020) 'A field and video-annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages' *Methods in Ecology and Evolution*, 11:1401-1409.

Knott NA, Williams J, Harasti D, Malcolm HA, Coleman MA, Kelaher BP, Rees MJ, Schultz A and Jordan A (2021) 'Coherent, representative and large-scale marine reserve network shows consistent change in rocky fish assemblages through time', *Ecosphere*, 12:e03447.

Harasti D, Malcolm H, Gallen C, Coleman MA, Jordan A and Knott NA (2015) 'Appropriate set times to represent patterns of rocky reef fishes using baited video', *Journal of Experimental Marine Biology and Ecology*, 463:173-180.

Harasti D, Davis T, Mitchell E, Lindfield S and Smith S (2017) 'A tale of two islands: decadal changes in rocky reef fish assemblages following implementation of no-take marine protected areas in New South Wales', Australia *Regional Studies in Marine Science*, 18:229-236.

Harasti D, Williams J, Mitchell E, Linfield D and Jordan A (2018) 'Increase in relative abundance and size of snapper *Chrysophrys auratus* following the implementation of a temperate marine protected area', *Frontiers in Marine Science*, 5:208.

Harasti D, Davis T, Jordan A, Moltschaniwskyj N and Erskine L (2019) 'Illegal recreational fishing causes a decline in a fishery targeted species (Snapper: *Chrysophrys auratus*) within a remote no-take marine protected area', *PLoS One*, 14(1):e0209926.

Harvey ES, McLean DL, Goetze JS, Saunders BJ, Langlois TJ, Monk J, Barrett N, Wilson SK, Holmes TH, and Lerodiaconou D (2021) 'The BRUV workshop – An Australian wide synthesis of baited remote underwater video data to answer broad-scale ecological questions', *Marine Policy* 127:104430.

Malcolm H, Williams J, Schultz AL, Nielson J, Johnstone N, Knott N, Harasti D, Coleman M and Jordan A (2018) 'Targeted fishes are larger and more abundant in 'no-take' areas in a subtropical marine park', *Estuarine, Coastal and Shelf Science*, 212:118-127.

Noble M, Harasti D, Fulton C and Doran B (2020) 'Identifying spatial conservation priorities using Traditional and Local Ecological Knowledge of iconic marine species and ecosystem threats', *Biological Conservation*, 249:108709.

Williams J, Jordan A, Harasti D, Davies P, Ingleton T and Barrett N (2019) 'Taking a deeper look: Quantifying the differences in fish assemblages between shallow and mesophotic temperate rocky reefs', *PLoS One*, 14(3):e0206778.

C.5.7 Statewide monitoring of shallow rocky reef biodiversity (UVC) – F10

C.5.7.1 Overview

NSW shallow rocky reefs (a significant part of the Great Southern Reef) provide a wide range of social, economic and environmental values for the people of NSW. These values are derived by people who enjoy, or work, doing fishing, spearfishing, hand gathering, snorkelling and/or scuba diving. All of these values and activities stem from the amazing biological diversity of these reef habitats which includes fishes (e.g. yellowfin bream, blue groper, snapper), sessile and mobile invertebrates (e.g. abalone, lobster, urchins, seastars, sponges) and algae (e.g. kelp, crayweed).

This project aims to monitor the condition of algae (e.g. cover/biomass), invertebrates (e.g. abundance/cover/size) and fishes (e.g. abundance/size/biomass) on shallow rocky reefs along the NSW coastline. This is of great importance due to concerns about the condition of NSW rocky reefs in relation to climate change and the numerous anthropogenic stressors – for example, changes in kelp and barrens cover due to urchin grazing; loss of macroalgae such as crayweed and kelp due to human influences and climate change; latitudinal shifts of fishes, invertebrates (e.g. corals) and algae; the effects of marine heat waves (e.g. algae and corals); and monitoring invasive species (e.g. *Caulerpa*).

Traditionally, underwater visual census has been carried out either using SCUBA or snorkelling and sampled by direct observation and/or estimation of density and size of fishes, invertebrates and algae within belt transects by highly trained biologists. These techniques have been used by DPI for long-term monitoring at numerous locations along the NSW coastline (e.g. Jervis Bay since 1996; Solitary Islands since 2002; Sydney since 2002; Batemans Bioregion since 2005; Port Stephens since 2010; Barrett et al. 2008; Coleman et al. 2013; Curley et al. 2013a; Coleman et al. 2015; Malcolm et al. 2015; Ferguson et al. 2016; Fulton et al. 2016; Davis et al. 2017; van Lier et al. 2017; Kim et al. 2019; Edgar et al. 2023).

