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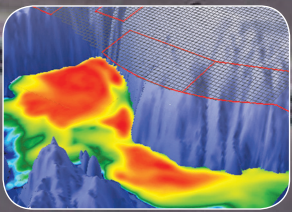

Towards a blueprint for monitoring Key Ecological Features in the Commonwealth Marine Area

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Important Disclaimer

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EXECUTIVE SUMMARY

The Australian Government Department of the Environment is seeking to strengthen the evidence base to protect, sustainably manage and report on the health of the Commonwealth Marine Area (CMA). The Department is also (but initially in a terrestrial and freshwater context) trying to improve the availability of timely and meaningful information on trends in the state of the environment through a new initiative, called the Essential Environmental Measures for Australia, under the National Plan for Environmental Information (NPEI). This document supports these objectives by providing options for monitoring of, and reporting on, Key Ecological Features (KEFs) to help the Department identify a limited set of Essential Environmental Measures and strengthen the evidence base for reporting on the health of the CMA: it represents the first step towards a blueprint for a sustained approach to environmental monitoring and reporting.

KEFs are elements of the CMA environment that, based on current scientific understanding, are considered to be particularly important to a region's biodiversity or ecosystem function and integrity. The scope of this document is restricted to improving the understanding, and reporting on the status and trends, of these KEFs. To date 54 KEFs have been identified in the CMA, of which 32 are sufficiently well understood to model and provide an initial prediction of their response to a range of anthropogenic pressures. Commonality among the ecosystem components and processes represented in the KEFs allows them to be classified into 6 reporting groups: (i) Canyons; (ii) Deep sea beds; (iii) Areas of enhanced pelagic productivity; (iv) Seamounts; (v) Shelf reefs (tropical, subtropical and temperate); and (vi) Shelf sea beds. Towards a blueprint is structured around these 6 groups and the KEFs within them.

Implementing a sustained monitoring programme for KEFs requires that the department transition from focussing on KEF-related research to focussing on prioritised, operational KEF monitoring and reporting. This will also require a change in the current governance structures within the Department. Formal or voluntary advisory committees could provide initial oversight and coordination for a monitoring programme, with support from existing groups such as National Marine Science Committee, the Integrated Marine Observing System (IMOS) advisory board and the National Environmental Science Programme marine hub steering committee. This advisory committee could progressively builds towards a permanent governance structure on an as needs basis.

When designing a sustained monitoring programme it is important to consider the existence of prior data sets and legacy monitoring sites. The search and retrieval capabilities of existing data portals, however, cannot currently identify, time stamp and geolocate data sets that intersect irregularly shaped areas of interest such as KEFs. We therefore developed an Australian Region MARine Data Aggregation (ARMARDA) tool that is able to identify the location, and number of samples per year, of physical and biological observations taken within the boundaries of KEFs. We used this tool to identify existing data held in six geoservers (an open source server for sharing geospatial data) housing data by the Australian Institute of Marine Science (AIMS), CSIRO, Geoscience Australia, the Institute of Marine and Antarctic Studies (IMAS), IMOS and the Australian Coastal Ecosystem Facility (ACEF). ARMARDA provides a (as yet incomplete) national marine data catalogue that can be automatically and routinely updated. We use it here to identify legacy data sets in KEFs across the CMA.

A national analysis of the data sets visible to ARMARDA suggests that the IMOS satellite tag programme and Multi-spectral Ocean Colour products, together with the Continuous Plankton Recorder and CSIRO's Conductivity, Temperature and Depth records, provide a sufficient basis (i.e. are sufficiently replicated in space and time) for identifying trends in at least some of the indicators identified for the Enhanced pelagic productivity KEF group. The analysis also suggests that images and data acquired by seabed towed video, remote and autonomous video and divers, held by CSIRO, AIMS, IMOS and IMAS are likely to provide a sufficient basis for an initial analysis of condition for at least some reefs in the Shelf reefs KEF group.

Towards a blueprint is built around the three basic principles of the scientific method: prediction, observation and (in)validation. This document illustrates the implementation of these principles to monitoring by comparing qualitative model predictions of the direction of change of some of the indicators from the Enhanced Pelagic Productivity KEF group with a statistical estimate of the long term trends in these indicators based on satellite-derived observations of ocean colour and Sea Surface Temperature. These observations and analysis increase our understanding of these KEFs and provide insights to prioritising data to further enhance understanding.

Our analysis prioritises future monitoring and reporting options across the CMA by ranking observation methods or platforms according to: (i) their relevance to KEF indicators; and (ii) current deployment constraints, for each of six KEF reporting groups: Canyons, Deep Seabeds, areas of Enhanced Pelagic Productivity, Seamounts, Shelf Reefs and Shelf Seabeds. Observation methods that are highly relevant - i.e. relevant to more than 61% of the indicators within the KEF group, and have low capacity constraints, score highly in this process. The relative ease of deployment, and the number indicators that can be observed with a single method, together with extent and location of existing data sets, provides a logical basis for prioritising future investments.

This prioritisation procedure suggests three options, that if implemented sequentially, provide for a gradual ramp up towards a sustained national KEF monitoring and reporting programme. Option 1 has relatively low annual costs ($500k - $1m), short time horizons (3-5 yrs), informal oversight structures and does not commit the Department to a monitoring programme. It focusses on enhancing the value of existing data in the shelf reefs and enhanced pelagic productivity KEF groups, and extending baselines in the former group using high relevance, low constraint monitoring methods such as demersal baited remote underwater video and diver visual methods.

Option 2 has moderate annual costs ($1m - $5m), longer time horizons (3-10 yrs), a formal more collaborative oversight structure and commits the Department to coordinating and/or managing monitoring and reporting. It focusses on extending baselines and time series data records from Option 1 and developing new baselines and time series, using low and moderate relevance and constraint methods for monitoring Canyons and Seamounts KEF groups.

Option 3 has longer time horizons (10 - 20 yrs), requires relatively significant funding (annual costs in the range $5m - $10m), and needs a formal long-term governance structure. It will require the Department to commit to a KEF monitoring and reporting programme and develop new policy proposals to support this. This stage aims to extend time series data and analysis to allow national and regional scale reporting on KEF indicator trends. It builds on the Option 1 and 2 monitoring methods but also uses moderate relevance/high constraint methods for monitoring Shelf Sea beds and Deep Sea beds KEF groups.

This staged approach to the roll out of a national KEF monitoring and reporting programme, provides the Department and it's research providers the opportunity to build on existing data sets, refine the programme as it develops and influence how monitoring technologies and capabilities are introduced into the national research infrastructure. Integrating the monitoring and reporting programme with other national activities, in this manner, will also help ensure it maintains a broad support base.

1. INTRODUCTION

KEY POINTS

1. The Australian Government Department of the Environment is seeking to strengthen the evidence base to protect, sustainably manage and report on the health of the Commonwealth Marine Area (CMA).
2. The Department is currently developing a programme – called the Essential Environmental Measures for Australia – under the National Plan for Environmental Information (NPEI) that aims to improve the availability of timely and meaningful information on trends in the state of the environment.
3. This document provides recommendations and options for monitoring of, and reporting on, Key Ecological Features (KEFs). This will help the Department to identify a limited set of Essential Environmental Measures and strengthen the evidence base for reporting on the health of the CMA.
4. The scope of the blueprint is restricted to improving the understanding, and reporting on the status and trends, of KEFs. Although there is spatial overlap between KEFs and Commonwealth Marine Reserves (CMRs), this document does not specifically address CMRs, and also does not address monitoring of the Great Barrier Reef or State waters.

1.1. Why is this blueprint needed?

The *Environmental Protection and Biodiversity Conservation Act* 1999 (EPBC Act) lists nine matters of national environmental significance, including the Commonwealth Marine Area (CMA), defined as any part of the sea, including the waters, seabed, and airspace, within Australia's exclusive economic zone and/or over the continental shelf of Australia, that is not State or Northern Territory waters.

The Australian Government Department of the Environment (the Department) is seeking to strengthen the evidence base for decision making to protect, sustainably manage and report on the health of the CMA. One way to do this is to implement the principles of Evidenced Based Decision Making (EBDM).

EBDM helps people make better decisions by putting the available evidence at the heart of policy development and implementation (Davies et al., 2000). EBDM principles are exemplified within the health care sector where different types of evidence are placed within a hierarchy that emphasises experiments and observational studies over expert opinion and personal experience (Davies and Nutley, 1999).

The evidence base that underpins EBDM requires the sustained collection of data that improves management by increasing confidence in the causal relations between anthropogenic actions and system response. The Australian government's desire to strengthen its evidence base establishes the need for a sustained monitoring programme for the CMA. This document is an initial step in the planning process for this programme.

While EDBM principles provide the high-level rationale for a sustained monitoring programme, the key policy driver for implementing such a programme is the National Plan for Environmental Information (NPEI). NPEI aims to improve the quality and accessibility of Australia's environmental information, and it is currently developing a new programme, called the Essential Environmental Measures for Australia (EEMA) programme, that aims to identify a limited set of Essential Environmental Measures.

The EEMA programme aims to provide up to date reports on the status and trends of Essential Environmental Measures at local, regional and national scales. It will do this by delivering time series information on a limited set of environmental indicators, with delivery of its first products scheduled for December 2015. The Department envisages that the EEMA's information products will serve several roles and will be included in the national State of the Environment (SoE) report.

In the first instance the EEMA programme will focus on terrestrial and freshwater ecosystems, but if successful will seek to extend its remit to include marine ecosystems. The scope, approach and methodology of this blueprint document is consistent with, and complementary to, the EEMA programme. The blueprint will therefore serve as a guide for the future extension of the programme to the Commonwealth Marine Area.

1.2. What is the purpose of this blueprint

The purpose of the blueprint is to provide high-level guidance on the governance requirements of a sustained monitoring strategy, and to identify a staged approach to the collation of marine ecosystem information to implement such a strategy. It is important to emphasise, however, that the purpose of the blueprint is to support the Department's reporting obligations under the EPBC Act. The development of a blueprint does not imply that the Department will gather, store or analyse information itself. It is designed to help the department shape its priorities, and thereby help shape and drive the monitoring priorities of other agencies.

The blueprint considers the needs of a monitoring programme for marine ecosystem health, Australia's capacity to meet this need and options for improving this capacity. As the name implies, however, it is not a detailed "how to" guide for monitoring. Specific details on how to implement an environmental monitoring programme, including a list of essential monitoring functions, are available in related publications (see for example Hedge et al. (2013)) and these details are not replicated here.

This document provides monitoring, reporting, governance and data management recommendations that are designed to help the Department meet its requirements to: (i) conserve and protect the CMA as a matter of national environmental significance; (ii) strengthen the evidence base for decision making and SoE reporting of the CMA; and (iii) identify a set of Essential Environmental Measures that will allow the EEMA programme to be progressively rolled out for Australia's marine ecosystems.

1.3. The role of Key Ecological Features

The Department's understanding of the CMA's ecosystems and conservation values are articulated in the Marine Bioregional Plans (MBPs) that cover four of the CMA's five regions, namely the South west, North west, North and temperate East. The same level of understanding has also been developed for the Coral Sea and the South East region.

The conservation values described in the MBPs include Key Ecological Features (KEFs). KEFs are elements of the CMA environment that, based on current scientific understanding, are considered to be particularly important to a region's biodiversity or ecosystem function and integrity. The scope of the blueprint is restricted to improving the understanding, and reporting on the status and trends, of these KEFs.

To date 54 Key Ecological Features have been identified in the Commonwealth Marine Area (Figure 1). 32 of these KEFs are sufficiently well understood to model and provide an initial prediction of their response to a range of anthropogenic pressures. These predictions provide a basis for identifying a set of ecosystem health indicators for the Commonwealth Marine Area (Hayes et al., 2015).

KEFs are an essential component of the blueprint architecture described in this report because they define the why, what and where of the progressive monitoring programme that the blueprint outlines. In addition to this, however, they play several other important roles within the Department's policy frameworks:

- They are a systems-based expression of the Department's conservation values, as identified in the marine bioregional plans, and they helped inform the design of the Commonwealth Marine Reserve (CMR) network.
- They provide a focus for State of the Environment reporting because they identify biodiversity and productivity values (of regional and national importance) within specific geographical boundaries.
- They articulate the notions of "marine ecosystem functioning or integrity" and "significant areas of habitat" listed in the significant impact guidelines for matters of national environmental significance (`http://www.environment.gov.au/epbc/publications/significant-impact-guidelines-11-matters-national-environmental-significance`), and as such they inform regulatory decisions by agencies such as the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA).

KEFs also have a number of attractive properties that would enhance the current approach to SoE reporting. Firstly, they adopt a system's perspective that would integrate many of the currently disaggregated SoE reporting components, link them to explicit values and place them within spatially defined regions. In other words they link species, habitats and processes, to the pressures that threaten them, for regionally and nationally important ecosystem features.

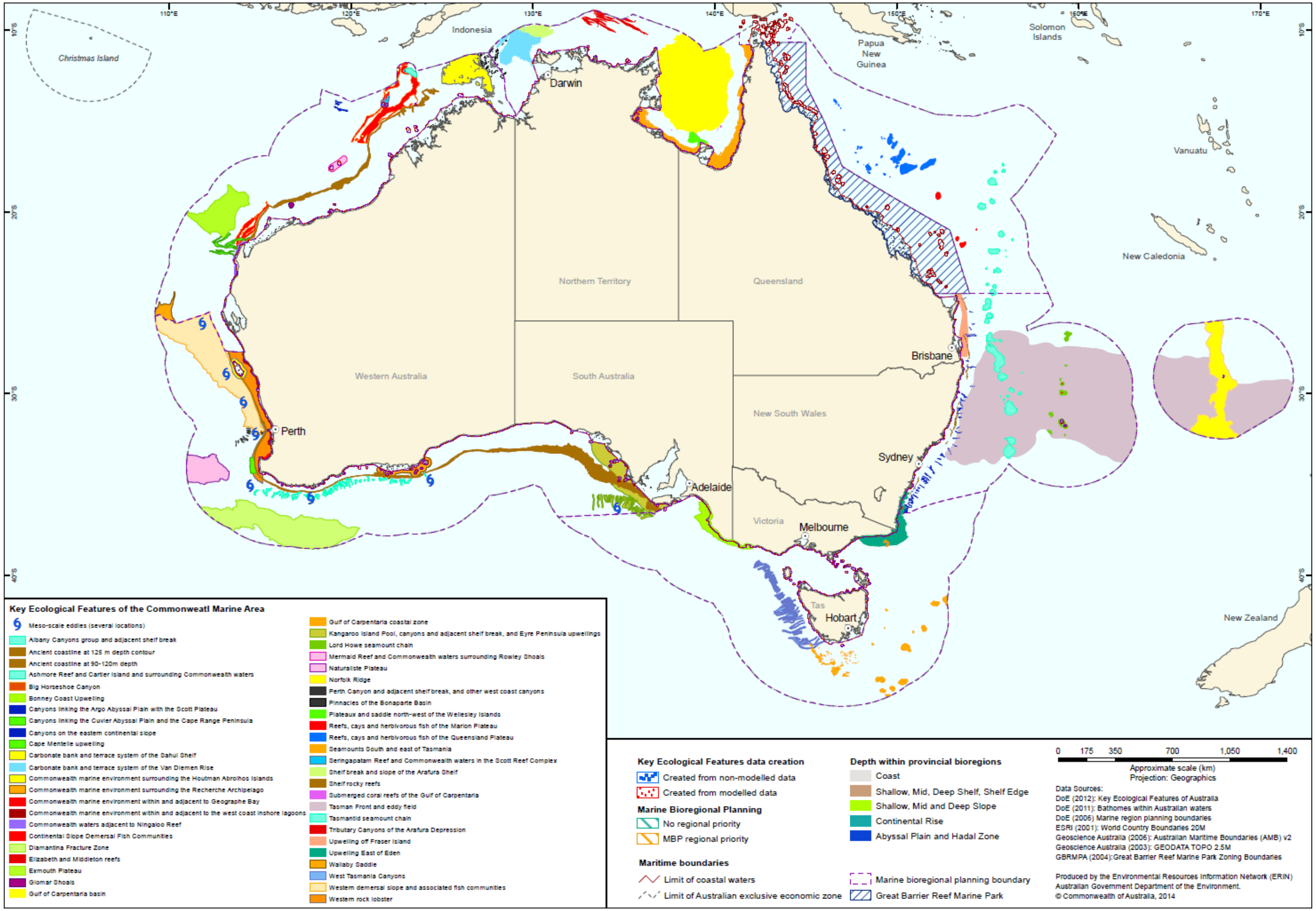

Figure 1: Schematic representation of all 54 Key Ecological Features (KEFs) identified through expert consultation during the Marine Bioregional Planning process. This map highlights the spatial coverage of KEFs and provides some context when considering KEFs as a focus for monitoring the health of the Commonwealth Marine Area.

Secondly, KEFs provide a focus for modelling that in turn provides a more transparent representation of expert beliefs, and a basis for uncertainty analysis and prediction of the KEF response to anthropogenic pressure. This would allow SoE reports to document not only the status and trends of marine ecosystems, but also potentially the reasons why trends are occurring (which in turn may inform government interventions or decisions).

Thirdly, KEFs allow for reporting at local, bioregional and national scales either by reporting on individual KEFs or by reporting on groups of KEFs that reflect the same underlying value, such as a national analysis of areas of enhanced pelagic productivity (Section 5).

It is important to emphasise at this point that the KEFs listed in this document are not final and may be subject to variation. The Department is currently drafting a formal procedure for reviewing and updating KEFs that specifically allows for the amendment of existing KEFs, and the addition of new ones, on a case-by-case basis. This procedure also allows for a periodic review of all KEFs to ensure that they reflect current learnings, and are representative of the CMA estate as a whole.

Finally it should be noted that the blueprint does not address the monitoring and reporting requirement of the Commonwealth Marine Reserves, the Great Barrier Reef or State waters. It also does not address monitoring to regulate or manage industries (e.g. fisheries or offshore oil and gas), although it may inform these areas.

1.4. Reporting priorities and KEF groups

All four MBPs specify seven strategies including: a) providing relevant, accessible and evidence based information to support decision making with respect to development proposals that come under the jurisdiction of the EPBC Act (i.e. the CMA); and, b) improve monitoring, evaluation and reporting on ecosystem health in the marine environment.

The MBPs continue by identifying two actions to improve monitoring, evaluation and reporting: (i) collate information on the components and function of KEFs, and the pressures and potential cumulative impacts upon them; and (ii) develop effective ecological indicators that will facilitate future monitoring, evaluation and reporting of marine ecosystem health.

Over the last eight years, the Marine Biodiversity Hub has collaborated with the Department to help implement these actions by identifying how KEFs might inform its national reporting priorities. These priorities emerged by examining the ecosystem components and processes that were repeatedly identified in the individual KEFs. The fact that common systems were repeatedly identified in the (independently) regionally-developed KEFs, provided a basis for identifying the key reporting priorities of a national marine health assessment.

Subsequent discussions with the Department around these issues settled on 6 KEF reporting groups for ecosystems associated with: (i) Canyons; (ii) Deep sea beds; (iii) Areas of enhanced pelagic productivity; (iv) Seamounts; (v) Shelf reefs (tropical, subtropical, temperate); and, (vi) Shelf sea beds. It is recognised that KEFs may evolve over time as system understanding improves but these groups are anticipated to remain unchanged.

The blueprint is structured around these 6 groups and the KEFs within them (Appendix A). This approach represents a move away from reporting on disaggregated components and process of the CMA's ecosystems to a more holistic, system-based perspective centred around groups of KEFs that reflect the same key values.

1.5. Important links and relevant initiatives

The blueprint provides recommendations and options that support the identification of Essential Environmental Measures under the National Plan for Environmental Information, and further develop the basis for evidence based decision making in the CMA. This evidence base is necessary to not only inform the regulatory regime under the EPBC Act but also to inform management and regulation by others such as NOPSEMA. NOPSEMA may therefore require industry to assess the impacts of proposed activities on KEFs and other conservation values.

In addition to NOPSEMA, there are a number of other national initiatives whose objectives are relevant to those of the blueprint, notably:

- The Australian Research Data Infrastructure Strategy (TARDIS) – aims to maximise the availability and delivery of data generated by agencies and inside and outside of the research sector.
- The Integrated Marine Observing System (IMOS) – funded under the National Collaborative Research Infrastructure Strategy. IMOS delivers sustained marine observations to support research and management of Australia's marine ecosystems. It is a fully integrated national system, observing at ocean-basin and regional scales, and covering physical, chemical and biological variables.
- The Australian Ocean Data Network (AODN) – an important collaboration for marine data management between six Australian Government agencies with primary responsibility for marine data. It provides a single access point for marine data published by Australian Commonwealth agencies, IMOS and by a large number of other data contributors.

The scope and focus of the blueprint is deliberately narrower than these initiatives but its objectives are nonetheless complementary, and in many respects the Department's ability to implement the blueprint will depend on successful integration with these initiatives.

Finally, as noted above, the blueprint anticipates periodic review and amendment of the KEFs. This process aims to balance the need for continuity with improvements in scientific understanding. The Marine Biodiversity Hub is currently assisting the Department to develop a protocol for updating existing, and creating new, KEFs. The purpose of the protocol is to ensure a systematic, standardised and transparent approach to managing the Department's official information for KEFs. It describes a process for capturing information on KEFs (both deliberate and incidental), the circumstances under which information about KEFs, including their boundaries, may be changed and by whom.

2. OVERVIEW OF THE BLUEPRINT

KEY POINTS

1. The Department has yet to establish a governance structure to oversee and coordinate a marine monitoring programme for the CMA. Section 3 of this report describes governance structures the Department could consider
2. Section 4 of the report provides a nation-wide summary of physical and biological observations that have, or currently are, being collected in KEFs using a new tool specifically designed to meet the user case requirements of a national KEF data catalogue.
3. Section 5 of the report provides a statistical analysis of SST, chlorophyll-a and Net Primary Production in 7 of the 9 enhanced pelagic productivity KEFs. This section demonstrates the hypothesis-prediction-observation-(in)validation philosophy that underpins the KEF monitoring and reporting framework.
4. Section 6 of the report ranks physical and biological observation platforms (monitoring methods) by their relevance to KEF indicators, and by the constraints on their deployment.
5. Section 7 examines the data management and infrastructure needs on an environmental monitoring programme.
6. Section 8 concludes the report by detailing three roll-out options that if implemented sequentially provide for a staged-implementation of sustained, national programme for the Commonwealth Marine Area.

2.1. Historical context

The MBPs describe the conservation values of each of the marine regions, including their associated KEFs. In 2006 the Department and CSIRO recognised that KEFs provide a mechanism for collating information and developing ecological indicators to facilitate monitoring, evaluation and reporting of marine ecosystem health. Since then, the Department, CSIRO and the NERP Marine Biodiversity Hub have worked closely to identify indicators and predict their response to anthropogenic pressures (Hayes et al., 2012a,b; Dambacher et al., 2012; Hosack and Dambacher, 2012; Hosack et al., 2012).

A critical next step in transitioning from research on KEFs to operational KEF monitoring was the discovery, collation and (where appropriate) analysis of existing relevant data sets, followed by prioritising the collection of new data to develop or extend existing baselines and time series. In 2012 the NERP Biodiversity Hub began to discuss this transition with the Department to understand its drivers and analysis needs, together with the constraints and options for a national monitoring programme (Appendix B).

This engagement resulted in a plan to meet the stated objectives and actions of the Marine Bioregional Plans by merging the Department's desire to strengthen the evidence base for decision making with a monitoring and reporting logic built around the central tenets of the scientific method (Figure 2).

2.2. Governance

An appropriate governance structure is an essential pre-requisite of any monitoring strategy. The Department has yet to establish a governance structure to oversee and coordinate a marine monitoring programme for the CMA. Section 3 of the blueprint describes governance structures the Department could consider, using the framework of the Global Ocean Observing System as a guide. This section of the document provides options for governance and includes a number of suggestions for establishing a formal or informal initial oversight group.

2.3. Australian Region MArine Data Aggregation

Section 4 of the blueprint provides a nation-wide summary of physical and biological datasets that have, or currently are, being collected in KEFs using the Australian Region MArine Data Aggregation (ARMADA) tool specifically designed to meet the user case requirements of this analysis.

The analysis aims to identify: (i) existing data sets that may serve as a baseline for the current (or historical) status of KEF indicators; and (ii) the existence of time series data that are sufficiently well replicated in space and time to provide a representative picture of how KEF indicators are trending in response to identified pressures.

This section details the user case requirement of a national data catalogue and describes how this user case was met for the purposes of the blueprint. The analysis presented here includes data sets from all of Australia's largest marine research and infrastructure organisations, but is nonetheless an incomplete snapshot, but one that can in time be continually improved as marine data sets are made available as Web Feature Services on publicly accessible geoservers.

2.4. Initial analysis of Enhanced Pelagic Productivity KEFs

The results presented in Section 4 of the report suggest that high resolution spatio-temporal data sets with which to assess the status and trends of indicators in the Australian commonwealth marine region are rare. An important example of type of data, however, are satellite observations of Sea Surface Temperature and ocean colour.

The availability of satellite observations of these two variables, and the Chlorophyll-a and Net Primary Productivity products that are derived from the latter, provides an opportunity to demonstrate the hypothesis -prediction-observation-(in)validation methodology that supports the assessment of KEF indicator trends, and underlies KEF model review (Figure 2).

Section 5 of the report provides a statistical analysis of SST, Chlorophyll-a and NPP estimates in 7 of the 9 enhanced pelagic productivity KEFs. It highlights which KEF indicator trend predictions, under

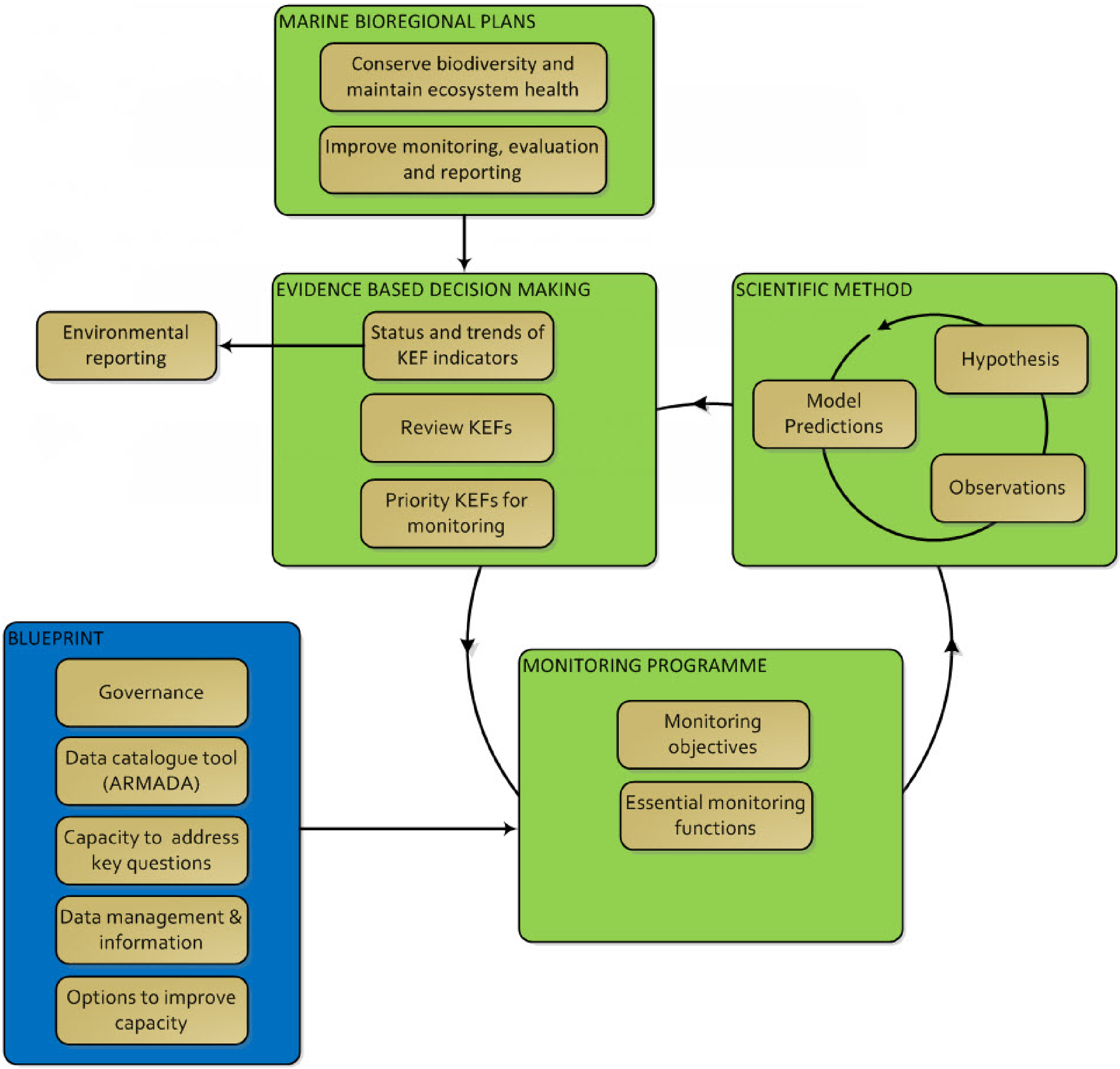

Figure 2: The blueprint and its role in a monitoring programme for the Key Ecological Features (KEFs) of the Commonwealth Marine Area. The aim of the programme is to provide observations to a scientific method that builds the evidence base to inform the Department's environmental reporting and decision making processes. Collecting observations on the status and trends of KEF indicators is central to the successful achievement of the Department's stated objective to conserve biodiversity, maintain ecosystem health and improve its monitoring and reporting arrangements, as articulated in the Marine Bioregional Plans. The key components of the blueprint are the governance structures, KEF data catalogue, an assessment of Australia's capacity to monitor and address reporting questions (for six key KEF groups), data management and provision of information services, and options to improve capacity.

which pressure scenario's, are consistent with observations, and which are not. Under the framework described by (Hayes et al., 2015) predictions that are inconsistent with observations – i.e. a predicted pressure did not eventuate or the KEF did not respond as predicted – trigger a review of the KEF models and/or pressure scenarios.

2.5. Capacity to monitor

The indicators identified for each of the KEFs, grouped under the six key reporting questions, enables the blueprint to identify what observation platforms or monitoring methods are required to implement an environmental monitoring programme for the CMA. This is an important first step in examining the Department's and Australia's capacity to implement such a programme.

Section 6 of the blueprint gauges the importance of different monitoring techniques, divided into visual/video-based, remote/acoustic, and extractive sampling methods, in terms of their relevance to the KEF indicators. This section also examines the current constraints associated with each technique, scored against a range of constraint-determining criteria.

2.6. Managing data and providing information

Section 7 of the blueprint examines the data management and infrastructure needs of an environmental monitoring programme. This section also provides a broad assessment of existing data infrastructure that may be made available to a KEF monitoring programme. This assessment is limited to the Department's existing data management arrangement and those of the research community. It identifies important data management initiatives and gaps for KEF monitoring.

As the lead agency for KEF monitoring, the Department will need to determine what data infrastructure will be used to support monitoring and reporting, and the specific information outputs required to communicate the status and trends of KEF indicators. This section of the blueprint is designed to assist the Department in this regard.

2.7. Options to improve capacity

The blueprint also aims to identify options for improving the Department's capacity to implement an environmental monitoring programme by examining: (i) the limitations (including key data gaps) on existing capacity; (ii) the scope for further prioritisation within the key reporting questions, (iii) opportunities to increase co-ordination of existing capacity, (iv) opportunities to re-focus existing capacity; and, (v) ways to increase capacity.

Section 8 of the blueprint describes three options for developing capacity in this manner, each of which entails an increasing funding commitment. If implemented sequentially these options provide a staged-implementation strategy that provides proof of concept (on completion of Option 1) and demonstrates the value of monitoring investment (on completion of Option 2) prior to the Department supporting a sustained national environmental monitoring and reporting programme (Option 3).

3. GOVERNANCE

KEY POINTS

1. Governance mechanisms providing leadership, oversight and coordination to enable KEF reporting and associated monitoring have not been established.
2. Establishing an initial oversight and coordination group is an important step in transitioning from KEF research to prioritised, operational KEF monitoring and reporting.
3. Initial coordination could be provided by a formal group or a voluntary advisory committee. The initial oversight and coordination group would progressively build governance on an as needs basis.
4. There are some existing groups that could help coordinate Departmental priorities and the marine science and observing community, notably the National Marine Science Committee, the IMOS Advisory Board and the NESP research hub steering committee.

Good governance is a prerequisite for effective KEF monitoring and reporting. It should provide vision, leadership and oversight to ensure reporting and monitoring remains focused on its primary purpose and objectives. It should also provide expert oversight on the agreed practices and procedures, and coordinate groups involved in the collection, management, analysis and reporting of monitoring data.

The Department is positioned to identify the primary purpose and objectives of KEF reporting, but it currently does not have the capacity (coordination and infrastructure) to collate and analyse data to manage a monitoring programme. Australia's marine monitoring capacity is spread over a number of institutions and sectors (hereafter called the marine science and observing community). Sustained KEF monitoring and reporting will therefore require a governance system with two fundamental elements: (i) strong Departmental leadership and oversight; and, (ii) effective coordination across the marine science and observing community.

The framework for global ocean observing (UNESCO, 2012) recognises three tiers in the overall marine science community – oversight and coordination, expert reviews and implementation. This framework provides a guide to look across the Department and the marine science and observing community, and identify existing governance mechanisms that could be used to support KEF reporting and monitoring, and the gaps that need to be filled.

3.1. Existing governance

There is a broad range of existing governance arrangements that oversee and coordinate marine conservation and components of marine science and observing (Table 1). While all of these are potentially relevant, none were established to specifically support KEF reporting and monitoring.

Existing governance arrangements at the oversight and coordination tier have been established to meet the needs of an agency, program or specific marine observing facility. KEF reporting and monitoring would be one of many competing items on the agenda of these groups. Moreover, their terms of reference, supporting principles and policies currently do not identify KEF reporting and monitoring as a priority.

Most of these groups will be important for promoting cooperation. For example the National Marine Science Committee, Bureau of Meteorology (BOM), the Integrated Marine Observing System (IMOS) advisory board and the Marine National Facility Steering Committee, could agree to take on an oversight role for KEF reporting and associated monitoring. However, establishing a dedicated oversight and coordination group signals the priority placed on this activity by the Government, and will be critical to provide the oversight and coordination to transition from research on KEFs to operational KEF reporting and monitoring.

At the expert advice tier there are a number of existing groups that could design, develop and review a KEF reporting and monitoring programme. The NESP research hubs convene groups that bring together the necessary design and development expertise. The NESP Marine Biodiversity Hub, for example, includes CSIRO, Geoscience Australia (GA), Charles Darwin University, Museum Victoria (MV), two state agencies from New South Wales (Department of Primary Industry and Office of Environmental Heritage), the Australian Institute of Marine Science (AIMS), the University of Tasmanian (UTAS), the University of Western Australia and IMOS. The hub designs and develops methods that could be used to monitor selected KEFs. IMOS also convenes groups of experts that design, develop and review requirements for observing physical, chemical and biological variables, much of which overlap with KEF indicators, and could therefore establish or contribute to a group to oversee KEF monitoring.

At the implementation tier, some of the NESP research Hubs and IMOS convene groups that collect, manage, analyse and report marine data, some of which will be relevant to monitoring and reporting for KEFs. Under the National Plan for Environmental Information, the BoM has been assigned the operational role to improve the quality and accessibility of environmental information. A number of existing policies would support collecting and managing KEF indicator data, but dedicated policies for collecting, managing and analysing KEF indicator data will be needed.

	Department of the Environment	Whole of Australian Government	Other
Oversight and coordination of KEF reporting	Department Board (http://www.environment.gov.au/topics/science-and-research/state-environment-reporting/about-soe-reporting#roles) Governance principles of the Business planning and performance reporting framework	National Marine Science Committee (http://aims.gov.au/opsag), Bureau of Meteorology Environmental Information Advisory Group (http://www.bom.gov.au/environment/coordination.shtml#advisoryGroup) The ANAO governance principles	Integrated Marine Observing System Advisory Board, Marine National Facility steering committee (http://mnf.csiro.au/) IMOS business node planning and reporting (http://imos.org.au/plans.html#c1096)
Expert advice to design, develop and review the requirements to monitor KEF indicators	Environmental Resources Information Network (http://www.environment.gov.au/about-us/environmental-information-data/erin)	AODN Technical Advisory Group (http://imos.org.au/aodn_tag.html)	NERP Marine Biodiversity Hub steering committee (http://www.nerpmarine.edu.au/governance), NERP Tropical Ecosystem Hub steering committee, IMOS steering committee and supporting nodes Publications by the US National Parks service, for example Fancy and Bennetts (2012)
Implementation to collect, manage, analyse and report KEF indicator data	Environmental Resources Information Network ERIN Data Guidelines	Australian Ocean Data Network, Bureau of Meteorology NEII Reference Architecture, AODN data policy and cook book, MNF assessment of research proposals	IMOS Facilities and research partners, NERP Marine Biodiversity Hub and Tropical Ecosystem Hub ISO 19156 Geographic information Observations and measurements model, ISO 19115-1:2014 Geographic information meta-data

Table 1: Existing groups and existing principles/policies that could contribute or link to the governance arrangements for KEF reporting and associated monitoring, organised by the tiers of the GOOS framework

3.2. Initial oversight and coordination

The Department has an Executive Board and supporting committees to provide oversight and coordination. These, however, are primarily focused on strategic direction, financial accountability and workforce management. It is unlikely that the Executive Board and its existing committees will wish to provide the technical oversight and coordination for KEF reporting and associated monitoring.

An oversight and coordination group, and program sponsor who is accountable for the approach, is critical for evolving from one-off observations of KEFs to sustained monitoring that provides time series data to inform environmental reporting, such as essential environmental measures or State of the Environment reporting. The group will need to facilitate the prioritisation of KEFs within the Department and help coordinate the marine science and observing community. This group may require a cross-divisional committee or be set within a suitably positioned Division of the Department with either the appropriate policy lead (i.e. Wildlife, Heritage and Marine Division or Parks Australia) or coordination role (i.e. Science Division). Figure 3 provides insights to how an initial oversight and coordination group could link with existing groups to commence governance arrangements for KEF reporting and associated monitoring.

The oversight and coordination group can also provide an initial nucleus to commence governance, and identify the other supporting governance groups or policies that may be formed as needs arise. Mature governance arrangements may take many forms from very simple (AEMWG, 2012) to relatively complex (Morton and Tinney, 2012). The functions of the initial oversight group could include:

- Establishing a vision for the KEF reporting and associated monitoring.
- Identifying a set of high-level principles to guide decision-making for KEF reporting and associated monitoring.
- Prioritising KEFs for reporting and developing partnerships for associated monitoring.
- Seeking expert advice on appropriate approaches to collecting, analysing and managing data to enable KEF reporting.
- Convening DoE with Australian Government portfolios for science and industry, and the marine science and observing community to understand potential to align interests and develop partnerships that would support KEF reporting and associated monitoring.
- Developing and overseeing a start-up strategy or plan to develop a program that would support KEF reporting and associated monitoring.
- Connecting KEF reporting with analogous monitoring and reporting frameworks for other environmental values (e.g. Great Barrier Reef World Heritage Area) and into State of the Environment reporting (e.g. through Essential Environmental Measures).
- Reporting to the program sponsor, including reviews of progress against declared objectives.

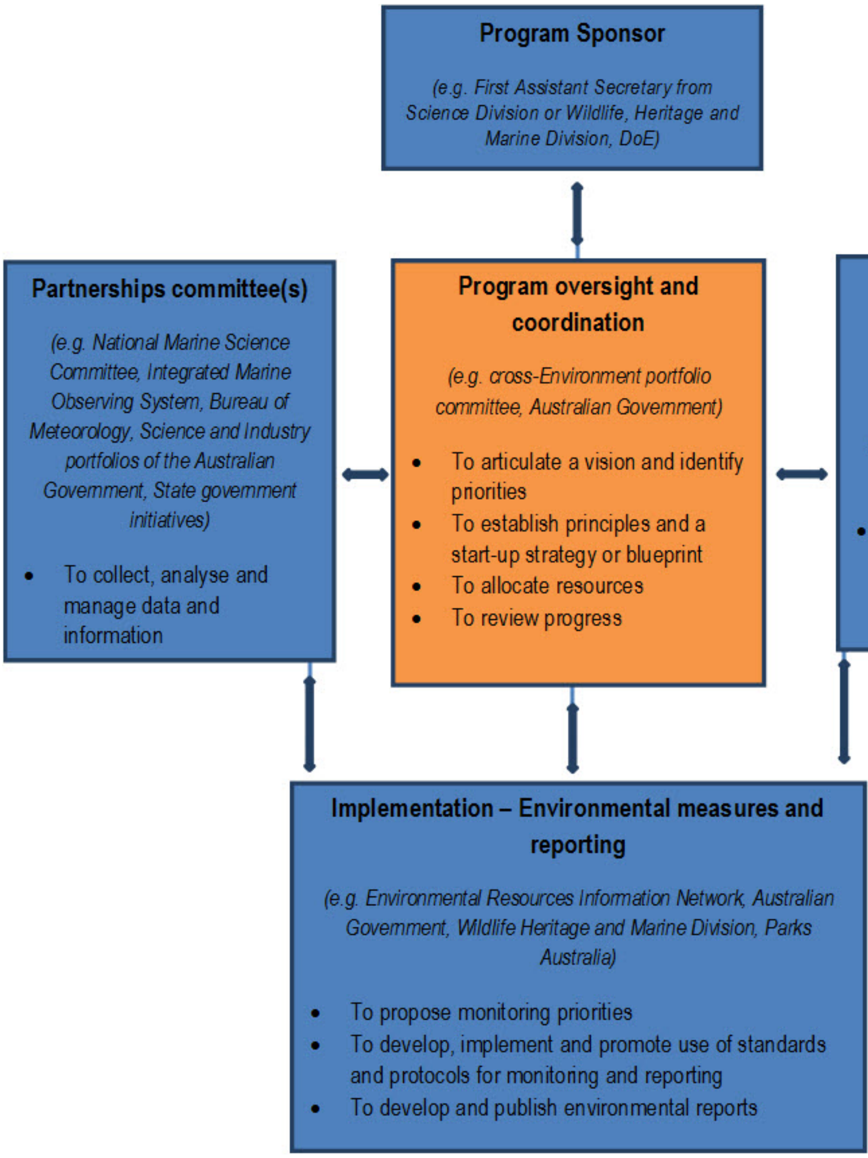

Figure 3: Options for how an initial oversight and coordination group could function by linking to groups, programs and an accountable program sponsor to commence governance arrangements for KEF reporting and monitoring.

4. NATIONAL KEF DATA CATALOGUE

KEY POINTS

1. The search and retrieval capabilities of marine data portals are currently limited. They do not provide an efficient way to identify, time stamp and geo-locate data that intersects with irregularly shaped areas of interest such as KEFs.

2. We developed a data aggregation tool that collates information on existing data from marine research institutions. It identifies the location and number of samples per year of physical and biological observations taken within KEF boundaries. An initial analysis of the data collated to date, grouped here by six KEF reporting groups, suggests:

   - **Canyons**: indicator-relevant observations exist but these have a low to moderate spatial replication and are unlikely to be repeated in time. These observations may serve as a (potentially unrepresentative) comparison or baseline for future observations in some canyons, particularly the Perth Canyon and big horseshoe canyon.
   - **Deep Sea beds**: appear to have the poorest collection of prior data collection. Indicator-relevant observations display low spatial replication and appear to be one-off in time. The applicability to future assessments is therefore severely restricted.
   - **Enhanced pelagic productivity**: this reporting group has the best collection of existing data, including physical and biological observations taken at high spatial and temporal resolution. This data will probably provide a suitable basis for trend assessment into the future.
   - **Seamounts**: the amount of existing indicator-relevant observations varies between seamounts. Mid-water acoustic data on the Lord Howe rise chain has moderate to high spatial replication and this may serve as a useful comparator to future observations. Approximately half of the seamounts south and east of Tasmania, however, appear to have no prior observations.
   - **Shelf reefs**: the distribution of prior sample effort appears to heavily skewed to temperate reefs but this may be an artefact of the data collation conducted to date. Overall the existing data shows a low to high degree of spatial replication and may even be replicated intermittently in time. The existing data may serve as a (potentially unrepresentative) comparison or baseline for future observations in some reefs, and in restricted cases may allow some form of trend assessment.
   - **Shelf seabeds**: Indicator relevant prior observations in Geographe Bay are too spatially restricted to serve a useful role going forward. In the Gulf of Carpentaria, however, the existing data may serve as a (potentially unrepresentative) comparison or baseline.

4.1. Australian Region Marine Data Aggregation tool

A KEF monitoring programme aims to monitor, evaluate and report on the status and trends of KEF indicators. The groundwork for such a programme has been completed by predicting how KEF indicators will respond to anthropogenic pressures (Dambacher et al., 2012; Hayes et al., 2015). The next preparatory step is to discover the existence and extent of past data collections and to gauge if they are sufficient for assessing either the baseline status of KEFs or evaluating trends in indicators.

The user-case (Appendix C) for a national KEF data catalogue is not currently met by existing data providers. To address this the NERP Marine Biodiversity Hub developed a data aggregation and display tool, known as the the Australian Region Marine Data Aggregation (ARMADA) tool (`http://www.cmar.csiro.au/data/armarda/`). ARMADA reads data feeds from Web Feature Services (WFS) produced by marine research institutions, and housed on publicly accessible geoservers. The tool reads the WFS data feeds and then aggregates and harmonizes the data into a single repository that allows the user to identify spatially explicit data content within or adjacent to irregular shaped polygons such as KEFs.

ARMADA currently retrieves and reads WFS feeds from six geo-servers housing data sets provided by AIMS, CSIRO, GA, IMAS, IMOS and the Australian Coastal Ecosystem Facility (ACEF). To date, all of the WFS feeds provided by IMOS, AODN and CSIRO have been harvested and analysed. For example, the IMOS/AODN geoserver currently provides access to over 240 WFS records. ARMADA has collated all of these and eliminated duplicates (with records drawn from the CSIRO geoserver), records in estuaries, lakes and on land, and records without a geographical position. Each of the remaining WFS feeds were then manually assigned to a biological (Table 2) or physical (Table 3) observation type to enable comparisons across institutions and facilitate a national-scale analysis (Section 4.2)[1].

The observation categories developed here were designed to improve the specificity of the national data catalogue analysis by choosing observation categories that are relevant to KEF indicator groups (Tables 8, 9 and 10). These categories, however, may not align with monitoring method categories developed in other initiatives. This issue could be addressed in any future development of ARMADA, or its functionality within other data portals, if this was deemed advantageous, for example to comply with national or international attempts to harmonise sampling gear and monitoring method nomenclature.

ARMADA can create integrated data queries for any area of interest if the boundaries are described by a standard GIS shape file. Currently it has on record the shape files for 50 KEFs, 173 Commonwealth Marine reserves, and four regions of the GBR. ARMADA also allows the user to employ a buffer that includes sites within a specified distance from the shape file boundary (default distance is 20 kms). The retrieved data are then summarized by a map that depicts the spatial location of observations within the search region, and an annual time series plot of sampling frequency (Figure 4).