These data can be further supplemented by data from a wide range of university, consultancy and citizen science projects. Academic research on NSW shallow rocky reefs has a long history and provides extensive coverage of the NSW coastline (Kingsford and Battershill 1998; Curley et al. 2013b). Similarly, marine surveys carried out by a wide range of environmental consultancies for a variety of assessment purposes (e.g. monitoring or impact assessment) could provide a rich source of high-value data from rocky reefs across NSW (via publicly accessible Australian Government supported data portal: GlobalArchive). Finally, citizen science groups like Reef Life Survey (RLS, https://reeflifesurvey.com/) provide freely available, high quality and standardised data across many NSW sites which has been collected since 2007. RLS, in particular, have completed annual surveys at representative locations along the NSW coastline (e.g. Solitary Islands, Port Stephen, Sydney and Jervis Bay; Coleman et al. 2015). The DPI and RLS long-term datasets will form the backbone of this monitoring program (Barrett et al. 2014; Coleman et al. 2015; Stuart-Smith et al. 2017); with academic, consultancy and other citizen science data utilised to fill in data gaps spatially and temporally where applicable.

Recent technological developments have meant that calibrated diver-video can be used to quickly and cost-effectively sample rocky reef fish, invertebrates and algae. This video technique enables data to be collected in a consistent manner which is important as different staff will be used for surveys on long-term monitoring and these staff are likely to differ greatly in their expertise of species identification. Also, the raw video can be scrutinised by multiple staff to check the species identifications (even well after the event), the accuracy of the sizes can be assured and objectively defined (i.e., due to having a calibrated system); and the raw videos can be archived or used directly for presentations to stakeholder groups and the general public. There is also the potential for the video analysis to be automated in relation to species identification, counting and sizing using artificial intelligence. These new developments offer further opportunities to improve the efficiency and cost-effectiveness of these techniques. Furthermore, new remote technology or approaches such as towed underwater video or remotely operated video may enable data to be collected without the need to have divers in the water. These techniques currently do not yield the detail provided by standard diver surveys [for example, cryptic fishes and invertebrates (i.e., within cracks, crevices or among kelp) and generally produce lower fish counts and species numbers]. Nonetheless, these remote techniques could be used to extend the data coverage over large spatial scales (i.e., kilometres rather than 100s of metres) and complement the data-rich diver surveys which may be used to assess specific areas.

To date, the DPI long-term monitoring of NSW shallow reefs has provided data for several national and international high-level publications related to climate change and condition monitoring (Edgar et al. 2014; Coleman et al. 2015; Hughes et al. 2017; Stuart-Smith et al. 2017; Kim et al. 2019). These publications indicate the immense value of the current dataset and the continuation of the program. This program has also been a substantial collaboration between DPI and a range of university groups (e.g. UTAS, UNEW, USYD, UOW, UQ, SCU, UNSW and JCU) demonstrating the wider value to marine science and education; while also ensuring cost-effective collection, analysis and

distribution of the data. In future, it is expected that this project will incorporate and have closer ties with citizen science groups (e.g. RLS and SURG). This is a unique and world class project with demonstrated ability to chart long-term changes on rocky reef condition which will have broad appeal and applied value.

C.5.7.2 Project type

- monitor condition and trend
- fill knowledge gaps
- contextual data.