[1] Note: A WFS feed for the IMOS AATAMS array and curtain data is not currently available. These data sets, however, are known to intersect with a number of shelf reef and enhanced pelagic productivity KEFs

Code	Gear name	Count	UoM	Description	Colour
AI,SV	Airborne & ship observations		locations	Observations acquired by aircraft (e.g. light detection and ranging equipment LIDAR) and ships	
CPR	Continuous plankton recorder	47165	taxa occurrence	CPR trawl targeting zooplankton and large phytoplankton	
CSI	compound specific isotopes		samples	CSI derived from feather/flesh etc samples targeting trophic level	
DBRUV	Demersal remote underwater video	281	deployments	Baited or unbaited demersal remote underwater video targeting demersal fish and epibenthic invertebrates	
DOV,DV	Diver operated video & visual	4769	surveys	Transects and video operated within diver depth targeting benthic habitats and associated biota	
DT_S	Demersal trawls, lines or sleds	27821	deployments	Epibenthic sleds or demersal trawls targeting demersal fish and epibenthic invertebrates	
MSOCS	Multi-spectral ocean colour sensors	See text		Satellite observations of ocean colour from which chl-a and productivity indices are derived	
MW_A	Mesopelagic (mid-water) acoustics	62967	1 hr observation block	Mid-water acoustics targeting pelagic prey species such as small fish, squid, krill and jellyfish	
PBRUV	Pelagic remote underwater video		deployments	Pelagic baited or unbaited remote underwater video targeting pelagic prey and predator functional groups	
PP	Phytoplankton sample	11802	observations	Point location (e.g. drop net) phytoplankton samples	
R.A_UV	Remote/autonomous underwater video	1432	deployments	AUV or ROV video targeting demersal habitats and associated biota	
RAPT	Radio acoustic positioning & telemetry	14	sites	Shore based radio tags typically targeting large pelagic fish and marine mammals	
S_TV	Seabed towed video and stills	41067	deployments	Towed video systems target benthic habitats and associated biota	
SeaGr	Seagrass	10678	observations	Seagrass specific sampling - unknown method	
ST	Satellite tag	67007	dive locations/haul out sites	Satellite tags attached to large pelagic fish or marine mammals targeting oceanographic properties and host position	
PT_L	Pelagic trawls & lines		deployments	Pelagic trawls and lines targeting pelagic predator and prey functional groups	
TN	Turtle nesting locations	5421	Nest counts	Turtle nest specific observations - unknown method	
ZP	Zooplankton samples	20339	observations	Point location (e.g. drop net) zooplankton sample	

Table 2: Current configuration of biological sampling methods in ARMADA. Unit of Observation (UoM) refers to the units of the annual counts displayed by the tool. Count is the total number of observations in the Web Feature Services that ARMADA currently has access to. Colour refers to the mapping and histogram colour used to display the time and location of the observations

Code	Gear name	Count	UoM	Description	Colour
WQC	Water quality and chemistry	44933	deployments	Water samples taken with various gear types (e.g. Niskin bottle) targeting water chemistry	
CM_M	Current meter at moorings	76	Mooring deployments	Impellers on moorings measuring current at a single location	
CTD	CTD sensor	241442	Deployments (vertical profile/tows)	Conductivity (salinity) temperature and depth measurements in vertical profile or tows	
G	Glider	10545	locations	Gliders measuring physical oceanic variables, water quality/chemistry and phytoplankton	
SSPF	Surface/sub-surface profiling floats		locations	Floats (e.g. ARGO) measuring physical oceanic variables, water quality/chemistry and phytoplankton	
MBS	Multibeam sonar	9497	1 hr observation block	Multibeam side scan sonar providing bathymetry and habitat information	
MET	Meteorological, SST	215	deployments	Meteorological or air/sea flux observations	
OB_ACM	Ocean based acoustic current meter		Ensembles per day	ADCPs mounted on moorings measuring ocean current profiles	
SB_CM	Shore based current meter		locations	Shore based equipment using high frequency radar to measure currents and wave height	
SG	Sediment grab, core samples	4790	Deployments	Sediment grabs and corers targeting sediment and infaunal invertebrates	
SOA	Satellite ocean altimetry	see text		Satellite based ocean altimeters measuring sea surface height	
WH	Wave height buoys and stations	448	locations	Ocean mooring measuring wave heights	
XBT	eXpendable Bathythermograph	16089	deployments	Vessel deployed XBTs measuring physical oceanic variables and water quality/chemistry	

Table 3: Current configuration of physical sampling methods in ARMADA. Unit of Observation (UoM) refers to the units of the annual counts displayed by the tool. Count is the total number of observations in the Web Feature Services that ARMADA currently has access to. Colour refers to the mapping and histogram colour used to display the time and location of the observations.

The information that ARMADA aggregates is limited to the information that the WFS provides when it is queried. ARMADA uses this information to identify the time and location that observations were taken, and then aggregates those observations that intersect the boundaries of KEFs (or CMRs). The data are currently presented in the form of 18 types of biological observations (Table 2) and 13 types of oceanographic observations (Table 3). As noted above these categories may not align with other national or international harmonisation attempts, such as the European "SeaDataNet" (`http://seadatanet.maris2.nl/v_bodc_vocab_v2/welcome.asp`).

Despite its current limitations (Appendix D), ARMADA does permit a national scale analysis of observations within KEFs that is automated, relatively easy to update and sufficient to prioritise future monitoring efforts. Once a particular set of data has been discovered, the tool indicates the spatial and temporal resolution of the observations, lists the underlying data records, and identifies the host institution. For instance, inspection of the biological data aggregated for the Reefs, cays and herbivorous fish of the Queensland Plateau KEF (Figure 4) reveals a relatively low to moderate level of sampling that spans a 46 year period starting in 1968, and includes data sets for marine turtle nesting surveys (accessed via ACEF), reef life survey (via IMAS) and CSIRO catch data (CSIRO).

4.2. ARMADA retrieval results

This section of the report documents the results of the national KEF data catalogue, structured by physical and biological observing methods (as described in Tables 2 and 3) for each of the six KEF reporting groups. This analysis should be considered as an initial completion of a KEF national data catalogue. The analysis is limited to those KEFs whose boundaries are currently described by GIS shape files, with important omissions associated with the enhanced pelagic productivity and shelf reefs groups[2], and is subject to the current limitations of ARMADA.

The results documented in this section of the report have been used to provide an initial analysis of the extent to which existing data sets within KEFs are suitable for establishing the status of, and trends within, KEF indicators based on the spatial and temporal replication of the data. This summary is provided in a series of simple coloured matrices that highlight for each monitoring method, in each KEF reporting group, the extent to which the available data is likely to be suitable for status and trend assessment. Figure 5 provides the key to these summaries, and identifies what type of analysis is likely to be possible based on the spatio-temporal resolution of the data.

The key identifies three broad categories of spatial and temporal replication. In space it distinguishes single sites (no spatial replication), low to moderate, and moderate to high replication. A status assessment (such as the average abundance of a species of interest) for spatial entities such are KEFs is not possible without some form of sampling strategy across space. Ideally a moderate to high level of spatial replication is achieved with samples taken according to a probabilistic, spatially balanced design. An adequate status assessment may still be possible (but not guaranteed) if there is a low to moderate degree of replication in space, particularly if sample sites are chosen according to a probabilistic design.

[2]Shape files for three of the nine EPP KEFs are currently unavailable, and there is as yet no shape file for shelf reefs at a national scale

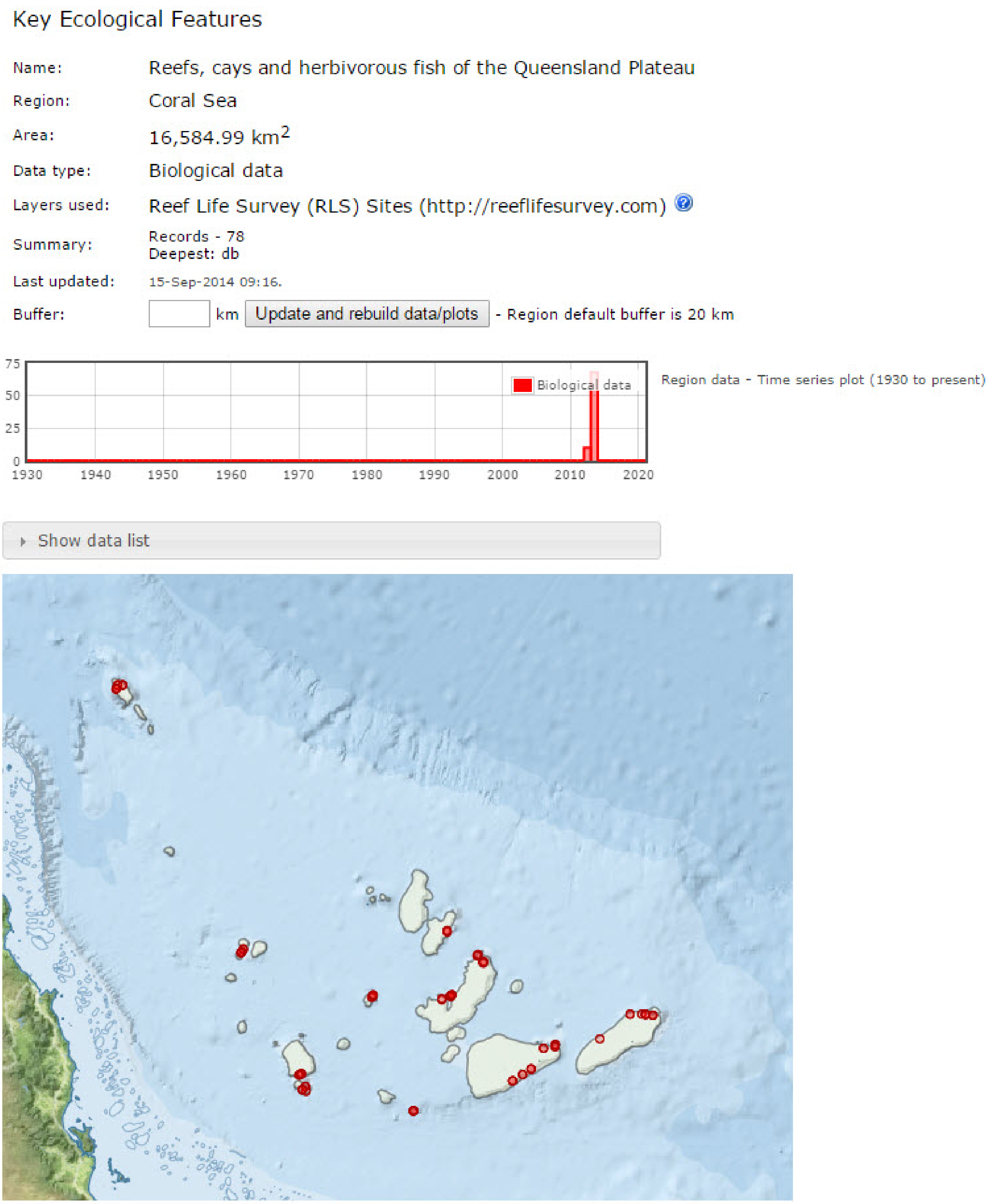

Figure 4: Example of ARMADA summary for Reefs, cays and herbivorous fish of the Queensland Plateau, a Key Ecological Feature of the Coral Sea. The data summary shows time, location and sample site locations from the Reef Life Survey data set

		SPATIAL		
		Single site (no replication)	Low to moderate spatial replication	Moderate to high spatial replication
TEMPORAL	One-off (no replication)	No assessment possible	Possibly representative status assessment	Representative status assessment
	Intermittent to regular replication	Potentially unrepresentative simple (long term) trend assessment	Possibly representative status & simple (long term) trend assessment	Representative status & simple (long term) trend assessment
	Frequent to near-continuous replication	Potentially unrepresentative complex (seasonal, cyclical, long term) trend assessment	Possibly representative status & complex (seasonal, cyclical, long term) trend assessment	Representative status & complex (seasonal, cyclical, long term) trend assessment

Figure 5: Key to interpreting the initial analysis of the suitability of currently available data to determine the status and trends of indicators within KEFs

The meaning of low, moderate or high in this context depends on the geographic extent of the KEF, the spatial heterogeneity of the indicator concerned and ultimately the extent to which the samples are representative of the KEF indicator population (in a statistical sense). At this level of analysis it is impossible to precisely define these terms, hence the summary analysis presented here should be viewed as an indicative guide to help prioritise future directions.

In time the key distinguishes one-off sampling strategies (no replication in time) from intermittent to regular replication in time followed by more intensive frequent or near-continuous replication. Again at this level of analysis it is impossible to be precise about the meaning of these terms because they depend on, for example, the life-history characteristics and expected rates of change in abundance in the indicator concerned. Nonetheless the more frequently indicators are sampled in time, the more accurately trends can be described. Frequent or near-continuous monitoring enables complex trends, potentially composed of one or more cycles (e.g. seasonal cycles) and longer term trends, to be distinguished.

The extent to which currently available observations within KEFs are replicated in space and time determines where they sit in the key (Figure 5) and hence their likely utility in determining the status and trends of KEF indicators. The subsections that follow uses the results of ARMADA to place the observing methods that intersect with KEFs within one or more the key's cells. ARMADA allows the user to qualitatively gauge the level of spatial and temporal replication of individual data sets within a KEF, and this can be used as a guide to help identify potentially important data sets, and approximately gauge the overall adequacy of existing data at a national scale.

4.2.1. Canyons

Observations of physical variables within the Canyon KEF reporting group date back to the early 1980's, and comprise mainly of ocean based acoustic current meters and CTD's, and more recently gliders (Figure 6). Early biological observations, with demersal trawls/sleds and seabed towed video, occur in disparate groups that reflect distinct surveys. Observations since 2010, however, have involved satellite tags and mid-water acoustics. The continuous plankton recorder has also intersected with the water above a number of canyons since this time (Figure 7).

The physical indicators within the KEF canyon group comprise nutrients and habitat rugosity. The pertinent observation platforms are therefore CTDs, XBTs and multibeam sonar. CTD and XBT observations occur throughout the canyons but the high variation in annual CTD counts, and overall low number of XBT counts, suggests there are no regularly repeated observations within this group. Multibeam sonar observations are generally very sparse and have occurred only intermittently in the last 15 years. This data, however, is typically collected in large swaths and the habitat features it records in canyons are unlikely to change appreciably over time.

The biological indicators within this group comprise mainly mobile and sessile benthic invertebrates (including coral), with phytoplankton, zooplankton, large pelagic predatory fish and marine mammals also identified for the head of the Perth Canyon. Demersal trawls/sleds and seabed towed video are therefore the most pertinent platforms. CPR samples and satellite tags, however, may also be relevant in the Perth Canyon.

Demersal trawl/sled and seabed towed video sampling has occurred in the canyons south west of Tasmania (single replicates), and in the big horse shoe canyon and Perth canyon (a few replicates). Satellite tags and CPR samples, however, occur primarily in the canyons of the Great Australian Bight and those of the eastern continental shelf - i.e. not in the locations where they are pertinent to the indicators identified to date.

This initial analysis suggests that the pertinent observations taken to date – i.e. those that are relevant to the physical and biological indicators identified for the Canyons reporting group – are unlikely to be sufficient for the purposes of trend assessment (Figure 8). Past observations in the Perth Canyon and Big Horseshoe Canyon may serve as comparators or baselines for new data collection exercises but this data may not be representative of the canyon more generally.

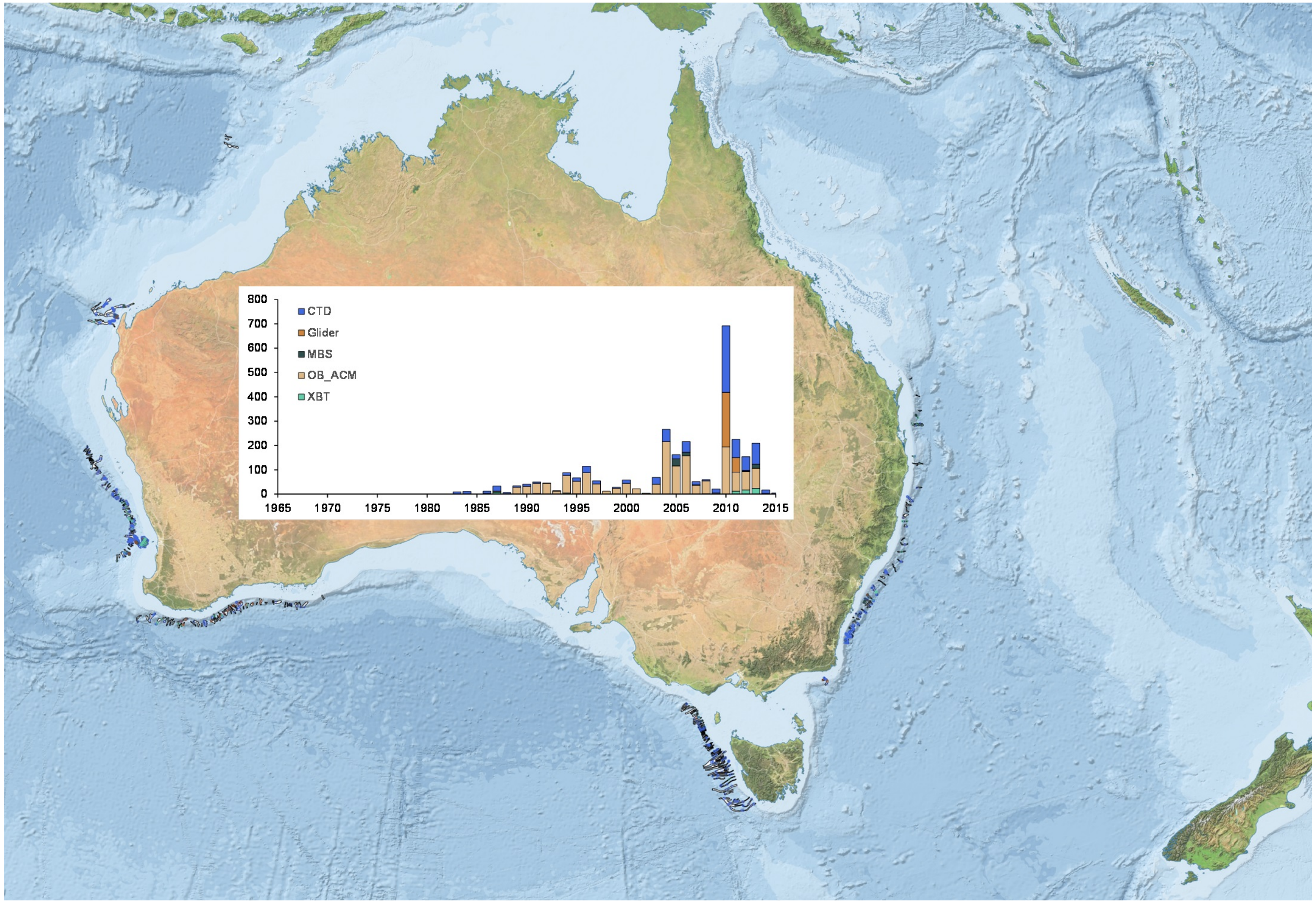

Figure 6: Summary of the physical data holdings across a selection of Australian marine research institutions for the canyons KEF reporting group, which includes the Albany Canyons group and adjacent shelf break, Big Horseshoe Canyon, Canyons linking the Argo Abyssal Plain with the Scott Plateau, Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula, Canyons on the eastern continental slope, the Perth Canyon and adjacent shelf break and other west coast canyons, and West Tasmania Canyons. Observation method codes are given in Table 3. Background maps are sourced from Lawrey (2013).

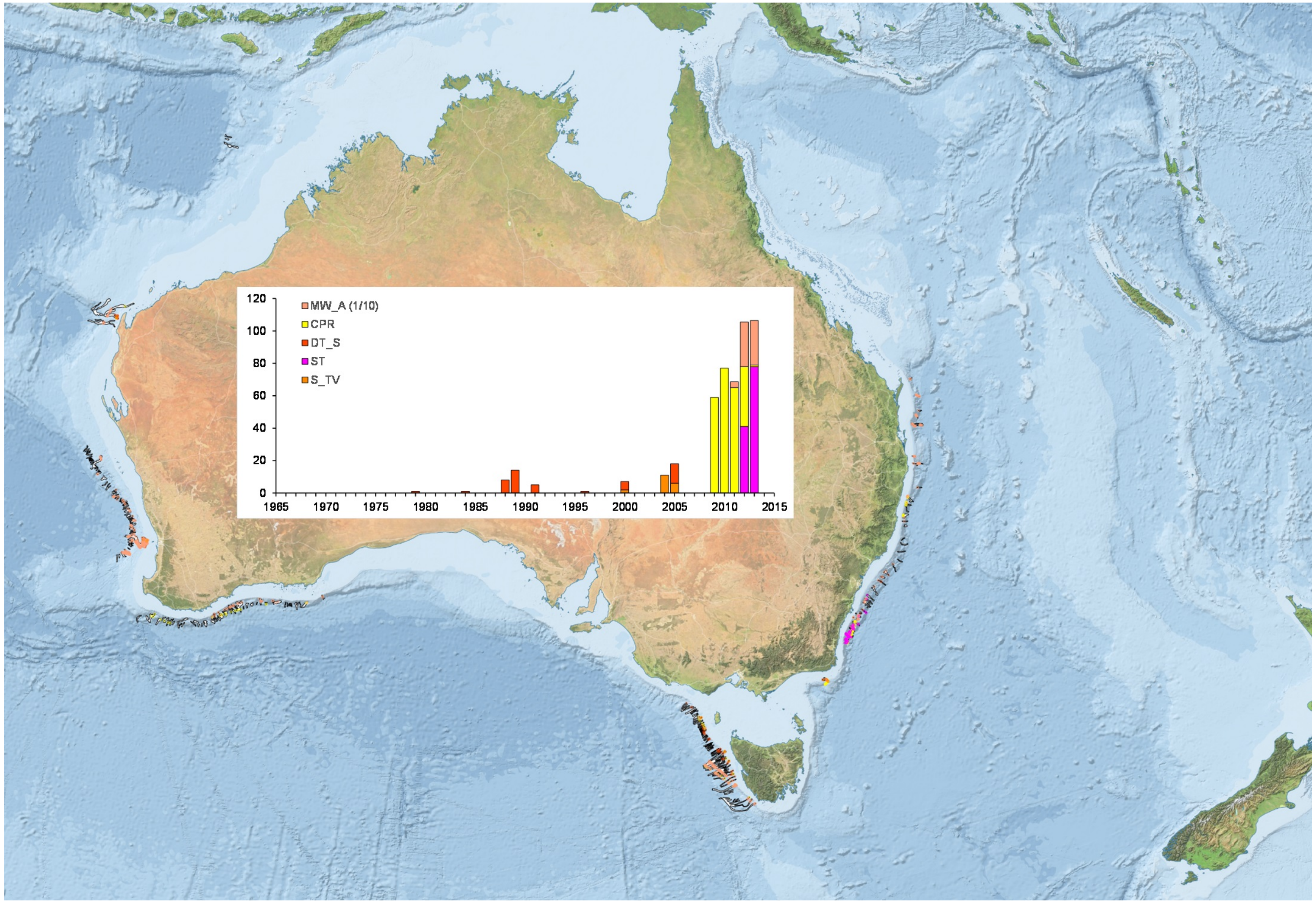

Figure 7: Summary of the biological data holdings across a selection of Australian marine research institutions for the canyons KEF reporting group, which includes the Albany Canyons group and adjacent shelf break, Big Horseshoe Canyon, Canyons linking the Argo Abyssal Plain with the Scott Plateau, Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula, Canyons on the eastern continental slope, the Perth Canyon and adjacent shelf break and other west coast canyons, and West Tasmania Canyons. Observation method codes are given in Table 2. Background maps are sourced from Lawrey (2013).

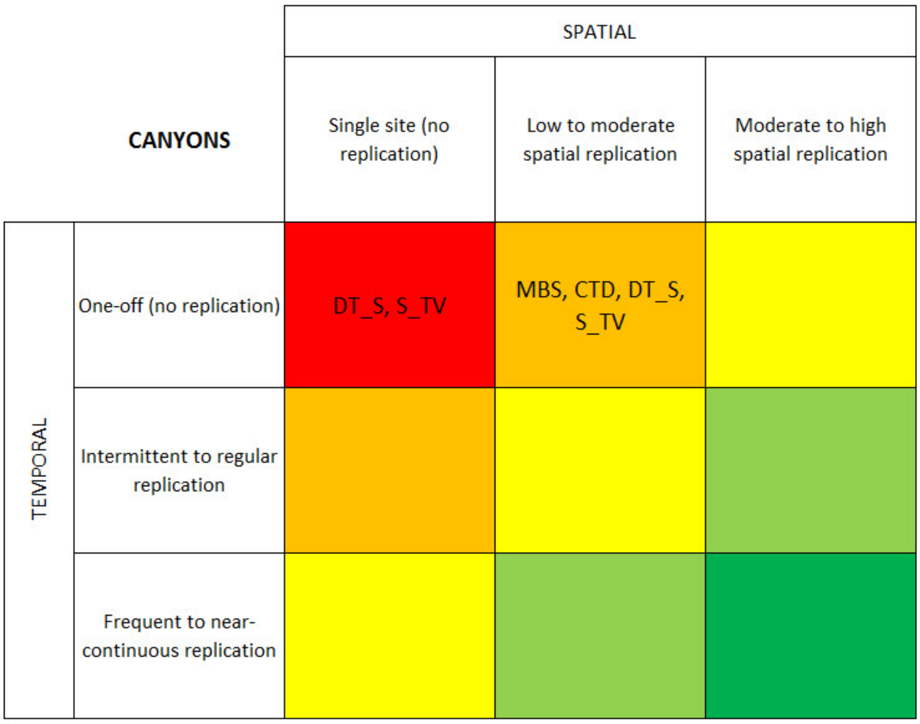

Figure 8: Initial analysis of the spatial and temporal replication of existing data sets (based on ARMADA) that are relevant to the indicators in the Canyon KEF reporting group. Observation method codes are given in Table 3 and Table 2

4.2.2. Deep sea beds

The physical observations in the two deep sea bed KEFs (Diamantina Fracture Zone and Norfolk Ridge) are almost exclusively CTDs with a small amount of sampling by XBT and ocean based acoustic current meters (Figure 9). The CTD measurements are well dispersed across the KEF, and given the large number of observations, may be replicated in time. There are, however, no physically-based indicators within these two KEFs so these observations are not currently relevant.