C.5.7.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Fish assemblages Shallow reefs Threatened and protected species Marine habitats	Participation (socialising and sense of community) Ecotourism Direct values (individual enjoyment value (consumer surplus)) Enjoyment (social intrinsic value; consumptive use) Indirect values (intrinsic and bequest)	Commercial fishing Recreational fishing Climate change Pollution Habitat destruction	Environmental Governance of the marine estate Resource use conflict

C.5.7.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Fish assemblages and fishing (commercial and recreational) Species protected under FMA and commercial fishing	Partial

C.5.7.5 Methods

Reef fish, invertebrates and algae have been surveyed across NSW rocky reefs within most of the state's bioregions as part of long-term monitoring projects. This has included: Bateman Marine Bioregion with 69 sites (Jervis Bay 33 sites: 1996, 1999, 2001, 2002, 2003, 2004, 2005, 2009, 2012 and 2016; Brush Island through to Narooma 36 sites: 2005, 2006 or 2007 and 2017 or 2019); Manning bioregion with 10 sites: 2010, 2011, 2013, 2015 and 2017; Tweed-Moreton Marine Bioregion with eight sites: 2002, 2004, 2006, 2009, 2011, 2013, 2016, 2017 and 2019). Data from these sites will be used to assess the long- term trends in the ecological condition of reefs over decadal time scales.

These survey methods involve identifying, counting and measuring fish, invertebrates and algae by trained scientific divers swimming along replicated belt transects and sampling replicated quadrats which are laid out at each site. Although the methods are generally similar among the various projects the specifics of transects vary among the bioregions due to historical reasons and/or the aim of the initial study. In the Batemans Bioregion, the sampling methods are those employed in ongoing long-term MPA monitoring projects in temperate Australia (Barrett et al. 2008; Barrett et al. 2014; Stuart-Smith et al. 2017; Knott et al. in prep.; https://atrc.au/). Similar UVC methods have been used in the Tweed-Morton (Malcolm et al. 2015), Manning (Fulton et al. 2016; Van Lier et al. 2017) and Batemans (Coleman et al. 2013; Ferguson et al. 2016) bioregions.

Reef Life Survey (Citizen science group): Reef fish, invertebrates and algae have been surveyed across much of the NSW coastline (https://reeflifesurvey.com/survey-data/) since commencing in 2007. Surveys have been carried out annually at sites at Sydney (31), Jervis Bay (24), Batemans Bay (12), Narooma (12), Coffs Harbour and Port Stephens (13) and biennially at Lord Howe Island (36). At other sites, the surveys have been carried out more sporadically. Data from these sites will be used to assess the long-term trends in the

ecological condition of reefs over decadal time scales as well as providing data for spatial comparisons (Coleman et al. 2015; Stuart-Smith et al. 2017).

These survey methods involve counting and identifying species of fish, invertebrates and algae by trained RLS divers swimming along line transects which are laid out at each site, and removed after use (fish: 50 m x 10 m; invertebrates: 50 m x 1 m; algae: 25 x 0.25 m^2 photo-quadrats).

Analyses

Full-subset GAMMs could be used to assess long-term changes in fish, invertebrates and algae on rocky reefs at specific sites and over large spatial scales covering large, representative sections of the NSW coastline. A range of environmental and physical variables will be assessed as predictors to explain the variation in the fish assemblages spatially and temporally (e.g. sea temperature, habitat structure, macroalgal cover).

C.5.7.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	**Measure**	**Spatial scale**	**Temporal scale and frequency**
Diversity, abundance, size and biomass (fish)	Mean densities, sizes and biomass of fishes on rocky reefs (3-10 m)	Statewide	Dependent on location – from as early as 1996 to present; 5 yearly
Diversity, abundance, size and biomass (mobile macro-invertebrates – urchins, lobster, abalone)	Mean densities, sizes and biomass of macro-invertebrates on rocky reefs (3-10 m)	Statewide	Dependent on location – from as early as 1996 to present; 5 yearly
Diversity and coverage of sessile macro-invertebrates (sponges, ascidians)	Mean diversity and coverage of sessile invertebrates on rocky reefs (3-10 m)	Statewide	Dependent on location – from as early as 1996 to present; 5 yearly
Diversity and coverage of macroalgae (e.g. kelp)	Mean diversity and coverage of macroalgae on rocky reefs (3-10 m)	Statewide	Dependent on location – from as early as 1996 to present; 5 yearly
Abundance (threatened and protected species)	Mean densities, sizes and biomass of fishes on rocky reefs (3-10 m)	Statewide	Dependent on location – from as early as 1996 to present; 5 yearly

Pressure/stressor indicators

N/A

C.5.7.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Rocky reefs				X		X	Stuart-Smith et al. 2017
Fish assemblages				X		X	Stuart-Smith et al. 2017

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Human population		X				X	Australian Bureau of Statistics - Australian Population Grid
Pollution						X	NSW Estuary Water Quality Data Compilation: 2007 – 2020
Fishing		X				X	SAFS

Australian Population Grid

NSW Estuary Water Quality Data Compilation: 2007 – 2020

C.5.7.8 Relevant contextual data

- Hawkesbury Shelf research (MEMS Stage 2) – assessing the biological diversity of shallow rocky reefs across the bioregion
- climate change research (MEMS Stage 2; MEMS Stage 1: Action 3.1) & Climate change monitoring (MEMS Stage 2; MEMS Stage 1: Action 3.2)
- climate change citizen science (MEMS Stage 2; MEMS Stage 1: Action 3.5.3)
- harvest strategy research (MEMS Stage 2; MEMS Stage 1: 6.1.2, 6.1.3, 6.1.4)
- species habitat research (MEMS Stage 2).

C.5.7.9 Other relevant projects/data

No other projects or data were specified.

C.5.7.10 Data storage

Data are stored on the Australian Temperate Reef collaboration and RLS database which is likely to be included within the Integrated Marine Observing Systems. Data are also stored on local Fisheries NSW servers which are backed up daily. It is envisaged that the Australian Government supported GlobalArchive could be the repository for the DPI data, academic and environmental consultancy data. All DPI Metadata will be stored on Information Asset Register (IAR) portal https://iar.environment.nsw.gov.au/

C.5.7.11 References

Barrett N, Bates A, Beger M, Syms C, Holbrook N, Knott N, Booth D, Kellaher B, Howe S, Buxton C and Edgar G. (2014) *Adaptive management of temperate reefs to minimise effects of climate change: Developing new effective approaches for ecological monitoring and predictive modelling*, Fisheries Research and Development Corporation FRDC 2010/506.

Barrett N, Edgar G, Polacheck A, Lynch T and F. Clements F (2008). *Ecosystem monitoring of subtidal reefs in the Jervis Bay Marine Park 1996-2007*, Tasmanian Aquaculture and Fisheries Institute.

Coleman M, Bates A, Stuart-Smith R, Malcolm H, Harasti D, Jordan A, Knott N, Edgar G and Kelaher B (2015) 'Functional traits reveal early responses in marine reserves following protection from fishing', *Diversity and Distributions*, 21:876-887.

Coleman MA., Palmer-Brodie A, and Kelaher BP (2013) 'Conservation benefits of a network of marine reserves and partially protected areas', *Biological Conservation*, 167:257-264.

Curley BG, Glasby TM, Curley AJ, Creese RG, and Kingsford MJ (2013a) 'Enhanced numbers of two temperate reef fishes in a small, partial-take marine protected area related to spearfisher exclusion', *Biological Conservation*, 167:435-445.

Curley BG, Jordan AR, Figueira WF and Valenzuela VC (2013b.) 'A review of the biology and ecology of key fishes targeted by coastal fisheries in south-east Australia: identifying critical knowledge gaps required to improve spatial management', *Reviews in Fish Biology and Fisheries*, 23:435-458.

Davis TR, Harasti D, Kelaher B and Smith SD (2017) 'Defining conservation targets for fish and molluscs in the Port Stephens estuary, Australia using species-area relationships' *Ocean & Coastal Management*, 136:156-164.

Edgar GJ, Stuart-Smith RD, Willis TJ, Kininmonth S, Baker SC, Banks S, Barrett NS, Becerro MA, Bernard ATF, Berkhout J, Buxton CD, Campbell SJ, Cooper AT, Davey M, Edgar SC, Forsterra G, Galvan DE, Irigoyen AJ, Kushner DJ, Moura R, Parnell PE, Shears NT, Soler G, Strain MA and Thomson RJ (2014) 'Global conservation outcomes depend on marine protected areas with five key features', *Nature*, 506:216-220.

Edgar GJ, Stuart-Smith RD, Heather FJ, Barrett NS, Turak E, Sweatman H, Emslie MJ, Brock DJ, Hicks J, French B, Baker SC, Howe SA, Jordan A, Knott NA, Mooney P, Cooper AT, Oh ES, Soler GA, Mellin C, Ling SD, Dunic JC, Turnbull JW, Day PB, Larkin MF, Seroussi Y, Stuart-Smith J, Clausius E, Davis TR, Shields J, Shields D, Johnson OJ, Fuchs YH, Denis-Roy L, Jones T and Bates AE (2023) 'Continent-wide declines in shallow reef life over a decade of ocean warming', *Nature*, 615:858-865.