Overall very few biological observations have been taken in the deep sea bed KEF reporting group (Figure 10). An isolated peak of biological sampling of Norfolk Ridge occurred during the 2003 NORFANZ survey, which included deep-water catch operations from demersal trawls (mid-water trawls and video recordings were also taken). A second set of observations was subsequently taken in 2012 using mid-water acoustics. Both of these observation platforms are relevant to the KEF indicators, however, on both occasions sampling was primarily targeted at seamounts, and are unlikely to be representative of the KEF as whole (Figure 11).

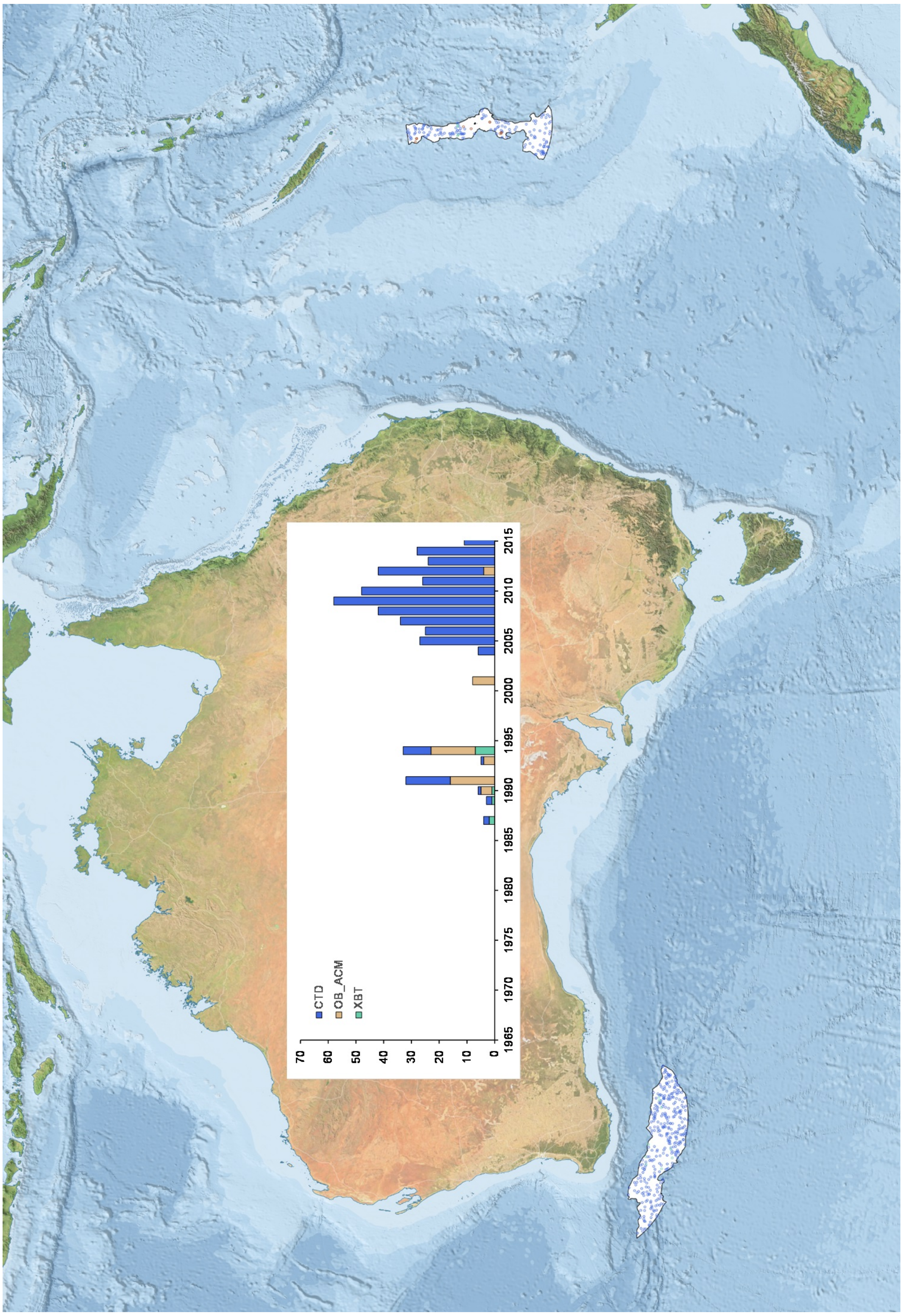

Figure 9: Summary of the physical data holdings across a selection of Australian marine research institutions for the Deep sea beds KEF group, which includes the Diamantina Fracture Zone and Norfolk Ridge. Observation method codes are given in Table 3. Background maps are sourced from Lawrey (2013).

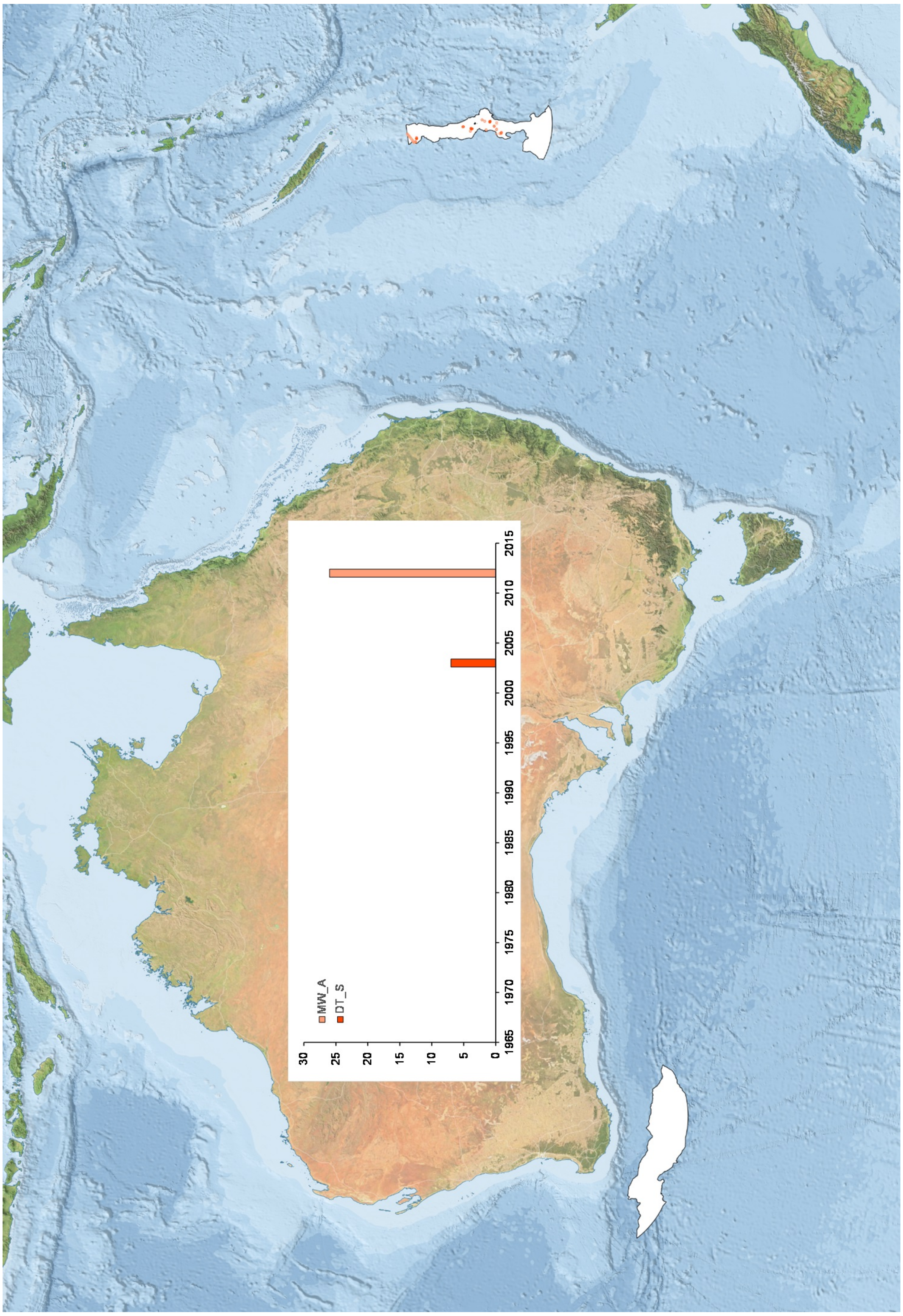

Figure 10: Summary of the biological data holdings across a selection of Australian marine research institutions for the Deep sea beds KEF group, which includes the Diamantina Fracture Zone and Norfolk Ridge. Observation method codes are given in Table 2. Background maps are sourced from Lawrey (2013).

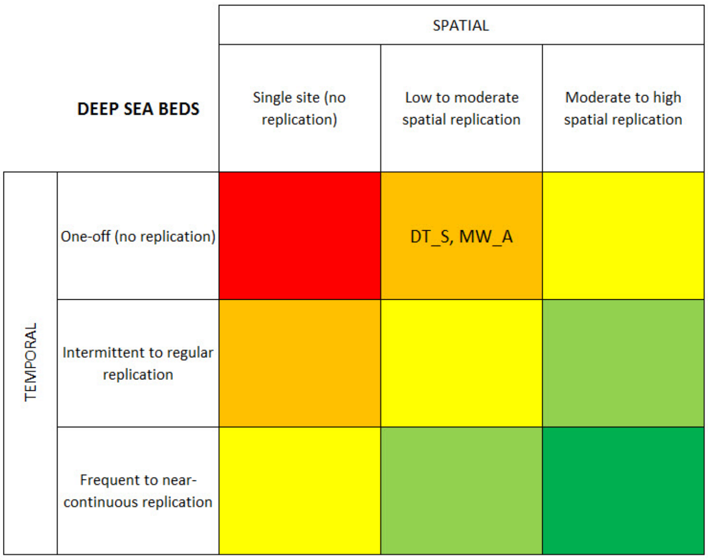

Figure 11: Initial analysis of the spatial and temporal replication of existing data sets (based on ARMADA) that are relevant to the indicators in the deep sea beds KEF reporting group. Observation method codes are given in Table 3 and Table 2

4.2.3. Enhanced pelagic productivity

Physical observations in the enhanced pelagic productivity KEF reporting group date back to the 1980's with a surge of activity around 2010 (Figure 12). A range of observations methods is recorded by ARMADA as intersecting with this group, almost all of which are relevant to the KEF group indicators, namely CTDs, XBTs, ocean based acoustic current meters and gliders. This data is augmented by sea surface temperature and ocean colour observations measured at a very high spatial (1 km^2) and temporal (daily) resolution across all of the enhanced pelagic productivity KEFs (Section 5)[3].

CTD samples are spatially well replicated across all of the enhanced pelagic productivity KEFs, and may also be replicated in time. Glider samples are well replicated in the Bass Cascade and Upwelling east of Eden, but not so in the other KEFs in this reporting group, and they do not appear as replicated in any years other than 2011. Similarly XBT samples are quite well replicated in the Upwelling off Fraser Islands, but less so in the other KEFs.

Biological observations in this KEF reporting group show an interesting pattern of primarily demersal trawls and sleds, dating back to the 1960s, transitioning to diver video, satellite tags, the continuous plankton recorder, remote/autonomous underwater video and mid-water acoustics around 2005 (Figure 13). All of these later methods, except diver video are relevant (to varying extents) to the indicators in this KEF group. Demersal trawls and sleds, however, are not.

[3]Note: these records are not shown in Figure 12 or Figure 13 because they would swamp and mask all other records

The biological observations in this KEF reporting group are concentrated in those KEFs that are closest to the coast. The Bonny coast upwelling and the Bass Cascade and upwelling east of Eden are repeatedly sampled by the continuous plankton recorder, and contain dense clusters of satellite tag records. Satellite tag records are also densely clustered in the small pelagics KEF off the Eyre Bonney coast and the Kangaroo Island Pool and Eyre Peninsula upwellings. The upwelling off Fraser Island also contains numerous mid-water acoustic transects. The number of independent observations within these clusters requires further analysis but at this level of analysis the replication appears promising.

By contrast the Tasman front and Eddy field contains fewer observations, consisting almost exclusively of mid-water acoustic transects, that appear to cluster around a seamount in the KEF, and in a region in the KEF's north east corner (Figure 13). These initial results of ARMADA suggest that there are several existing data sets – satellite tags, continuous plankton recorder and mid-water acoustics – that may provide a sufficient basis for assessing the status and trends of indicators in at least some of the KEFs in this reporting group (Figure 16).

4.2.4. Seamounts

Physical observations intersecting with the seamounts KEF reporting group are dominated by multibeam sonar observations (possibly high resolution bathymetry surveys), CTD and ocean based acoustic current meters (Figure 14). Only the MBS data, however, are relevant to the indicators (matrix forming stony coral in this instance) in this reporting group. MBS observations were collected primarily in the Lord Howe Seamount chain with good spatial replication for some (but not all) seamounts. MBS observations appear to be almost entirely absent from the seamounts to the south of and east of Tasmania, although observations from with this platform are know to exist here (see below).

Biological observations within this KEF reporting group show a similar pattern as before – demersal trawls and sleds before 2005 transitioning to seabed towed video, the continuous plankton recorder, mid-water acoustic and some diver video, presumably on shallow features (Figure 15). All of these (with the possible exception of the diver video) are relevant to the group indicators.

The biological observations, however, appear not as extensive as their physical counterparts. Demersal trawl and sled samples appear to be clustered around only two specific seamounts. Similarly seabed towed video appear to be restricted to just two seamounts to the south and east of Tasmania, whilst the CPR samples intersect only one specific feature south of Tasmania. The mid-water acoustic samples are well distributed across most of the seamounts in the Lord Howe rise chain, but intersect with less than half of the seamounts to the south and east of Tasmania. For some seamounts this data may provide a suitable comparator for later observations (Figure 17).

An identified shortcoming of this summary is the omission of some of the data records from the mid-2000s NORFANZ survey and the 2005/06 CSIRO surveys of the southern Tasmanian seamounts including the 10 year resurvey of the deep seamounts of the Tasmanian Seamounts (Althaus et al., 2009). Some of these records (with geo-referencing) have yet to be entered into the CSIRO geoserver. When these records are added the number of biological records between 2005 and 2007 will increase.

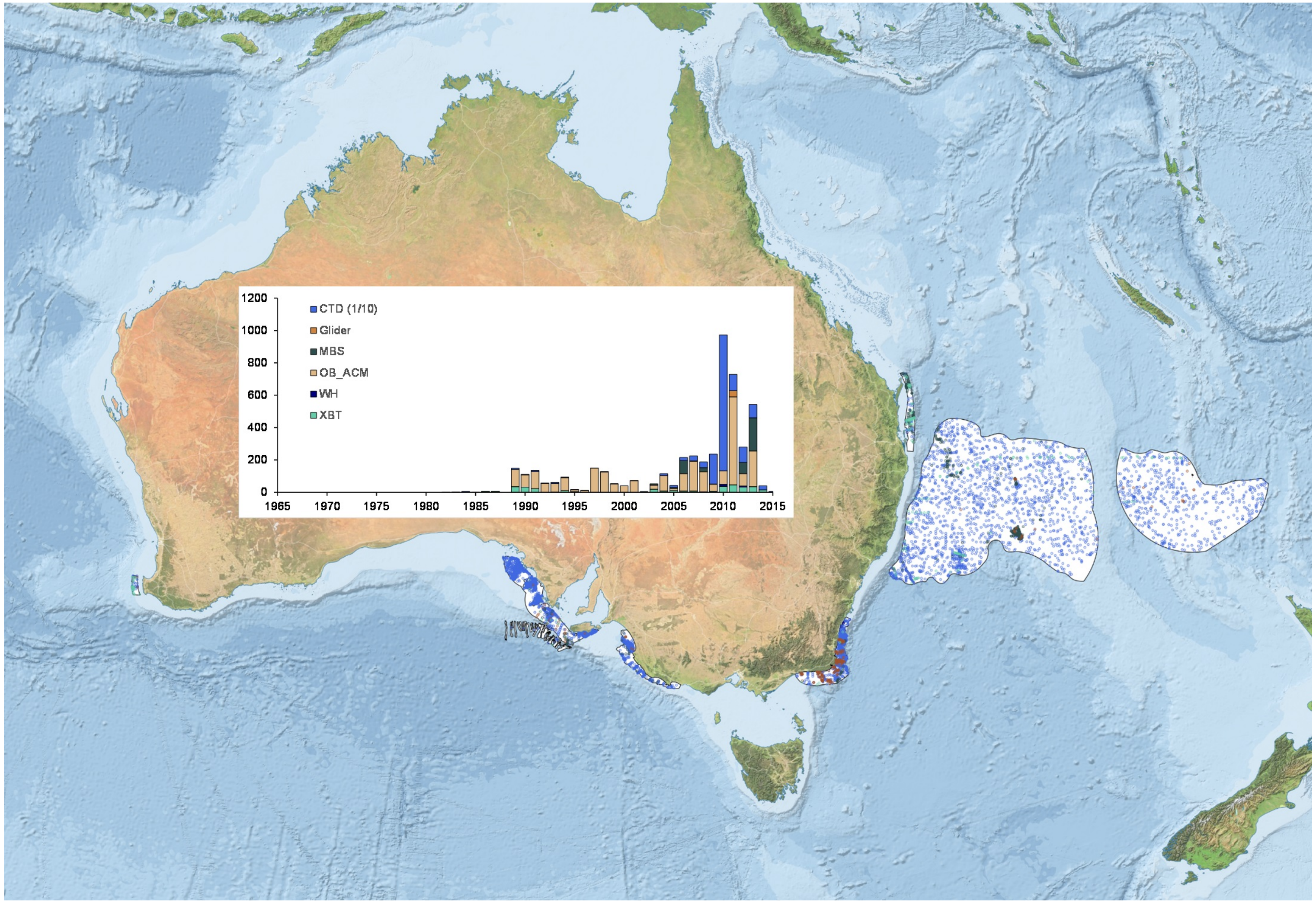

Figure 12: Summary of the physical data holdings across a selection of Australian marine research institutions for the enhanced pelagic productivity KEF group, which includes the Bonney coast upwelling, the Cape Mentelle upwelling, the Eyre Peninsula upwellings, the Tasman front and eddy field, the Kangaroo Island pool, the upwelling east of Eden, and the upwelling off Fraser Island. Observation method codes are given in Table 3. Background maps are sourced from Lawrey (2013).

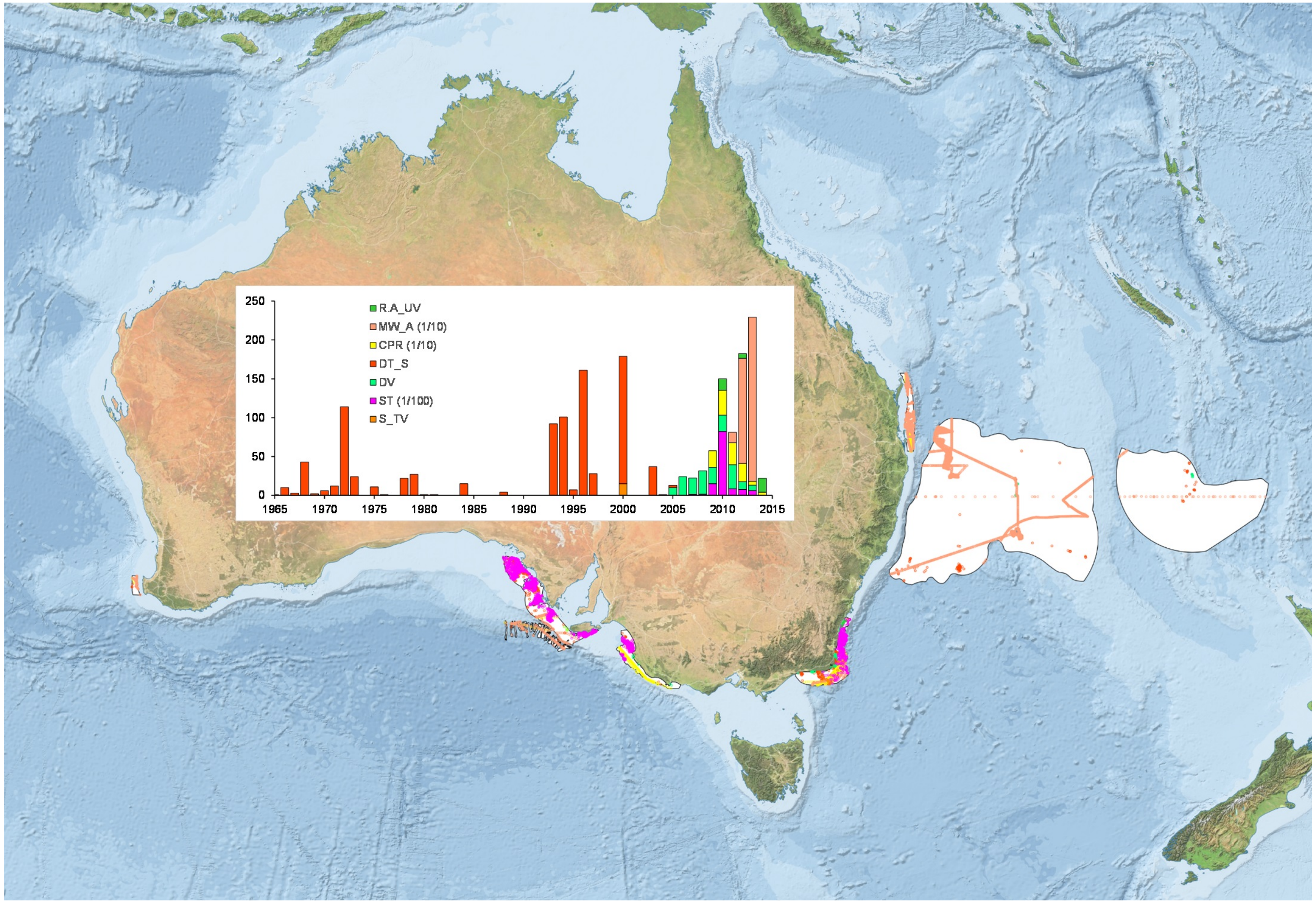

Figure 13: Summary of the biological data holdings across a selection of Australian marine research institutions for the enhanced pelagic productivity KEF group, which includes the Bonney coast upwelling, the Cape Mentelle upwelling, the Eyre Peninsula upwellings, the Tasman front and eddy field, the Kangaroo Island pool, the upwelling east of Eden, and the upwelling off Fraser Island. Observation method codes are given in Table 2. Background maps are sourced from Lawrey (2013).

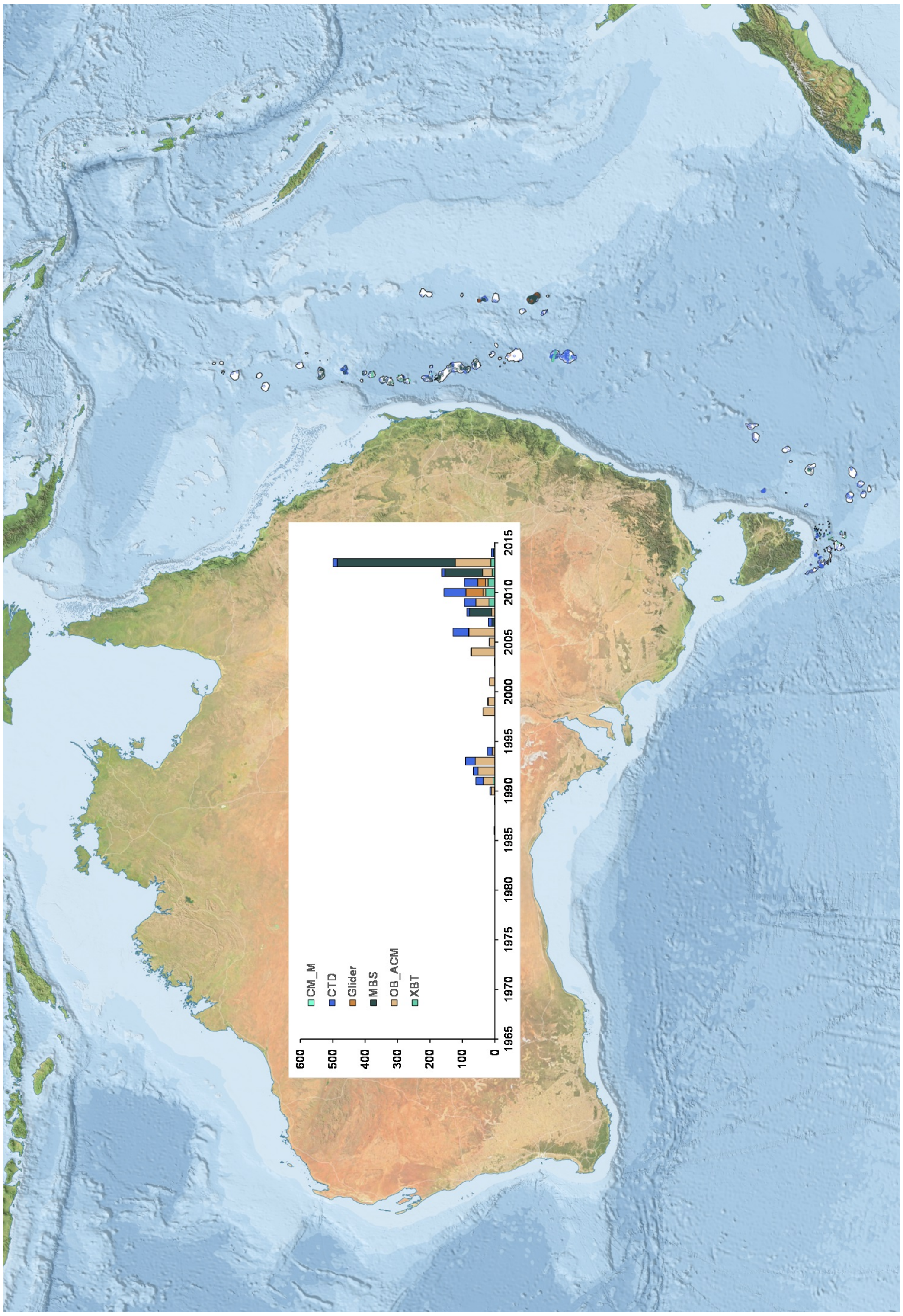

Figure 14: Summary of the physical data holdings across a selection of Australian marine research institutions for the seamount KEF reporting group, which includes the Lord Howe seamount chain, the seamounts south and east of Tasmania and the Tasmantid seamount chain. Observation method codes are given in Table 3. Background maps are sourced from Lawrey (2013).