Ferguson AM, Harvey ES and Knott NA (2016) 'Herbivore abundance, site fidelity and grazing rates on temperate reefs inside and outside marine reserves', *Journal of Experimental Marine Biology and Ecology*, 478:96-105.

Fulton CJ, Noble MN, Radford M, Gallen C and Harasti D (2016) 'Microhabitat selectivity underpins regional indicators of fish abundance and replenishment', *Ecological Indicators*, 70:222-231.

Hughes TP, Kerry JT, Álvarez-Noriega M, Álvarez-Romero JG, Anderson KD, Baird AH, Babcock RC, Beger M, Bellwood DR and Berkelmans R (2017) 'Global warming and recurrent mass bleaching of corals', *Nature*, 543:373-377.

Kim SW, Sampayo EM, Sommer B, Sims CA, Gómez-Cabrera MdC, Dalton SJ, Beger M, Malcolm HA, Ferrari R and N Fraser N (2019) 'Refugia under threat: Mass bleaching of coral assemblages in high-latitude eastern Australia', *Global Change Biology*, 25:3918-3931.

Kingsford M and Battershill C (1998) *Studying temperate marine environments: A handbook for ecologists*, Canterbury University Press, Christchurch, New Zealand.

Knott NA, Barrett NS, Davis T, Stuart-Smith R and Edgar GJ (in prep.) 'Longterm patterns of rocky reef biodiversity on temperate Australian rocky reef: management effectiveness and climate-driven change'.

Malcolm HA, Jordan A, Creese RG and Knott NA (2015) 'Size and age are important factors for marine sanctuaries: evidence from a decade of systematic sampling in a subtropical marine park', Aquatic Conservation: *Marine and Freshwater Ecosystems*, 26:1090-1106.

Stuart-Smith RD, Edgar GJ, Barrett NS, Bates AE, Baker SC, Bax NJ, Becerro MA, Berkhout J, Blanchard JL, Brock DJ, Clark GF, Cooper AT, Davis TR, Day PB, Duffy JE, Holmes TH, Howe SA, Jordan A, Kininmonth S, Knott NA, Lefcheck JS, Ling SD, Parr A, Strain E, Sweatman H and Thomson R (2017) 'Assessing National Biodiversity Trends for Rocky and Coral Reefs through the Integration of Citizen Science and Scientific Monitoring Programs', *BioScience*, 67:134-146.

van Lier JR, Harasti D, Laird R, Noble MM and Fulton CJ (2017) 'Importance of soft canopy structure for labrid fish communities in estuarine mesohabitats', *Marine Biology*, 164: 45- 56.

Image: NSW DPI, State of New South Wales

Appendix C.6 Enabling safe and sustainable boating (Initiative 7)

Initiative objective: To balance protection of coastal and marine habitat and species with ongoing access and safe and sustainable boating.

Boating activity will increase in the future. We need to accommodate this increase while managing the marine estate's social, economic and environmental benefits. MEMS initiative 7 aims to meet the demand for safe and sustainable boating access to our waterways. This will be achieved with a suite of discrete projects and ongoing business activities.

In the short term, the actions in this initiative have improved boating infrastructure and increased community, government and industry awareness of the regulatory framework to support safe and sustainable boating.

In the intermediate term, we will build on these actions and refine them to continue education programs and achieve increased compliance with guidelines and regulations for safe and sustainable boating.

The aim is to improve opportunities and experiences for both recreational and commercial boating, while balancing social, economic, cultural and environmental values on NSW waterways.

The main MEMS management action in initiative 7 that relates to environmental monitoring indicators and the ECF is:

- 7.6 Integrate research and monitoring into the Monitoring Program to address key knowledge gaps associated with shipping movements and interactions with threatened and protected species.

The main contributing project is outlined in Table C10 and included in this document.

TABLE C10. Projects contributing monitoring information to Initiative 6 management actions.

Project	MEMS action(s)	Supports MEMS action(s)
Review of Offshore Anchoring	7.6	2.5

C.6.1 Review of offshore anchoring – F14

Note: project formerly named "Towards greener ports: impacts of anchor scour near ports".