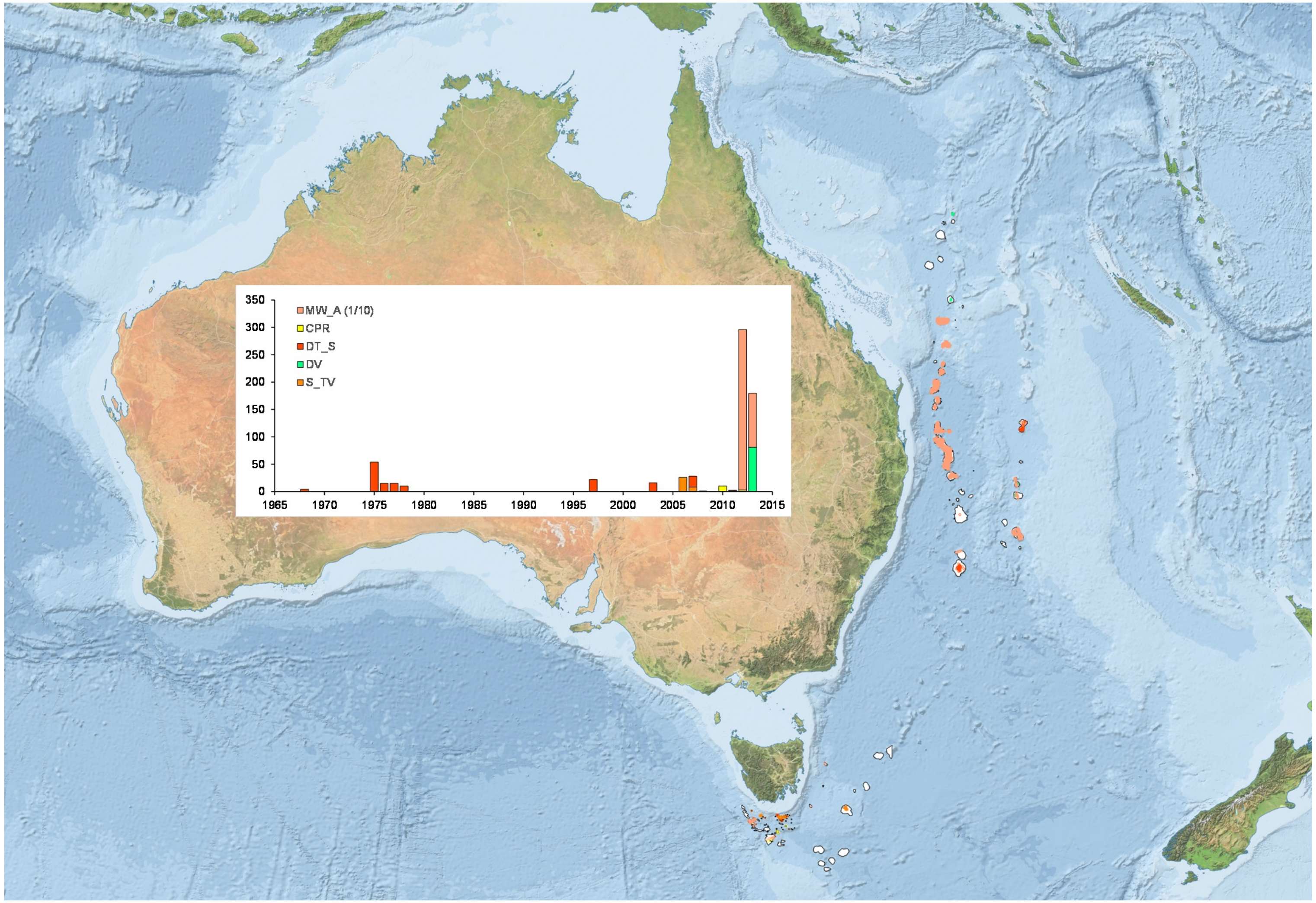

Figure 15: Summary of the biological data holdings across a selection of Australian marine research institutions for the seamount KEF reporting group, which includes the Lord Howe seamount chain, the seamounts south and east of Tasmania and the Tasmantid seamount chain. Observation method codes are given in Table 2. Background maps are sourced from Lawrey (2013).

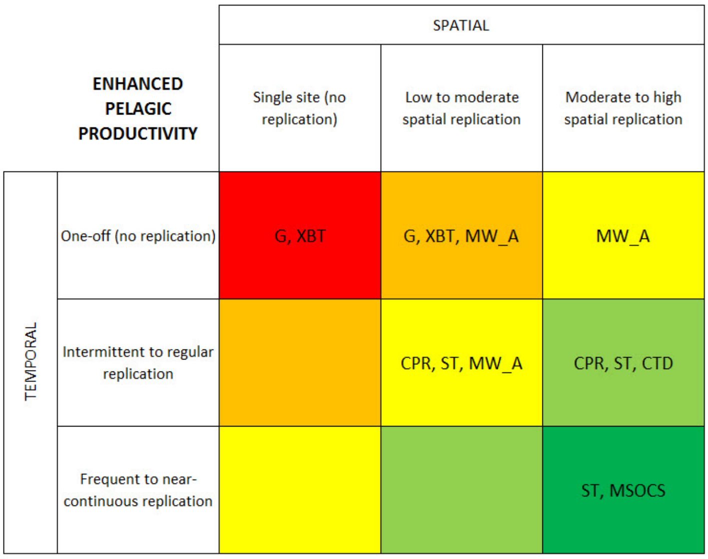

Figure 16: Initial analysis of the spatio-temporal resolution of existing data sets (based on ARMADA) that are relevant to the indicators in the enhanced pelagic productivity KEF reporting group. Method codes are given in Table 3 and Table 2.

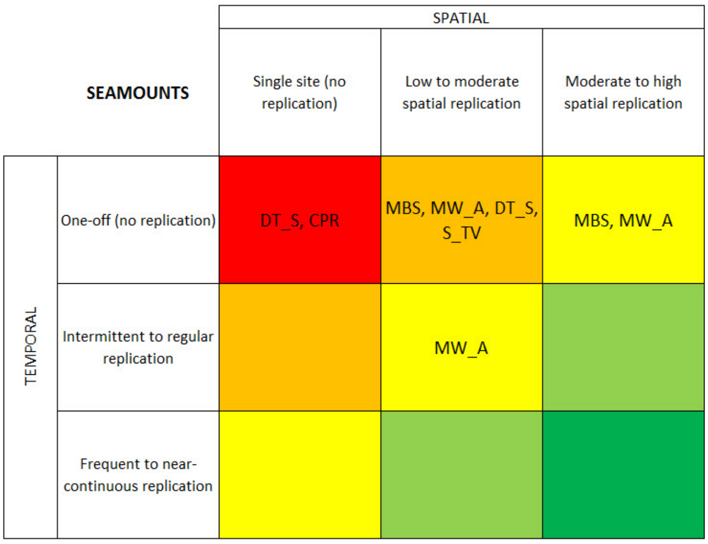

Figure 17: Initial analysis of the spatio-temporal resolution of existing data sets (based on ARMADA) that are relevant to the indicators in the seamounts KEF reporting group. Method codes are given in Table 3 and Table 2. Records for seabed towed video (S_TV) and multi-beam sonar (MBS) are known to be incomplete.

4.2.5. Shelf reefs

Shelf reefs are the most widely distributed group of KEFs, spanning tropical, sub-tropical and temperate habitats. A single, national scale, shape file that accurately identifies all shelf reefs, however, is not currently available. The results presented here uses a (currently incomplete) shape file of known reefs and the continental shelf. ARMADA may therefore identify false positives – i.e. observations that do not in fact intersect with reef features.

Physical observations of shelf reefs have used eight methods, but three of these – meteorological samples, ocean based acoustic current meters and wave height buoys – are not relevant to the KEF reporting group indicators. Moreover, the spatial distribution of samples taken with the other relevant observation platforms is sometimes masked by the high density of CTD observations on the shelf (Figure 18).

Biological observations show the same transition pattern noted before – monitoring methods are almost exclusively demersal trawls/sleds up to about 2005, but from here onwards there is marked shift towards diver visual/video methods, remote and autonomous underwater video, seabed towed video, demersal baited remote underwater video and satellite tags (Figure 19). All of these methods, with the possible exception of demersal trawls and sleds (except on low profile reefs) are relevant to the shelf reefs indicators.

The distribution of sampling effort (physical and biological) in this KEF reporting group appears to be heavily skewed towards the temperate reefs. This may, however, be an artefact of the current ARMADA coverage and the inaccuracies in the Shelf reefs shape file. The biological observations in the tropical and semi-tropical locations are largely diver visual from the Reef Life Survey (`http://reeflifesurvey.com/`) and remote/autonomous video funded largely through IMOS. Both of these platforms display a low to moderate spatial replication but to date repeat surveys are limited to a small number of sites (Figure 20).

Demersal trawls and sleds in the temperate shelf reefs show a moderate to high degree of spatial replication but are probably not replicated to similar extent temporally. The dense clustering of satellite tags suggests a high degree of spatial and possibly temporal resolution but additional analysis of the actual data, to identify what species is actually tagged, is necessary to determine how many of these samples are relevant to the shelf reefs indicators.

An identified shortcoming for this summary is the omission of New South Wales demersal BRUV observations and samples from the Kapala marine commercial fish surveys. The Kapala surveys were conducted on the continental shelf in the South East and Temperate East Marine Regions from 1975-2008. The data currently have an embargo that prevents display of the sample locations. Information on the NSW demersal BRUV data is not currently available via a WFS feed on a publicly accessible geoserver.

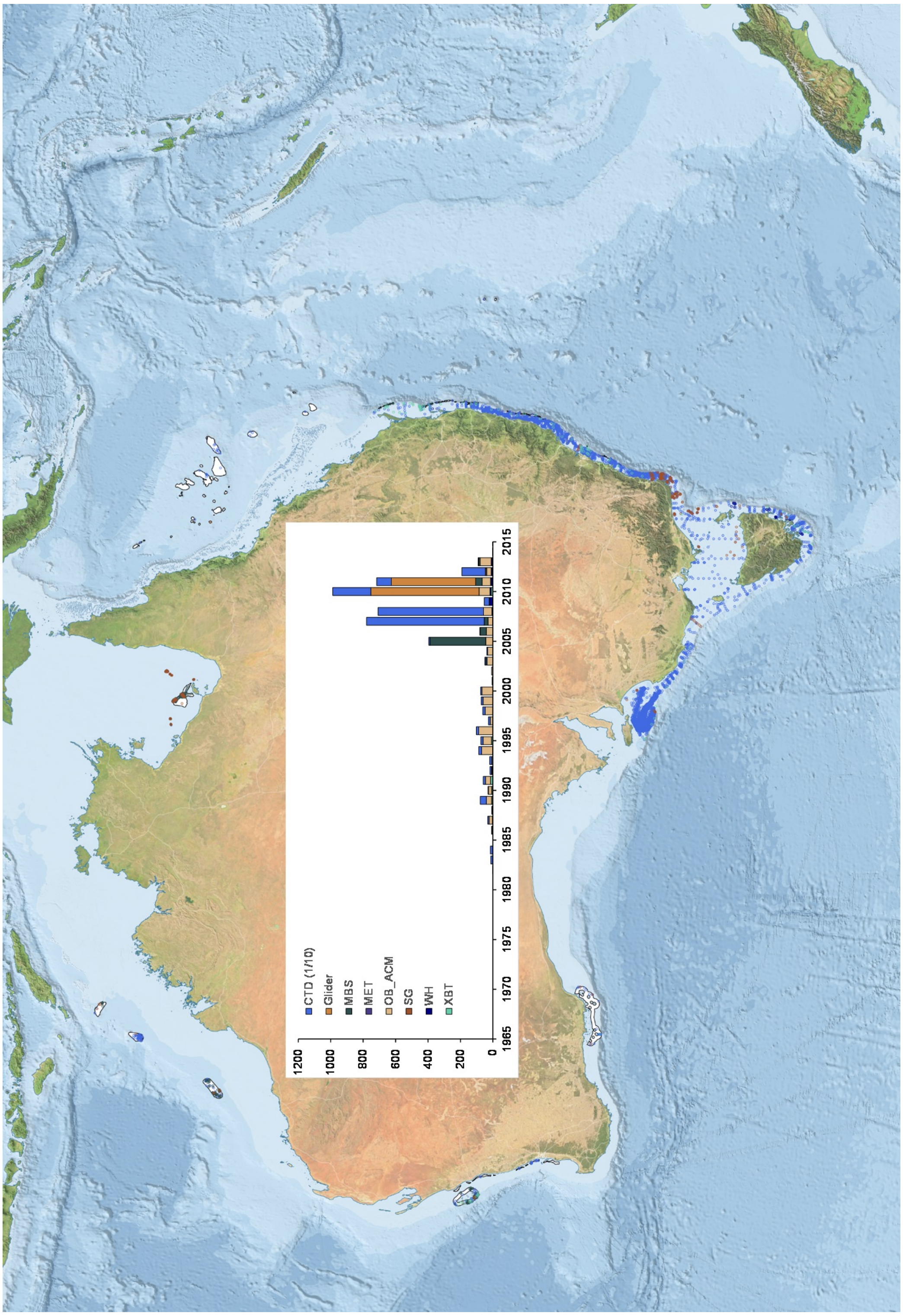

Figure 18: Summary of the physical data holdings across a selection of Australian marine research institutions for the shelf reefs KEF group, which includes the temperate, sub-tropical and tropical shelf reefs. Observation method codes are given in Table 3. Background maps are sourced from Lawrey (2013).

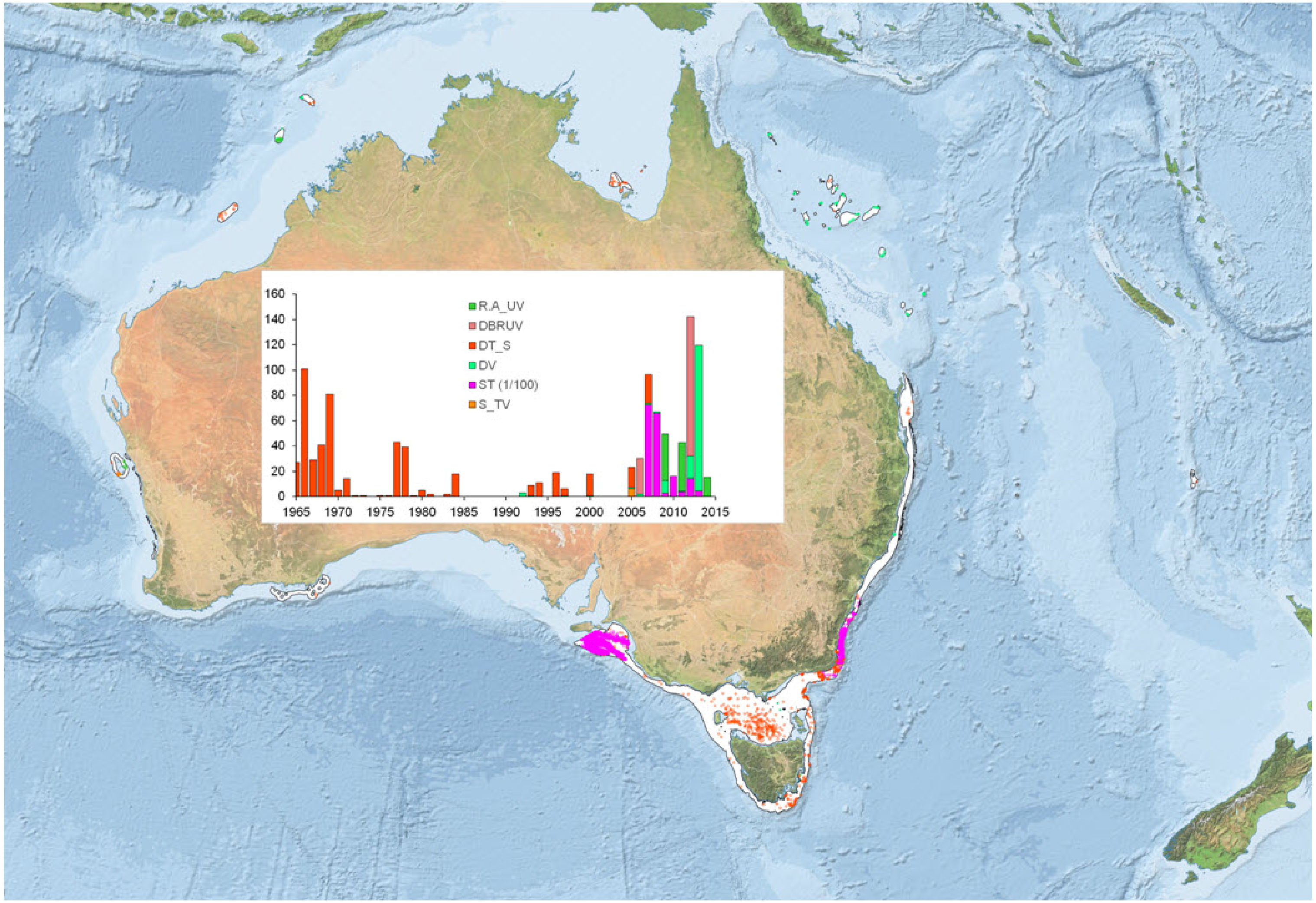

Figure 19: Summary of the biological data holdings across a selection of Australian marine research institutions for the shelf reefs KEF group, which includes the temperate, sub-tropical and tropical shelf reefs. Observation method codes are given in Table 2. Background maps are sourced from Lawrey (2013).

SHELF REEFS		SPATIAL		
		Single site (no replication)	Low to moderate spatial replication	Moderate to high spatial replication
TEMPORAL	One-off (no replication)		MBS, DV, DT_S, R.A_UV, DBRUV	MBS, DT_S
	Intermittent to regular replication		ST, DV, R.A_UV	
	Frequent to near-continuous replication			

Figure 20: Initial analysis of the spatial and temporal replication of existing data sets (based on ARMADA) that are relevant to the indicators in the shelf reefs KEF reporting group. Observation method codes are given in Table 3 and Table 2

4.2.6. Shelf seabeds

The shelf seabed KEFs contains three KEFs but currently shape files are only available for the Gulf of Carpentaria and commonwealth marine environment within and adjacent to Geographe Bay. A shape file for the third – Benthic invertebrate communities of the eastern Great Australian Bight – is currently unavailable. Physical observations in the Gulf Carpentaria have been made with multibeam sonar, CTDs and ocean based acoustic current meters, dating back to the early 1980's, with a reasonable degree of spatial replication. In Geographe Bay, however, observations are restricted to CTDs clustered in the western tip of the KEF (Figure 22). Only the multibeam sonar observations are relevant to the KEF indicators.

The pattern of biological observations mirrors that of the physical observations. In Geographe Bay observations are limited to diver video methods deployed within a very small part of the KEF. In the Gulf of Carpentaria the observations have been made with satellite tags, mid-water acoustics and demersal trawls/sleds. The tags and trawls are largely restricted to the western edge of the KEF, whilst the mid-water acoustics are more evenly spread across the KEF (Figure 22). All of these methods are also relevant to the indicators in this reporting group (Figure 20).

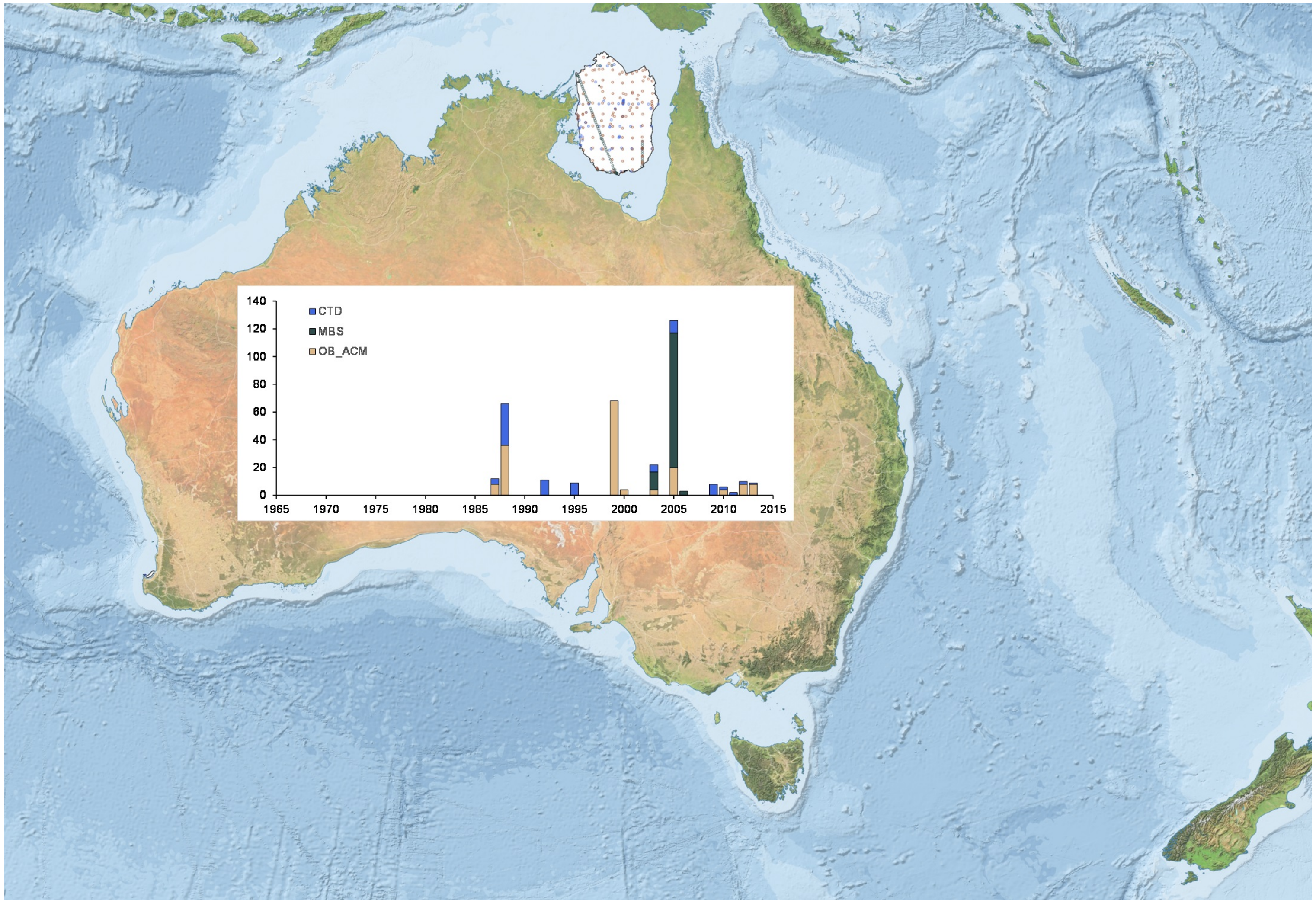

Figure 21: Summary of the physical data holdings across a selection of Australian marine research institutions for the shelf sea beds KEF group, which includes the Commonwealth marine environment within and adjacent to Geographe Bay and the Gulf of Carpentaria basin. Observation method codes are given in Table 3. Background maps are sourced from Lawrey (2013).