C.6.1.1 Overview

Shipping is vital to NSW trade and industry, yet anchoring by these large vessels may lead to the physical damage of seabed habitats and impact their fauna. For this reason, anchoring by large commercial vessels was rated as a high and moderate risk to deep soft sediments and deep rocky reefs, respectively, in the central region of the NSW coastline (BMT WBM 2017). Importantly, this rating was based on information that was considered 'inferred' (BMT WBM 2017) indicating that there is high uncertainty regarding the risk of this activity to seabed habitats. Hence, there is a need to address this knowledge gap to better understand the risks associated with this activity.

The proposed research will attempt to quantify the potential effects of large ships anchoring on offshore seabed habitats and their associated biodiversity (e.g. kelp, sponge gardens and fishes; Broad et al. 2020, 2023).

This will involve remote underwater video sampling of seafloor environments in places where anchoring does and does not occur. Results from this study should provide a clearer understanding of the effects and risks of this activity and will inform future threat and risk assessments. Initially, Port Kembla will be used as a case study before extending the study to a number of ports in NSW.

This project is led by DPI Fisheries and funded from the MEMS. Work is ongoing from the MEMS Stage 1 to Stage 2.

C.6.1.2 Project type/objectives

- review current scientific literature investigating the impacts of anchor scour by large vessels.
- Assessment of the risk of this activity to deep seafloor habitats and their associated marine life
- increased understanding of the risk of this activity to environmental assets
- contributes to monitoring progress towards MEMS outcomes

C.6.1.3 TARA assets and threats addressed

TARA assets/benefits addressed		TARA threats addressed	
Environmental assets	Social, cultural and economic benefits	Environmental	Social, cultural and economic
Deep soft sediments (Central only) Deep reefs (Central only)	Enjoyment benefits Cultural heritage & use benefits Intrinsic & bequest Viability of businesses Direct economic values	Physical disturbance through anchor damage	Habitat (physical) disturbance

C.6.1.4 Knowledge gap(s) addressed

Knowledge gap(s) addressed	Level knowledge gaps is addressed
Shipping (BMT WBM 2015)	Partial

C.6.1.5 Methods

The initial focus for the research project will be in the Illawarra region where ships waiting to berth at Port Kembla Harbour often anchor upon deep reef environments in State and Federal waters. A remotely operated underwater vehicle will be used to collect video footage over reefs that have recently been anchored upon by large commercial ships, which will be compared to reefs outside of the anchoring roadstead. Approximately 20 reefs will be surveyed. The underwater video footage will be scored for the abundance, diversity and size for a range of marine organisms, including kelp, sponges, ascidians and fish. These monitoring data will then be used to assess the possible effects of large ships anchoring on deep reef seafloor habitats and associated marine life. Following the initial surveys on deep rocky reefs the project will endeavour to replicate this methodology on deep soft sediments in the NSW central region.

C.6.1.6 Indicators, measures, protocols

Condition indicators

Indicators, measures and protocols			
Indicator	Measure	Spatial scale	Temporal scale and frequency
Changes in species composition	Number of species	NSW central region	1 yr
Changes in the size of species	Number of height and width of species	NSW central region	1 yr
Changes in seafloor morphology	Number of cracks and abrasions on seafloor	NSW central region	1 yr

Pressure/stressor indicators

Indicators, measures and protocols			
Indicator	Measure	Spatial scale	Temporal scale and frequency
Anchored ships	Number of anchored ships on deep reef/deep soft sediment Footprint of anchored ships	NSW central region	1-2 yrs

C.6.1.7 Baseline data

Condition data

Asset	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	< 5 yrs	5-10 yrs	>10 yr	Local	Statewide	
Fishes	X			X	X	X	Knott et al. 2021; Rees et al. 2021

Pressure/stressor data

Pressure/stressor	Temporal scale				Spatial scale		References where relevant data are captured (for the identified indicators)
	<1 yr	<5 yrs	5-10 yrs	>10 yrs	Local	Statewide	
Number of anchored ships			X			X	AMSA (VMS)

C.6.1.8 Relevant contextual data and projects

DPE-EHG bathymetry data; AMSA vessel positioning data.

C.6.1.9 Other relevant projects/data

Collaborative research project between UoW, DPI and DPE-EHG investigating the potential effects of large ships anchoring on deep reef habitats

C.6.1.10 Data storage

All data save on DPI Fisheries corporate databases and long-term data storage are stored in GlobalArchive which includes metadata derived from Eventmeasure software. Data are also stored on external hard drives at various Fisheries locations.

C.6.1.11 References

BMT WBM (2015) *Threat and Risk Assessment for the Hawkesbury Shelf Marine Bioregion*, Marine Estate Management Authority, 62 pp.

BMT WBM (2017) *New South Wales Marine Estate Threat and Risk Assessment Report*, Marine Estate Management Authority, 251 pp.

Broad A, Rees MJ and Davis AR (2020) 'Anchor and chain scour as disturbance agents in benthic environments: trends in the literature and charting a course to more sustainable ting and shipping', *Marine Pollution Bulletin*, 161:111683.

Broad A, Rees MJ, Knott N, Swadling D, Hammond M, Ingleton T, Morris T and Davis AR (2023) 'Anchor scour from shipping and the defaunation of rocky reefs: A quantitative assessment', *Science of the Total Environment*, 863:160717.

Knott NA, Williams J, Harasti D, Malcolm HA, Coleman MA, Kelaher BP, Rees MJ, Schultz A and Jordan A (2021) 'Coherent, representative and large-scale marine reserve network shows consistent change in rocky fish assemblages through time', *Ecosphere*, 12:e03447.

Rees MJ, Knott NA, Hing ML, Hammond M, Williams J, Neilson J, Swadling DS, Jordan A (2021) 'Habitat and humans predict the distribution of juvenile and adult snapper (Sparidae: *Chrysophrys auratus*) along Australia's most populated coastline', *Estuarine, Coastal and Shelf Science*, 257:107397

Appendix D. Glossary of terms

Activity – something occurring in the marine estate. This may be a community benefit and/or a threat to an environmental asset or social, cultural or economic values, for example, boating, fishing, dredging or shipping.

Asset – the physical features of the marine estate, but does not include people. There are three main types of assets:

- environmental assets – the natural attributes, components and living resources of the marine estate for example habitat (e.g. beaches or rocky shores) or threatened species,
- cultural assets – structures, places or associations that form or contribute to cultural identity,
- infrastructure assets – functional structures installed for people to use and interact with the marine estate.

Benefit – see 'community benefit'.

Community benefit – anything that contributes to the wellbeing of the community. There are three separate categories of community benefits: economic, social and environmental benefits. Many community benefits are based on what people think is important (what they value). A community benefit of the marine estate could be:

- swimming at the beach,
- boating in an estuary,
- doing something as a hobby (e.g. fishing, kayaking, surfing, bird watching, etc.),
- running a business (e.g. whale watching business, charter fishing, commercial fishing, etc.),
- clean waters and marine biodiversity,
- intrinsic values i.e. valuing the environment regardless of direct benefits.

The *Marine Estate Management Act 2014* uses the term 'community value' for this.

Community wellbeing – the overall aggregate of economic, social and environmental benefits.

Consequence – the result of something happening, including a change in circumstances affecting objectives. It can be certain or uncertain and have positive or negative effects on objectives. A consequence can be expressed qualitatively or quantitatively.

Cumulative impacts, threats or risks – the impact (positive or negative) resulting from the effects of one or more impacts, and the interactions between those impacts, added to other past, present and reasonably foreseeable future pressures.

Ecological – the relationship between organisms and their environment.

Economic – the production, distribution, and use of income, wealth, and commodities.

Economic benefits – benefits derived by the community from the marine estate that are of an economic or financial nature.

Effect – a deviation from the measured status. Effects can be positive or negative.

Environmental benefits – benefits derived by the community from an environmental asset.

Evidence – relevant and credible information sources relating to threats and risks (environmental, social or economic) such as scientific research or reports, unpublished data/research or supporting background reports.

Impact – the outcome of the direct or indirect effect of activities and natural events on the assets or values of the environmental, social or economic components (i.e. pressure + response).

Key stressors – These are stressors that are responsible for impacts on environmental assets and related risks to community benefits e.g. an activity such as stormwater discharge can adversely impact environmental assets through several key stressors, such as water pollution, marine debris and sediment contamination.

Likelihood – the chance of something happening.