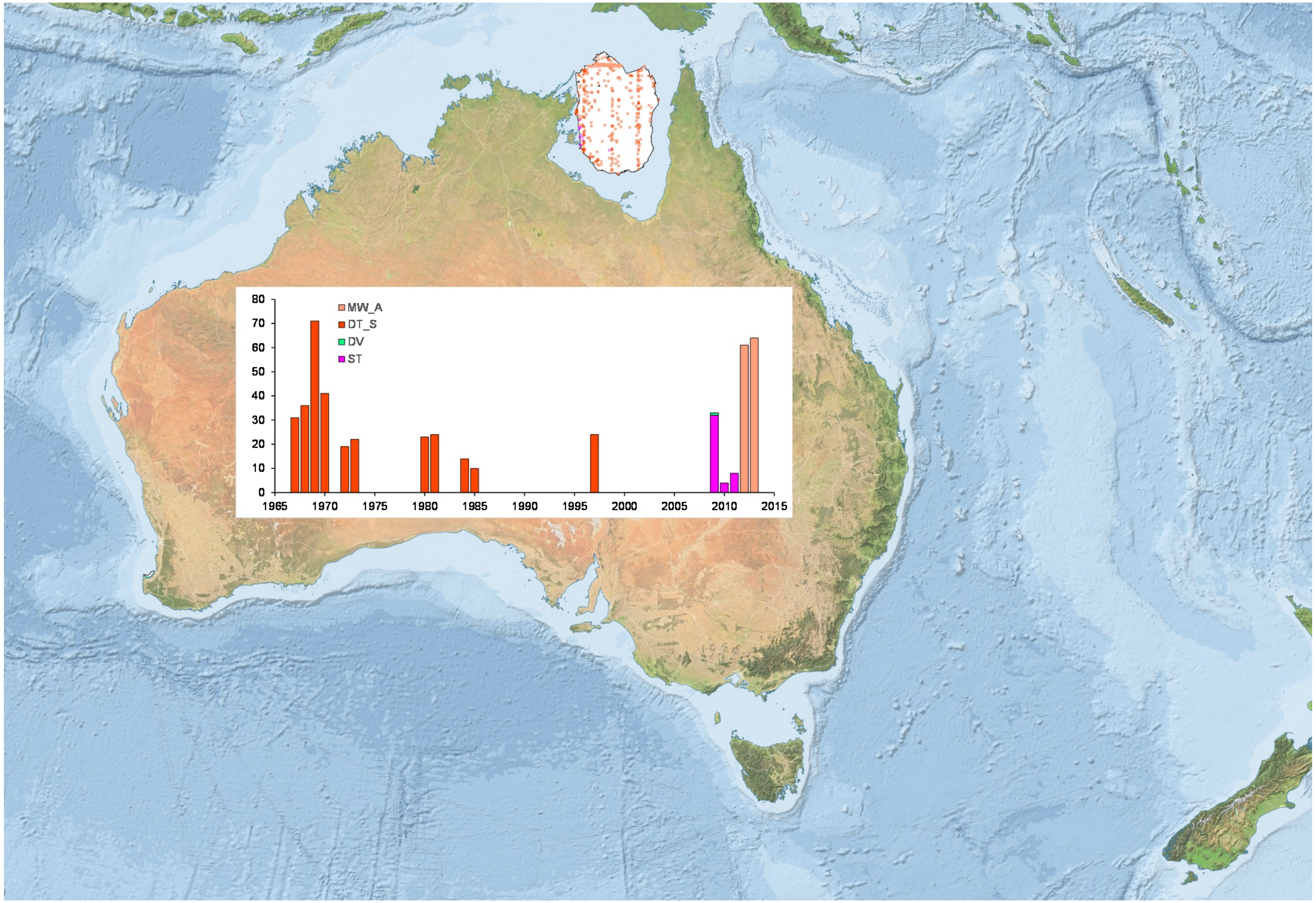

Figure 22: Summary of the biological data holdings across a selection of Australian marine research institutions for the shelf sea beds KEF group, which includes the Commonwealth marine environment within and adjacent to Geographe Bay and the Gulf of Carpentaria basin. Observation method codes are given in Table 2. Background maps are sourced from Lawrey (2013).

SHELF SEA BEDS		SPATIAL		
		Single site (no replication)	Low to moderate spatial replication	Moderate to high spatial replication
TEMPORAL	One-off (no replication)		MBS, ST, DT_S, DV	MW_A
	Intermittent to regular replication			
	Frequent to near-continuous replication			

Figure 23: Initial analysis of the spatial and temporal replication of existing data sets (based on ARMADA) that are relevant to the indicators in the shelf sea beds KEF reporting group. Observation method codes are given in Table 3 and Table 2

Additional surveys conducted by CSIRO and the South Australian Research and Development Institute (SARDI) are known to exist for the Great Australian Bight (GAB). The data collected by CSIRO will be visible in ARMADA once the Department finalises the GAB shape file.

5. INITIAL ANALYSIS FOR EPP KEFS

KEY POINTS

1. Sea Surface Temperature and Chlorophyll-a observations in the enhanced pelagic productivity KEFs are analysed with a time series model that distinguishes long term trends from temporal cycles at different frequencies (seasonal and inter-annual). The analysis concludes that:

   - **Bonney coast upwelling**: the observed (decreasing) long term trend in Net Primary Productivity (NPP) is consistent with predictions that climate-change is causing a decrease in upwelling.
   - Confirmation of the long term trend in: (i) summer south-easterly wind stress; (ii) abundance of Australian and New Zealand fur seals; (iii) concentrations of photic zone dissolved inorganic Nitrogen; (iv) the biomass of Euphausids; or (v) the number of whale sightings in the KEF, is needed to verify these conclusions.
   - **Kangaroo island pool and Eyre peninsula upwellings**: the observed (no-change) long term trend in NPP is inconsistent with the predicted direction of change (decrease in 4 pressure scenarios, increase in 4 other scenarios) in the KEF.
   - Confirmation of the long term trend in: (i) catch per unit effort of the small pelagic fishery; (iii) biomass of small pelagic fish; or (iii) abundance of crested terns, penguins, shearwaters and petrals, is needed to resolve the inconsistent predictions
   - **Small pelagics off the Eyre-Bonney coast**: the observed (increasing) long term trend in NPP is consistent with the predicted direction of change in the KEF.
   - Confirmation of the long term trend in: (i) photic zone dissolved inorganic nitrogen; (ii) the abundance of petrals and shearwaters; and, (iii) the number of baleen cetacean sightings in the KEF is needed to verify these conclusions.
   - **Bass Cascade and upwelling East of Eden**: the observed (no change) long term trend in NPP is consistent with predictions that climate change is not decreasing upwelling.
   - Confirmation of the long term trend in: (i) upwelling indices; (ii) concentrations of nutrients and silicates; and (iii) biomass of top predators, is needed to verify these conclusions.
   - **East Tasmania subtropical convergence zone**: the observed (no change) long term trend in NPP is consistent with predictions that the strengthening EAC is not affecting this KEF.
   - Confirmation of the long term trend in: (i) the strength of the EAC; (ii) small pelagic catch per unit effort; (iii) fur seal abundance; (iv) concentrations of nutrients and silicates; and (v) biomass of top predators is needed to verify these conclusions.
   - **Upwelling off Fraser Island**: the observed (slightly increasing) long term trend in NPP is only consistent with four of the fourteen pressure scenarios.
   - Confirmation of the long term trend in: (i) the strength of the EAC; and (ii) concentrations of nutrients is needed to further resolve this uncertainty.

5.1. Enhanced pelagic productivity KEFs

Areas of enhanced pelagic productivity (EPP) occur in the Commonwealth Marine Area because of interactions between ocean currents, water bodies, wind and sea-floor features that lift nutrient-rich water from depth into the photic zone. The increased supply of nutrients into the photic zone fuels phytoplankton blooms that in turn trigger cascades of feeding aggregations from plankton and fish to seabirds and marine mammals. These areas are also important for recruitment of marine life and as refuelling stations for migratory marine life, such as whales, seabirds and tunas.

To date, the Australian government has identified nine key ecological features occurring in three marine bioregions: Meso-scale eddies in the Leeuwin current (south west region); the Kangaroo Island Pool, canyons and adjacent shelf break and Eyre Peninsula upwellings (south west region); the Cape Mentelle Upwelling (south west region); the Bonney Upwelling (south east region); Bass Cascade (south east region); Eden upwelling (south east region); the East Tasmania sub-tropical Convergence Zone (south east region); the Tasman Front and Eddy Field (east region); and the Upwelling off Fraser Island (east region). All of these except the Cape Mentelle upwelling have been modelled (Hayes et al., 2015).

The EPP KEFs are identified in the marine bioregional plans because they provide foraging grounds that support aggregations of marine life in our oceans. These areas are predictable hotspots of biological productivity in an otherwise unpredictable, ephemeral or sparse pelagic environment. For example, the Kangaroo Island Pool, canyons and adjacent shelf break, and Eyre Peninsula upwelling is identified in the South-west Marine Bioregional Plan (MBP) as a regional priority on the basis of its important contribution to the region's biodiversity.

The South-west MBP recognises this KEF for its high productivity and aggregations of marine life. The adjacent shelf break has unique sea floor features with ecological properties of regional significance. The Kangaroo Island canyons are known for their seasonal upwellings of deep ocean waters that support aggregations of krill, small pelagic fish and squid, which in turn attract marine mammals, sharks, large predatory fish and seabirds. Biologically important areas within or adjacent to this KEF include foraging and migration areas for the pygmy blue whale and sperm whale, and connecting habitat for the endangered southern right whale.

The South-west MBP identifies changes in sea temperature and other oceanographic characteristics, extraction of living resources, by-catch, noise pollution and oil pollution as pressures of potential concern for this KEF. These pressures, however, are not well understood or expected to increase. The priority pressures for this region are climate induced changes to oceanographic characteristics and processes, and extraction of living resources.

The 2011 SOE report identified climate related pressures (such as increasing ocean temperatures and acidity) as beginning to have significant impacts in all regions, with the worst affected areas in the south-east and south-west. Changes in ocean current dynamics are also affecting the South-west Marine Region. Fishing pressures in the south-west are also identified as widespread and causing serious degradation.

5.2. Data and derived products

In this sub-section we provide a demonstration of the prediction – observation – (in)validation philosophy that underlines the approach to KEF indicator selection advocated in Hayes et al. (2015). The analysis uses two global, satellite derived, data sets of (i) Sea Surface Temperature; and (ii) Chlorophyll-a, from which a third product, Net Primary Productivity (NPP), is derived.

Sea surface temperature is inferred from Advanced Very High Resolution Radiometer (AVHRR) High Resolution Picture Transmission data broadcast by the National Oceanic and Atmospheric Administration (NOAA) environmental satellites (NOAA9 to NOAA19). The NOAA satellites take observations of radiation from the top "skin" of the ocean in multiple infra-red wavelengths. These measurements are used to infer the temperature of the ocean's surface, after correction for the effects of the atmosphere and after the removal of clouds.

Surface chlorophyll-a is provided by the Aqua satellite platform. It carries a Moderate Resolution Imaging Spectroradiometer (MODIS) sensor that observes sunlight reflected from the ocean surface at multiple wavelengths. These multi-spectral measurements are used to infer the concentration of chlorophyll-a (Chl-a), most typically due to phytoplankton, present in the water. There are multiple retrieval algorithms for estimating Chlorophyll-a from the ocean reflected sunlight observations. The data used here are based on the Garver-Siegel-Maritorena (GSM) method implemented in the SeaDAS processing software . This product is specifically recommended for use in the model that is subsequently used to infer NPP.

The model used to compute an estimate of NPP is based on the depth integrated, vertically generalised production model (VGPM). VGPM estimates NPP from chlorophyll using a temperature-dependent description of chlorophyll-specific photosynthetic efficiency. In the VGPM, NPP is described as a function of chlorophyll, available light, and photosynthetic efficiency (see Behrenfeld and Falkowski, 1997, for a detailed description). In this analysis we have used a slight variant of the standard VGPM model, known as the Eppley-VGPM model. The only difference between the Standard VGPM and the Eppley-VGPM is the temperature-dependent description of photosynthetic efficiencies is modified to account for variation in photosynthetic efficiencies due to photo-acclimation (Eppley, 1972; Antoine and Morel, 1996). The similarity between these models (VGPM vs E-VGPM) is described in detail by Carr et al. (2006). This accuracy of this model has not been explicitly tested in Australian waters but it is considered to be a reasonable model for oceanic waters away from the coast (Saba et al., 2011).

The data have been remapped from satellite projection into a geographic (Latitude/Longitude axes) projection and are presented as a sequence of daily mosaics covering the region ($80 \leq$ Longitude $\leq 180, -60 \leq$ Latitude $\leq +10$) formatted as CF-compliant netCDF files. The data is not processed until the definitive spacecraft ephemeris becomes available, usually 12-24 hours after the overpass. This means that the geo-location should be of a uniformly high standard. Calibration and reprocessing caveats are, however, applicable to the data.

The NOAA SST data spans 20 years, from 1st October 1993 to the 19th February 2013, with up to 8 observations per 1kms^2 pixel per day for the entire Australian region (approximately 55 °S to 5 °N, 80

[3] http://oceancolor.gsfc.nasa.gov/DOCS/MSL12/master_prodlist.html/#prod15

°E to 190 °E). Here the data are analysed at a daily resolution on a grid that is approximately 4kms $\times$ 4kms so that there are up to $8 \times 16 = 128$ observations per grid cell per day.

The resolution of the MODIS chlorophyll-a data is similar. The data set has been compiled at the same temporal and spatial resolution as the SST data, for the same area, but over a shorter 12 year period (2002 - 2014). In the region analysed the total number of observation available (after correction) varies from between 1700 to 2500 per grid cell over the entire twelve year period, implying that for some days of the year no observations are available.

5.3. Statistical modelling

The statistical model is described in detail in Foster et al. (2014). Briefly, the model decomposes the time series of SST, Chlorophyll-a and derived NPP at each grid cell into three different components:

- Inter-annual variability – this includes the long-term trend and any variability with multi-year time-scales. This is modelled as a smooth function of time denoted $f(t)$, where t denotes the day of observation and ranges from $0 \leq t \leq 7091$ and $0 \leq t \leq 4383$ for SST and Chlorophyll-a.
- Annual cycle – this is a periodic function with the same timing and amplitude every year. It is assumed to be a smooth function of day – within – year but not necessarily a trigonometric function (e.g. sin, cos) or a function of trigonometric functions. This function is denoted g(d) where $0 \leq d \leq 365$ days (or 366 days in a leap year).
- Residual – all random and non-random deviations from the model. It includes: (i) temporal patterns that occur on a time scale shorter than 1-day (diurnal effects); and, (ii) non-smooth trends and other model misfit issues (e.g. when the annual cycle changes abruptly between years).

The model allows a number of useful statistical summaries to be extracted from the data and plotted over the entire Australian region. For this analysis we report three summary statistics:

- The average – this is overall mean of the data at each grid cell.
- The annual (seasonal) variability – this represents the total within-year variation attributable to seasonal changes in the observations. More formally, it is the root mean square difference between the long term trend and the estimated seasonal trend – i.e. it is the sum of the magnitude of the difference between $f(t)$ and $g(d)$.
- The average long term trend – this is the estimated overall trend in the data once the annual (seasonal) cycles have been removed. Long term trends may have low-frequency (e.g. decadal) cycles, this term however is a simple linear representation of the trend – i.e. it is a simplified linear representation of $f(t)$

The first two statistics sometimes allows us to confirm that the EPP KEFs are indeed associated with elevated production and the mechanism for this. The last provides a means to compare productivity predictions under each of the KEF pressure scenarios with the long term trend.

5.4. Results

5.4.1. Bonney coast upwelling

The Bonney coast upwelling is one of three upwelling regions on the continental shelf between Ceduna and Portland. The other two – off the southern tip of the Eyre Peninsula and off the south western tip of Kangaroo Islands – are discussed below. The Bonney upwelling, however, is the most persistent of the three features. It is clearly visible as a zone of very low annual variability in SST caused by upwelling of cold water in Summer (Figure 36, Appendix E).

Strong south easterly winds entrain nutrient-rich deep water into the photic zone that is entrained in the westerly flowing Flinders Current (Hosack and Dambacher, 2012). This fuels a zone of enhanced pelagic productivity, that extends west from Cape Jaffa (top panel Figure 36, Appendix E), with a concomitantly high average productivity estimate (bottom panel Figure 35, Appendix E).

Climate change is thought to influence productivity in this KEF by increasing summer south easterly winds and/or by shrinking the depth of the thermocline through enhanced El Nino effects. One other possible pressure is the recovery of Australian and New Zealand fur seal populations that forage within the KEF boundaries.[4]. The effect of climate change on the intensity and frequency of El Nino events, however, is uncertain, and current research provides inconsistent predictions (Hosack and Dambacher, 2012). Hence the effect of climate change on upwelling is highly uncertain and the pressure scenarios therefore provide for both an increase and decrease in upwelling (Figure 24).

The statistical modelling of SST, Chlorophyll-a and NPP suggests that there is a positive linear trend in SST in the Bonney upwelling KEF (top panel Figure 37, Appendix E) and a concomitant negative linear trend in Chlorophyll-a and productivity (middle and bottom panel Figure 37, Appendix E). These observations are consistent with pressure scenarios A and D and may indicate a decreasing trend in upwelling leading to a trend of decreasing pelagic productivity in this KEF (Figure 24).

One possible alternative explanation is that the upwelled water is being advected from the KEF before phytoplankton have responded fully to the increased nutrient levels (*pers. comm.* P Thompson, CSIRO). In this case upwelling and/or advection may actually be increasing (or thermocline shallowing) but the enhanced production is witnessed outside of the KEF. This hypothesis may explain the apparent long term increase in productivity outside the KEF (bottom panel Figure 37, Appendix E).

Pressure indicators data that could be analysed to help interpret these results include summer south easterly wind stress in this region and the population abundance of Australian and New Zealand fur seals on adjacent haul-out sites. Additional biological indicator data that could be prioritised to distinguish between pressure scenarios and verify these observations include: (i) the concentration of photic-zone dissolved inorganic nitrogen (from water quality and chemistry measurements); (ii) the biomass of euphausids (from zooplankton samples); and, (iii) the long term trend in the number of blue whale sightings in the KEF (from for example passive acoustics or airborne/ship visual observations).

[4]A third potential pressure considered in the KEF workshop was an increase in the mortality of small pelagic fish through increasing fishing pressure. This was not included in the final model, however, because no catches of small pelagic fish have been recorded in this KEF in recent years.

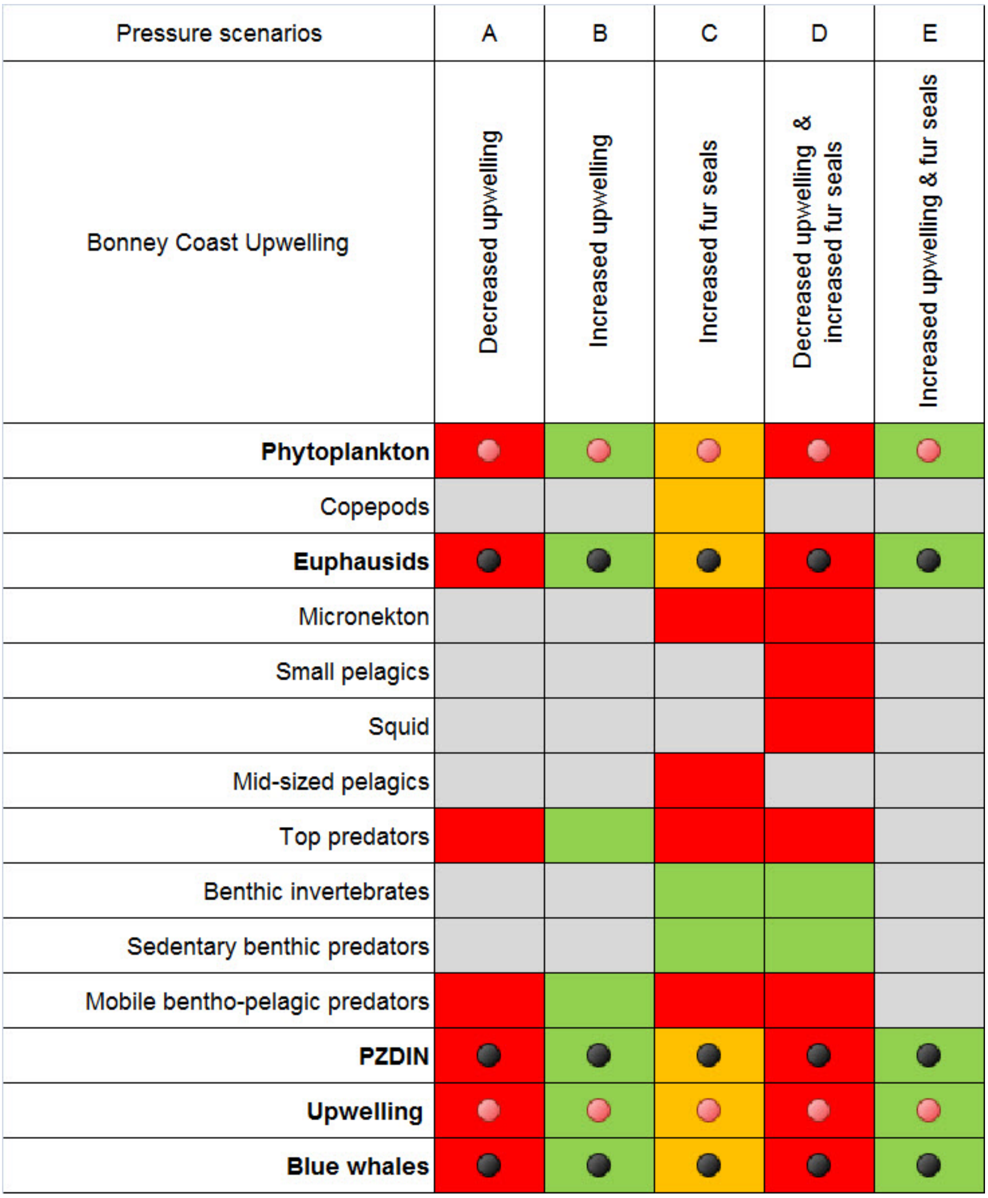

Figure 24: KEF model groups, recommended indicators (in bold) and pressure scenarios (A to E) for the Bonney coast upwelling KEF. Background colour of each cell indicates the predicted direction of change of each of the KEF model nodes (physical variables and biological functional groups) under each pressure scenario: Red = decrease, orange = unchanged, green = increase, light grey = ambiguous response. Foreground traffic light colours are shown for recommended indicators only, and indicate the observed average long term trend of the indicator: Red = decrease, orange = unchanged, green = increase, dark grey = additional data and analysis required to determine trend.

5.4.2. Kangaroo Island pool and Eyre Peninsula upwellings

Upwelling along the south western tip of Kangaroo Island and west of the tip of the Eyre peninsula is thought to be caused by the same phenomena as the Bonney coast upwelling – summer south easterly winds causing Ekman transport away from the coast. Upwelling in these regions, however, reaches the surface only sporadically and is not therefore evident as a strong surface chlorophyll signal. Rather, the cold nutrient rich water is thought to persist throughout the summer as a sub-surface nutrient pool, within the photic zone, which is advected north west along the Eyre peninsula coast towards Ceduna (Hayes et al., 2012b).

The results of the statistical analysis appear to support this theory. The average chlorophyll-a signal is not enhanced off the south west tip of Kangaroo Island, nor west of the Eyre peninsula, but the average productivity, based on the depth integrated VGPM model, does appear to show a small area of increased average NPP in these regions (Figure 35, Appendix E, middle and bottom panels respectively).

A more discernable signal is apparent in the seasonal SST variability to the south west of Kangaroo island and west of the Eyre peninsula, but without any equivalent signal in chlorophyll-a or NPP seasonality. This indicates that cool water must occasionally upwell to the surface in these KEFs but clearly not to the same extent as the Bonney coast upwelling (Figure 36, Appendix E).

The first KEF pressure first is climate change which is thought to increase upwelling and advection by increasing summer south easterly wind stress via enhanced El Nino conditions Hayes et al. (2012b)[5]. The second identified pressure was an increase in the mortality of small pelagic fish either via an increase in fishing mortality or disease outbreaks.

Combinations of these two pressures with four KEF models that reflect uncertainty regarding the biomass of large pelagic fish (and the strength of their predation effect on arrow squid) and the proportion of arrow squid in the diet of pelagic sharks, results in 12 pressure scenarios and four indicators that are predicted to respond in a consistent unambiguous fashion (Figure 25).

The statistical model suggests that surface chlorophyll-a signal is trending downwards, but there is no long term productivity trend in the equivalent regions west of the Eyre peninsula and off the south west tip of Kangaroo Island (middle and lower panels of Figure 37 Appendix E). The observed trend in NPP is therefore inconsistent with the predicted direction of change under the KEF model pressure scenarios.

Additional data that would resolve this issue, and also resolve some of the uncertainty surrounding the pressure scenarios, include the catch per unit effort of the small pelagic fishery, biomass of small pelagic fish in the KEF (measured for example by pelagic trawls or mid-water acoustic surveys) and/or the abundance of crested terns, penguins, shear waters and petrals that feed on small pelagics (Figure 25).

[5]Note, however, that the significant uncertainty surrounding the effect of climate change on El Nino conditions, identified for the Bonney Coast upwelling, was not identified for this KEF

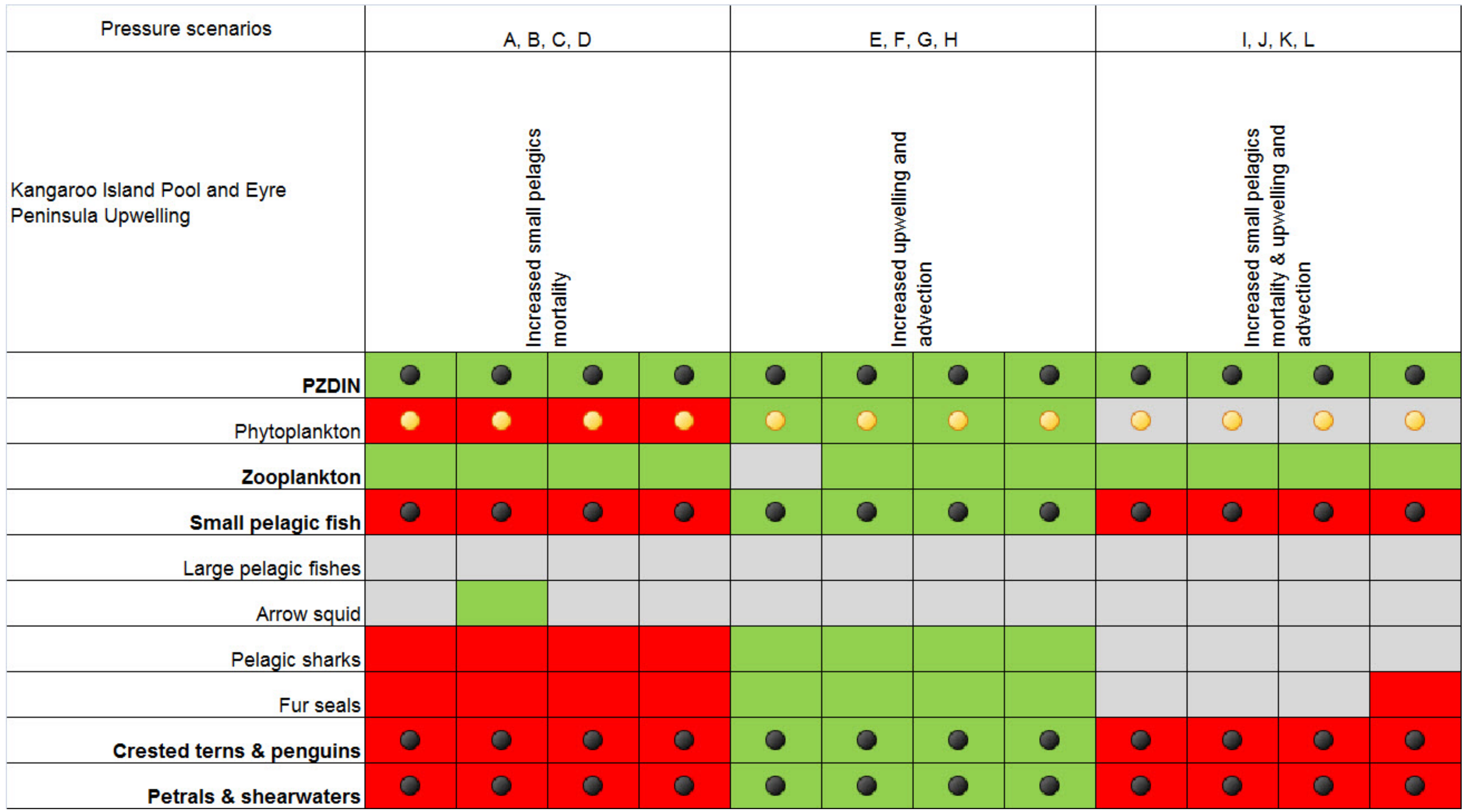

Figure 25: KEF model groups, recommended indicators (in bold) and pressure scenarios (A to L) for the Kangaroo Island pool and Eyre peninsula upwelling KEF. Background colour of each cell indicates the predicted direction of change of each of the KEF model nodes (physical variables and biological functional groups) under each pressure scenario: Red = decrease, orange = unchanged, green = increase, light grey = ambiguous response. Foreground traffic light colours are shown for recommended indicators only, and indicate the observed average long term trend of the indicator: Red = decrease, orange = unchanged, green = increase, dark grey = additional data and analysis required to determine trend. The four columns under each pressure scenario relate to different model structures.

5.4.3. Small pelagics off the Eyre Bonney coast

The KEF model for the small pelagic fishery off the Eyre Bonney coast is almost identical to the model for the Kangaroo Island and Eyre Peninsula upwelling, except it includes two additional function groups (baleen cetaceans and micronekton) that are present in the outer shelf waters but absent in the inner shelf water.

The climate change induced increase in upwelling and pressure on the biomass of small pelagic fish are also the same, but a possible additional fishing pressure on arrow squid may also operate in this KEF. The combination of pressures and similar model structure uncertainty leads to 8 pressure scenarios and four indicators predicted to respond in a consistent unambiguous fashion (Figure 26).

The overall average surface cholorphyll-a signal is unremarkable in this KEF, suggesting that any increased productivity occurs primarily below the surface. The average NPP in the outer shelf waters is somewhat elevated but not as high as the Kangaroo Island and Eyre peninsula KEF or the Bonney upwelling KEF (Figure 35, Appendix E).

The model suggests that there is very little seasonal variability in either the chlorophyll-a signal, which is to be expected, or the NPP signal which is unexpected for a summer upwelling phenomena (Figure 36, Appendix E). As noted above, however, the statistical model identifies a strong increasing trend in productivity in the outer shelf waters of this KEF which may reflect the delayed increase in biomass of phytoplankton responding to sharp increases in nutrients from upwellings in the inshore shelf KEFs.

The predicted increase in phytoplankton biomass in the KEF is consistent with the average long term trend in NPP identified by the model. Additional observations that would help add weight to these conclusions are similar to those identified for the inshore KEFs due to the similarity and connections between these KEFs (Figure 26), namely: (i) photic zone dissolved inorganic nitrogen (from water quality and chemistry measurements); (ii) the abundance of petrals and shearwaters (for example from census studies at nearby rookeries); and, (iii) the long term trend in the number of baleen cetacean sightings in the KEF (from for example passive acoustics or airborne/ship visual observations).

Note that crested terns and penguins are not identified here because of the potential confounding effects of the small pelagic fishery and arrow squid fishery. A similar effect does not occur for petrals and shearwaters because in this KEF they are identified as primarily feeding on micro-nekton rather than small pelagic fish.

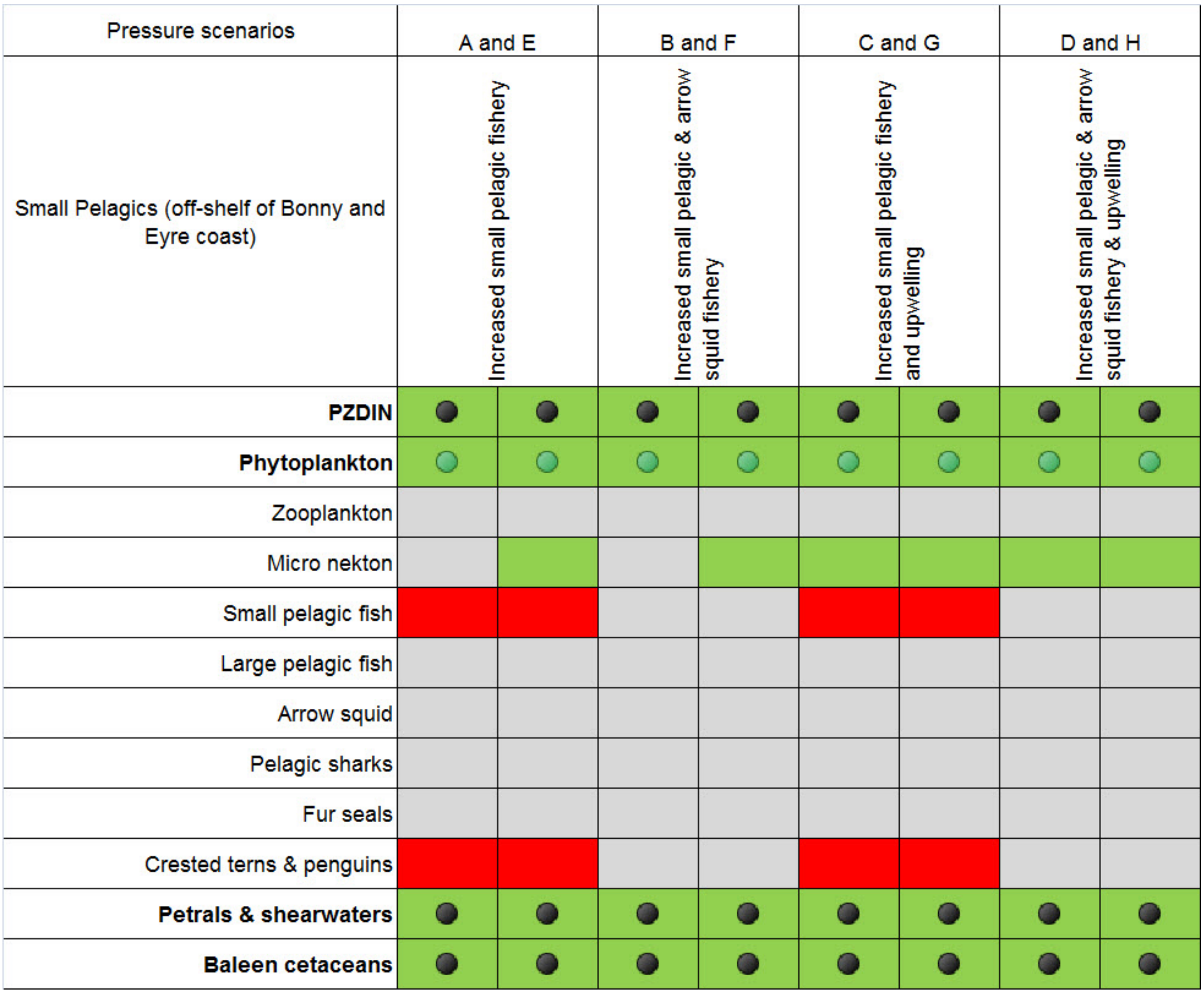

Figure 26: KEF model groups, recommended indicators (in bold) and pressure scenarios (A to H) for the Small pelagic KEF off the Eyre Bonney coast. Background colour of each cell indicates the predicted direction of change of each of the KEF model nodes (physical variables and biological functional groups) under each pressure scenario: Red = decrease, orange = unchanged, green = increase, light grey = ambiguous response. Foreground traffic light colours are shown for recommended indicators only, and indicate the observed average long term trend of the indicator: Red = decrease, orange = unchanged, green = increase, dark grey = additional data and analysis required to determine trend. The two columns under each pressure scenario relate to different model structures.

5.4.4. Bass Cascade and Upwelling East of Eden

The Bass Cascade is a winter phenomena, wherein relatively warm, high salinity, nutrient deficient water from Bass Strait is thought to slowly sink off the shelf, mix with subantartic water and flow north (Hosack and Dambacher, 2012). This process is believed to displace and uplift the nutrient rich, subantartic water causing a late winter/early spring increase in primary productivity in the eastern end of Bass Strait and along the coastline of Victoria and New South Wales.

The statistical model used here supports the conclusion drawn by Bax et al. (2001) that the Bass Cascade and East of Eden KEFs are contiguous and interrelated, showing a clear band of relatively high average chlorophyll-a and NPP stretching north east from Flinders Island to an area East of Eden (middle and lower panels, Figure 38, Appendix E).

The strong seasonal variance that would be expected with a late winter bloom phenomena, however, is not evident in the surface chlorophyll-a seasonal signal, perhaps because outside the short-lived surface bloom the upwelling is deep and rarely reaches the surface (Bax et al., 2001). The seasonal variance is weakly apparent in the NPP (Figure 39, Appendix E). The NPP signal may be masked by strong seasonal variability in the (relatively shallow) waters surrounding Flinders Island but this analysis has already made some allowance for this by eliminating all grid cells that are shallower than 50m.

Experts at the KEF model workshop identified three potential pressures in these KEFs: (i) a decrease in the biomass of small pelagic fish via an increase in small pelagic fishing effort; (ii) a decrease in the biomass of small pelagics, micro-nekton and squid caused by an increase in the abundance of Australian and New Zealand fur seals; and (iii) a decrease in upwelling caused by increased stratification of the water column due to climate change induced warming of these waters (Hosack and Dambacher, 2012). Combinations of these, with two uncertain KEF models, lead to 14 pressure scenarios (Figure 27).

The average long term trend distinguished by the statistical model supports the contention that SST in these KEFs is trending upwards. The statistical model does not, however, identify an equivalent downward trend in either chlorophyll-a or NPP (Figure 40, Appendix E). In this respect the model results are inconsistent with the pressure scenarios in this KEF that include a climate change induced decrease in upwelling. In this context (Hayes et al., 2015) note that recent research suggests that the effects of an increase in stratification due to climate induced warming may be counteracted by an increase in eddy activity in this KEF. The apparent absence of any clear trend in primary productivity in these KEFs would appear to support this hypothesis.

Additional observations of recommended KEF indicators that could be prioritised in order to examine these issues further include upwelling indices (from CTDs, XBTs, gliders and surface/sub-surface profiling floats), concentrations of nutrients and silicates (from water quality and chemistry samples) and the biomass of top predators (for example from pelagic trawls) (Figure 27). Time series analysis of the abundance of New Zealand and Australian fur seals, together with catch per unit effort of small pelagic fisheries that operate in this KEF, may also help to further constrain the pressure scenarios.

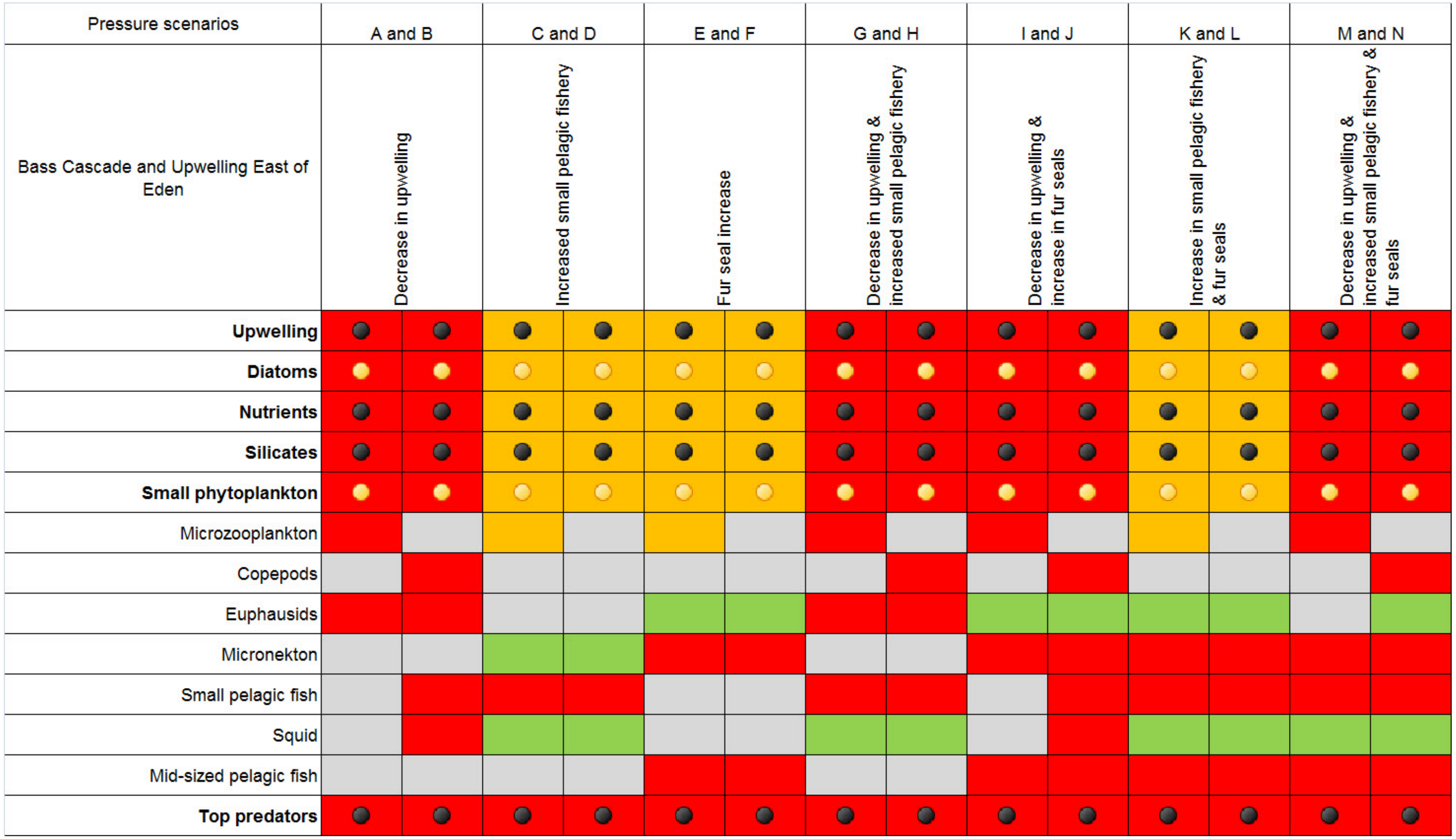

Figure 27: KEF model groups, recommended indicators (in bold) and pressure scenarios (A to N) for the Bass Cascade and upwelling East of Eden KEF. Background colour of each cell indicates the predicted direction of change of each of the KEF model nodes (physical variables and biological functional groups) under each pressure scenario: Red = decrease, orange = unchanged, green = increase, light grey = ambiguous response. Foreground traffic light colours are shown for recommended indicators only, and indicate the observed average long term trend of the indicator: Red = decrease, orange = unchanged, green = increase, dark grey = additional data and analysis required to determine trend. The two columns under each pressure scenario relate to different model structures.

5.4.5. East Tasmanian Subtropical Convergence Zone

The Subtropical Convergence Zone (SCZ) is a southern hemisphere circumpolar oceanographic feature that marks the transition between subantartic zone waters (nutrient rich, deeply mixed, but light limited in winter) and, warmer sub-tropical water masses. In the waters east of Tasmania this feature is influenced by the strength of the East Australian Current (EAC), shifting southwards in summer when the EAC strengthens and moving northwards in winter when the EAC weakens (Hosack and Dambacher, 2012). In some years, the convergence zone can move far enough North in Winter to intrude into the Great Australian Bight (Tomczak et al., 2004).

In early summer, increasing light levels, together with the mixing of warm, nutrient-poor, sub-tropical water with the cold, nutrient-rich subantartic water, triggers phytoplankton blooms along the SCZ. These blooms are mainly comprised of Coccolithophors and are clearly visible in natural light satellite imagery as milky-white clouds in the surface waters. These blooms can stretch in a "global calcite belt" around the southern hemisphere (*pers. comm.* Peter Thompson, CSIRO).

As summer progresses the strengthening EAC current is thought to displace the nutrient rich subantartic water, pushing the SCZ east of Tasmania south and ending the KEF bloom (Hosack and Dambacher, 2012). The SCZ, however, is highly dynamic and at times it is difficult to distinguish from the southern portion of the EAC that is deflected eastwards across the Tasman sea. The timing and location of enhanced pelagic productivity in this KEF may also be masked by a spring bloom that often occurs in the southern Tasman sea, just north of the SCZ.

The statistical analysis suggests that there is on average a somewhat elevated region of surface chlorophyll-a east of Tasmania in broad zone between -42°S and -46°S (Figure 41, Appendix E). There is no equivalent signal in NPP perhaps because this is being masked by higher than average productivity in the EAC. The seasonal variance, however, is very high for both chlorophyll-a and NPP (Figure 42, Appendix E) which is consistent with the summer bloom dynamics described above.

The pressures identified for the East Tasmanian Subtropical Convergence Zone are climate change (causing an increase in the strength of the EAC), a decrease in the biomass of small pelagic fish via increased fishing mortality and the effect on a range of pelagic prey groups by an increase in the abundance of Australian and New Zealand fur seals. Uncertainty about whether or not small phytoplankton contribute significantly to higher trophic levels in this KEF led to two alternative KEF models and 14 pressure scenarios (Figure 28).

The KEF qualitative modelling predicts that diatoms and small phytoplankton will either decrease or remain unchanged in response to the pressure scenarios. The results of the statistical modelling are inconclusive. NPP shows patchy level of average long term increases in the KEF but this signal is not mirrored in chlorophyll-a (Figure 28, Appendix E). This is consistent with the pressure scenarios that do not include a strengthening of the EAC.

Additional time series analysis of the strength of the EAC, small pelagic catch per unit effort and fur seal abundance is necessary to constrain the pressure scenarios. Additional observations and analysis of nutrients, silicates and top predators could help provide a more definitive picture of how productivity within this KEF is trending.

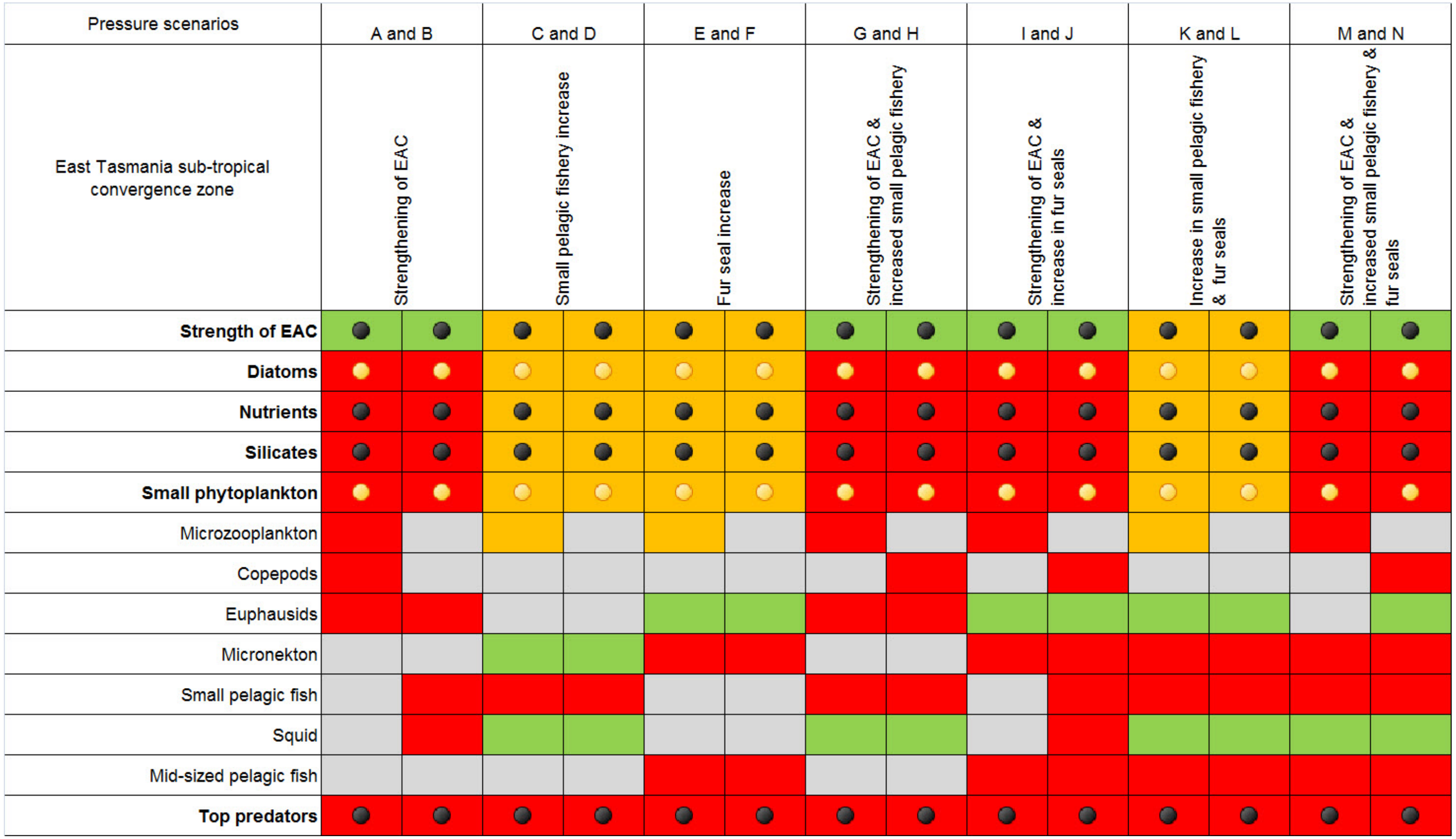

Figure 28: KEF model groups, recommended indicators (in bold) and pressure scenarios (A to N) for the East Tasmanian Subtropical Convergence Zone KEF. Background colour of each cell indicates the predicted direction of change of each of the KEF model nodes (physical variables and biological functional groups) under each pressure scenario: Red = decrease, orange = unchanged, green = increase, lg grey = ambiguous response. Foreground traffic light colours are shown for recommended indicators only, and indicate the observed average long term trend of the indicator: Red = decrease, orange = unchanged, green = increase, dark grey = additional data and analysis required to determine trend. The two columns under each pressure scenario relate to different model structures.