Marine estate – as defined in the *Marine Estate Management Act 2014* means:

- the coastal waters of NSW within the meaning of Part 10 of the *Interpretation Act 1987,*
- estuaries (being any part of a river whose level is periodically or intermittently affected by coastal tides) up to the highest astronomical tide,
- lakes, lagoons and other partially enclosed bodies of water that are permanently, periodically or intermittently open to the sea,
- coastal wetlands (including saltmarsh, mangroves and seagrass), lands immediately adjacent to, or in the immediate proximity of, the coastal waters of New South Wales that are subject to oceanic processes (including beaches, dunes, headlands and rock platforms),

- any other place or thing declared by the regulations to be the marine estate,
- but does not include any place or thing declared by the regulations not to be the marine estate.

Monitoring – A systematic collection of data on specified indicators to provide the main stakeholders of an ongoing management action with indications of the extent and trend of progress towards achievement of objectives. Monitoring can be at numerous scales and can include measures of inputs, activities, outputs, outcomes and impacts of management activities at the project and program levels. The Marine Estate Management Authority's Monitoring Program also includes systematic collection of data (including through research) to address knowledge gaps.

Pressures (environmental) – activities and factors that potentially cause environmental change.

Priority threat – those threats that have the greatest risk of producing adverse effects on the flow of benefits from the marine estate. A threat was considered to be a statewide priority if it had a high or moderate risk level for each of the three regions across the state (i.e. north, central and south). Risk levels of high or moderate in only one or two regions lead to those threats being identified as regional priorities.

Region – in reference to the TARA (management regions), the section of NSW that the TARA has been applied to (North region is from Tweed Heads to Stockton, Central region from Stockton to Shell Harbour and South region from Shellharbour to NSW/Victorian border).

Resilience – the maximum change (or disturbance) that can occur before a population or system can no longer resist it or recover from it. The change (or disturbance) can be:

- 'pulse' – an acute, short-term change that results in a temporary response,
- 'press' – a sustained or chronic change that could cause a long-term response,
- 'catastrophic' – a major, long-term change from which a population or system is unlikely to recover.

Resource use conflict – disagreements and disputes over access to and control of natural resources.

Risk – the chance of something happening that will have a negative impact on achieving environmental, social or economic objectives (note: this definition clarifies those in the TARA and MEMA glossaries to specify that risk is a *negative* impact).

Risk assessment – overall process of risk identification, risk analysis and risk evaluation.

Risk level – magnitude of a risk or combination of risks, generally expressed in terms of the combination of consequences and their likelihood e.g. high, moderate, low or minimal.

Social – of or relating to the life and relations of people in a community.

Social benefits – the social and relational benefits the community derives from the marine estate.

Social and economic benefit – also called community benefit, this is anything that contributes to the wellbeing of the community.

Spatial extent – the scale of the risk of the threat to a benefit being realised e.g. local, regional or statewide.

Stakeholder – a person, organisation (including agencies) that can affect, be affected by, or perceive themselves to be affected by a decision or activity.

Stressor – a consequence of an activity (e.g. water pollution, overcrowding) that causes an effect on an environmental asset (e.g. clean waters) or social and economic benefit (e.g. recreation and tourism activities at a local beach or waterway). Different activities may lead to the same stressors (e.g. foreshore development and dredging activities can produce different forms of water pollution if not managed effectively).

Stressor interaction – modification of a stressor's intensity or the sensitivity of an organism or ecosystem towards this stressor by another stressor or multiple other stressors (from Schäfer and Piggott (2018) https://doi.org/10.1111/gcb.14073).

Temporal scale – the timeframe in which the risk of the threat being realised will occur e.g. 1-2 years, 10 years or 20 years.

Threat – a broad activity, event or process that poses a potential level of risk to an environmental asset or social or economic benefit. Threats often affect multiple assets/benefits and similarly, an asset/benefit may be affected by multiple threats.

Threat and risk assessment – a process that identifies, assesses and prioritises threats and their associated risks to the marine estate. It also highlights areas where information is lacking and research is needed.

Trend – how a threat varies over time e.g. increasing, decreasing or stable.

Value – the term used by the *Marine Estate Management Act 2014* for 'community benefit'.

Image: R. Laird

Image: NSW DPI, State of New South Wales

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