5.4.6. Upwelling off Fraser Island

The upwelling off Fraser Island is thought to be due to a localised acceleration of the East Australian Current that in turn creates an Ekman flux that draws cold nutrient rich waters slope waters to the surface. This nutrient-enhanced surface water mixes with similar water in the Capricorn channel to the North of the Fraser Island that is nutrient enriched due to strong tidal flows (Dambacher et al., 2012).

The presence of these two areas of nutrient enriched waters is confirmed by on-average higher chlorophyll-a and productivity in waters south east of Fraser islands, that appear to be advected to the South perhaps in the EAC, and in waters further north at 223°S and 152°E (Figure 44, Appendix E) although the latter may reflect resuspension in shallow water (despite the fact that this analysis has excluded waters that are less than 50m deep). The waters to the north of Fraser Island show strong seasonal variability, whereas those to the south east exhibit very low seasonal variability (Figure 45, Appendix E), suggesting that the two process that generate the enhanced productivity in this KEF are indeed different.

The KEF qualitative model identifies three pressures in this KEF: (i) a strengthening of the EAC; (ii) oil spills; and, (iii) increase biomass removal from pelagic trawl fisheries. The combination of these pressures, together with uncertainty in the KEF model over the relative importance of small phytoplankton and micro-plankton to higher trophic levels via consumption by copepods, leads to 14 pressure scenarios (Figure 29).

The statistical model identifies a very slight and patchy long term increase in productivity in the waters to the south east of Fraser Island, but no long trend in chlorophyll-a (Figure 46, Appendix E). There is a similar if perhaps stronger increasing trend in the productivity and chlorophyll-a in the waters north of Fraser Island but this may also be an artefact of the shallow water dynamics noted above.

The increase in productivity is consistent with four of the fourteen pressure scenarios but the lack of a strong signal undermines the strength of this conclusion. Furthermore the inclusion of oil spills in the pressure scenarios introduces ambiguity into KEF model predictions, and this reduces the number of potential indicators that may provide reliable signals. Removing oil spills from the pressure scenarios would eliminate this effect and is probably justified as oil spills are not treated as a press perturbation in the other KEFs as they are unlikely to be of a sufficient magnitude and frequency to drive the ecosystem to a new equilibrium point.

Additional data gathering might most usefully be directed to: (i) confirming trends in the strength of the EAC (by gathering additional data from current meters at moorings or ocean based acoustic current meters for example); and (ii) gathering additional measurements of nutrients within the KEF.

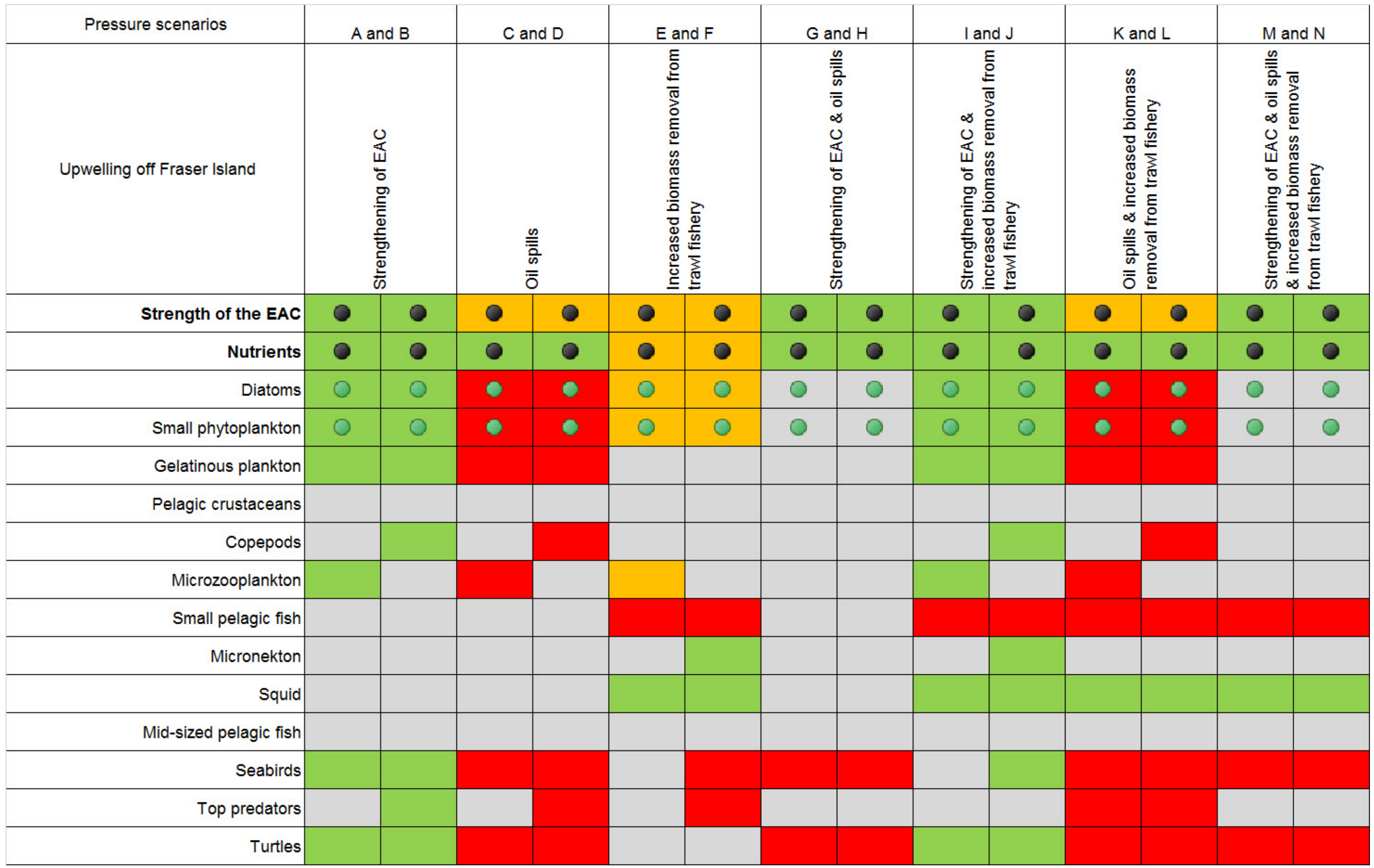

Figure 29: KEF model groups, recommended indicators (in bold) and pressure scenarios (A to N) for the Upwelling off Fraser Island KEF. Background colour of each cell indicates the predicted direction of change of each of the KEF model nodes (physical variables and biological functional groups) under each pressure scenario: Red = decrease, orange = unchanged, green = increase, light grey = ambiguous response. Foreground traffic light colours are shown for recommended indicators only, and indicate the observed average long term trend of the indicator: Red = decrease, orange = unchanged, green = increase, dark grey = additional data and analysis required to determine trend. The two columns under each pressure scenario relate to different model structures.

5.4.7. Meso-scale eddies and Tasman Front and Eddy field

The statistical model described in Section 5.3 treats each analysis pixel independently and in isolation from its neighbouring pixels. As currently applied, this model is not suitable for the meso-scale eddies and Tasman Front and Eddy Field KEFs because the regions (groups of pixels) of enhanced pelagic productivity in these KEFs are associated with meso-scale features that move across large (hundreds of kms) spatial scales.

By treating each pixel individually, the statistical model would effectively average over any change in productivity as, for example, a productivity-enhancing eddy passed through any given location. A brief analysis of the model results (not shown) for these KEFs confirms that the model is unable to identify long term trends or seasonal variability in a meaningful way.

This problem could be rectified by applying the model to pixels that are known to be within, for example, a warm or cold-core eddy in the Leeuwin Current. This would require that all pixels are pre-processed with an eddy-tracking algorithm that is able to identify which pixels are "inside" and "outside" of eddies as they form, migrate and eventually dissipate.

6. CAPACITY TO MONITOR

KEY POINTS

1. KEF indicators have been identified using a scientific process of hypothesising how KEF systems operate and predicting how they will respond to a range of anthropogenic pressures. 32 KEFs are considered to be sufficiently well understood to predict their response to anthropogenic pressures, and thereby identify indicators.
2. Diver visual/operated video, remote and autonomous underwater video and seabed towed video are relevant for monitoring 87%, 83% and 81% of shelf reef indicators respectively.
3. Multi-spectral ocean colour sensors, radio acoustic positioning and telemetry (RAPT), and satellite tags are most applicable to the enhanced pelagic productivity KEF group (24%, 25% and 29% of the indicators respectively). RAPT is also an important method for monitoring shelf reefs (67% of indicators), Deep sea beds (50% of indicators) and Seamounts (44% of indicators).
4. Demersal fishing gears and compound specific isotopes are relevant to 60% and 58% of the indicators associated with the Shelf reef KEFs respectively, whilst water quality and chemistry samples, CTDs and XBTs, and gliders and floats, are relevant to 40%, 64% and 66% of the indicators associated with the enhanced pelagic productivity KEF group.
5. When scored against four capacity determining constraints, such as cost, ease of deployment and maturity of data processing and analysis methods, methods that have a relatively longer history of deployment, such as diver visual census, active fishing gears (demersal and pelagic) and earth observing satellites, tend to have a lower overall constraint score.
6. Ranking observations against relevance to KEF indicators and deployment constraints suggests that the observation methods that are likely to be the most efficient into the future are
   - **Canyons**: remote/autonomous underwater video, demersal trawls/sleds, seabed towed video and multi-beam sonar.
   - **Enhanced pelagic productivity**: gliders, multi-spectral ocean colour sensors, water quality and chemistry samples and subsurface profiling floats.
   - **Seamounts**: pelagic trawls and lines, followed by remote/autonomous underwater video, seabed towed video, mid-water towed video, pelagic BRUVs, passive acoustics and possibly radio acoustic positioning and telemetry
   - **Shelf reefs**: diver visual/operated video, remote/autonomous underwater video, seabed towed video, demersal BRUVs ‘and passive acoustics
   - **Shelf seabeds**: demersal trawls/sleds, remote/autonomous underwater video, seabed towed video and passive acoustics

6.1. KEF indicators

KEF indicators have been identified using a scientific process of hypothesising how KEF ecosystems operate and predicting how they will respond to range of anthropogenic pressures (Hayes et al., 2015). Comparing observations with predictions is the essential next step in this process, and a partial demonstration of this process is provided in Section 5.

To date 53 KEFS have been identified in the CMA of which 32 are considered to be sufficiently well understood to predict their response to anthropogenic pressures, and thereby identify indicators. Indicators are initially identified as those components or processes of the KEF system that: (i) are predicted to change in a reliable fashion despite the limitations of the modelling approach; and, (ii) are predicted to respond in the same way despite our uncertainty about the structure of the KEF system and the anthropogenic pressures that it is subject to.

The indicators and their predicted direction of change under each of the KEF pressure scenarios (combinations of uncertainty about KEF structure and anthropogenic pressures) are detailed in a series of region-specific reports (see for example Hayes et al., 2012b; Dambacher et al., 2012; Hosack and Dambacher, 2012). For the purposes of the blueprint, all of the individual KEF indicators identified to date have been assigned to groups, and these groups have been scored with an indicator variable (0 or 1) to identify whether or not a monitoring method is relevant to them (Appendix C).

All of the potentially relevant monitoring techniques identified here have been categorised into three broadly similar types: (i) methods that rely on video or visual identification of the target indicator; (ii) methods that use employ acoustic or remote-sensing technologies; and, (iii) methods that require a biological or physical sample to be taken as part of the observation procedure. The following sections of the report examine the relevance of each method to the KEF groups and the types of constraints that may limit our ability to deploy these methods in the Commonwealth marine area.

6.2. Monitoring method relevance

6.2.1. Visual- and video-based methods

Visual- and video-based monitoring methods encompass a wide range of different monitoring platforms. Diver-based underwater visual-census methods – typically quadrat counts for sessile invertebrates and line-,strip-, time-transects, point counts or rapid visual census for mobile vertebrates – have been employed in shallow marine environments for over seventy years (Thresher and Gunn, 1986). They are generally considered to be reliable and cost-effective, have several notable advantages over extractive trawl-based methods, but are nonetheless subject to well documented biases and limitations (Buckland et al., 1993; Edgar et al., 2004; Murphy and Jenkins, 2010; Katsanevakis et al., 2012).

Video-based methods encompass mono- and stereo-techniques, including remotely operated and autonomous underwater video, baited and un-baited remote video (both pelagic and demersal), mesopelagic (mid-water) and seabed towed video and diver operated video (Mallet and Pelletier, 2014). With the exception of the last techniques, these methods are not limited by the depth and time constraints imposed by SCUBA methods and can be used to survey abyssal environments.

Technological improvements in battery life, data storage, camera resolution and stereo-image calibration, together with diminishing camera costs, have facilitated a rapid rise in the popularity of video-based methods (Shortis et al., 2009). The rapid adoption of these methods, however, has created its own image-processing bottleneck because imagery can be acquired at a faster rate than it can be currently (manually) processed.

Across the six key reporting questions and their associated KEFs, diver- and video-based monitoring methods are anticipated to be play an important role in any future monitor strategy. Diver visual/operated video, remote and autonomous underwater video and seabed towed video feature most prominently as methods capable of monitoring the indicators associated with shelf reef systems, with relevance for 87%, 83% and 81% of the indicators respectively Appendix D, Table 11).

Another important group of methods for monitoring shelf reefs are the demersal (baited and un-baited) remote underwater video methods. These methods are relevant to about 59% of the shelf reef indicators. Autonomous and remote underwater video are also likely to play an important role in the Canyons, Seamounts, Deep sea beds and Shelf sea beds KEF groups. Across these groups these methods are relevant to 44 – 67% of the indicators (Appendix D, Table 11). The high relevance of these methods for these KEF groups reinforces the need to increase Australia's autonomous systems capacity (National Marine Science Committee, 2014).

Visual and video-based methods are anticipated to be less important for monitoring indicators associated with enhanced pelagic productivity, although pelagic baited remote video, mesopelagic (mid-water) towed video, and air- or ship-based visual census methods can be used for cetacean, small pelagic fish and large pelagic predator indicators associated with this KEF group (Squire, 1972; Barlow and Taylor, 2005).

6.2.2. Acoustic and remote methods

Acoustic and remote methods refer to a series of methods for monitoring both physical and biological variables. Acoustic methods includes mid-water acoustic samplers designed to characterise mid-trophic level organisms such as mesozooplankton and micronekton communities between 2 and 20 cm in length (Trenkel et al., 2011), radio acoustic positioning and telemetry methods (acoustic tags), passive acoustics, satellite tags, multi-beam side scan sonar, ocean based acoustic current meters and shore-based high frequency ocean radar measuring current and wave height meters .

Remote methods include satellite tags, primarily targeting marine mega fauna (Hart and Hyrenbach, 2009), and earth observing satellites, using for example multi-spectral ocean colour sensors (MSOCS) and ocean altimeters. Acoustic and remote monitoring methods typically have the advantage of being able to sample over much larger spatial scales, and at a much higher temporal resolution, than visual/video- or sample-based methods (Trenkel et al., 2011), although the sampling scale across the methods listed here does vary dramatically.

When measured in terms of applicability to indicators, acoustic and remote methods feature most prominently in the enhanced pelagic productivity group and shelf reefs group. Their prominence in the enhanced pelagic productivity group largely reflects the oceanographic and "bottom of food-chain" indicators in this KEF grouping that can be monitored using multi-spectral ocean colour sensors (Section 5) and satellite tags. Together with radio acoustic positioning targeting top predator indicators at the "top of the food chain", these methods are applicable to 24%, 25% and 29% of the indicators in this group respectively (Appendix D, Table 12).

Radio acoustic positioning is also an important method for monitoring shelf reefs (63%), Deep sea beds (50%) and Seamounts (28%). In the shelf reefs group these methods feature more prominently in the shelf tropical reefs group, and are slightly less prominent in the sub-tropical and temperate reef groups because the tropical reef group includes a large number of piscovorous and herbivorous fish indicators, as well as large marine mammals and turtles, all of which have been successfully targeted with RAPT technology (O'Dor et al., 1998; Klimley et al., 2001).

6.2.3. Sample-based methods

Sample based methods refer to those monitoring techniques that physically extract a sample from the environment. This group of methods includes Water quality and chemistry samples acquired via (for example) Niskin bottles, and CTD rosettes, that take sea water samples to measure temperature, salinity and other oceanographic parameters. Sediment grabs, gliders and surface/sub-surface profiling floats (Roemmich et al., 2009), are included here, as well the continuous plankton recorder (Warner and Hays, 1994; Reid et al., 2003), drop net phytoplankton and zooplankton samples, demersal and pelagic trawls and lines (including traps and gillnets), and compound specific isotopes targeting tissue or feather samples of top predators (Williams and Bax, 2001; Ramos and González-Solís, 2012).

Amongst this group of methods, demersal trawls and lines, compound specific isotopes, gliders, profiling floats, water quality and chemistry samples, CTD rosettes and expendable bathythermographs (XBT) are the most prominent. Demersal fishing gears and compound specific isotopes are relevant to 60% and 58% of the indicators associated with the Shelf reef KEFs respectively, whilst water quality and chemistry samples, CTDs and XBTs, gliders and floats, are relevant to 40%, 64% and 66% of the indicators associated with the enhanced pelagic productivity KEF group respectively (Appendix D, Table 13). Demersal trawls and lines are also relevant to 40% of the indicators associated with Canyon KEFs and 63% of the indicators associated with shelf sea beds.

6.3. Monitoring method constraints

The Australian government's capacity to instigate and sustain a national monitoring programme to report on the ecosystem health of the CMA will be determined by the KEF indicators, the availability of relevant monitoring platforms and the current constraints associated with these platforms. The capacity constraints associated with different types of monitoring platforms can be summarised in terms of the answers to the following questions:

- Cost – how much does it cost to acquire samples with a particular piece of monitoring equipment?

- Observation and deployment platform – how many pieces or units of equipments are physically available, and what are the physical/infrastructure restrictions associated with deploying that type of equipment?
- Deployment and sampling procedures – are the field deployment process and survey designs associated with the observation platform well established and understood (i.e. are Standard Operating Procedure described)?
- Data processing and analysis – are the requisite infrastructure and procedures in place to allow appropriate data and meta-data collation, storage and archiving, and are the data processing and analysis methods well understood and established?

Constraints are high when costs per unit sample are high, observation or deployment platform availability is limited or otherwise constrained (for example by vessel size requirements), deployment and sampling procedures are in a pilot-stage or evolving but have yet to meet agreed standards, and data processing and analysis methods are in their infancy. The blueprint gauges the relative availability of each method by scoring it 1 for low, 2 for moderate and 3 for highly constrained, against these criteria.

In the context of KEF-based indicators an additional source of constraint occurs where the KEF systems are so poorly understood that it is not possible to articulate a conceptual model (qualitative or quantitative) of how the system operates, or how it will respond to anthropogenic pressures. Currently there are 23 KEFs that sit in this category. Seven of these belong to the Shelf reefs group, five to the canyons, and one each to the Seamounts, Deep sea beds and enhanced pelagic productivity group. In eight cases, our understanding of the KEF is so poor that it is currently unclear which of the six key reporting groups it should belong to.

6.3.1. Visual- and video-based methods

Among the visual and video-based methods, diver-visual and diver-operated video, together with airborne and ship-borne visual census and demersal baited/unbaited remote video (DBRUVs) have the lowest relative constraint score (Table 4). These methods have well established sampling and data analysis procedures. Ship and airborne-based visual census are flexible in that they do not require a dedicated vessel or aircraft – the survey can be conducted on a wide range of ships or aircraft, but nonetheless chartering vessels or aircraft can be expensive.

Diver operated methods are very cheap compared to other monitoring methods (particularly if trained volunteers are available) but their deployment is highly constrained because they are limited to very shallow (<30m) environments and very few of the KEFS are within this depth range. Otherwise they have very constraints as sampling procedures and analysis methods are mature and well described. The camera housings of most demersal BRUVs units are also depth limited (typically < 200m), but this places all shelf-based KEFs within their reach. The analysis of their data, however, is also hindered by uncertainty surrounding the sampling distribution of MaxN (the most commonly used summary statistic).

Seabed towed video has the highest overall constraint score amongst this group. It's vessel requirements are flexible (i.e. it can be deployed from research or commercial vessels) but its charter costs are moderately high, and the vessels typically must be of a minimum size with winch and cabling facilities. The availability of stereo (and mono) underwater video units in Australia is also limited, survey designs and analysis methods for this type of data are maturing, but the latter is often complicated by a relatively high rate of sea-bed image drop out (compared for example to autonomous underwater video).

Furthermore, seabed towed cameras (and autonomous/remote underwater video) typically capture hundreds to thousands of images per deployment and currently this data must be manually processed in some manner. Image scoring standards have recently emerged, such as CATAMI (Althaus et al. submitted), but automatic image recognition algorithms are still in their infancy.

6.3.2. Acoustic and remote methods

The two forms of earth observing satellites (MSCOCS and SOA) have the lowest constraint scores among the acoustic and remote monitoring methods group (Table 5). Although the initial deployment costs of satellites are very high, once deployed the data acquisition costs to Australian agencies is virtually zero because data on, for example, ocean colour from the SeaWifs and MODIS satellites is publicly accessible on the internet (see for example `http://oceancolor.gsfc.nasa.gov/`). Satellite data also comes with very high spatial and temporal resolutions. Satellite data does, however, require region-specific calibration and analysis, but the analysis algorithms are relatively mature and well developed, albeit limited in shallow coastal waters (Blondeau-Patissier et al., 2014).

Other methods with relatively low constraint scores are passive acoustics and satellite tags. Both of these methods are being increasingly used to track large fish, mammals and cetaceans, and in the case of satellite tags and more modern acoustic tags, can provide additional information on, for example oceanographic variables (Greene et al., 2009). Passive acoustic technologies have advanced considerably over years – acoustic tags have become smaller, more powerful and more durable – but they suffer from delays between deployment and data download (Bradford et al., 2011). Satellite tags avoid this but these systems are often more expensive.

Mid-trophic (mid-water) acoustic sampling has a relatively high constraint score amongst this group largely because this monitoring method is still relatively immature compared to other observation platforms. The technique incurs moderate vessel costs, and although deployment requirements are numerous and flexible (all fishing vessels for example have an echo sounder) very few platforms are calibrated to a scientific standard. The survey designs for this type of equipment are at a pilot stage, and processing of data to scientific information (e.g. biomass of mid-trophic functional groups) usually requires a coincident trawl sample.

6.3.3. Sample-based methods

The sample-based monitoring group has a high proportion of methods rated with a low overall constraint score (Table 6). This is because this group contains some of the oldest and most well established monitoring methods. With the exception of compound specific isotopes (CSI), the data

Method	Relative cost	Sample and deployment platform	Deployment and sampling procedures	Data processing and analysis procedures	Overall relative constraint
DV, DOV	Low (1)	Flexible, diver operations depth limited < 40m (3)	Mature. Deployment and designs well established (1)	Mature. Biases and limitations well documented and understood (1)	Low constraints (6)
AI, SV	Moderate to high (vessel or aircraft costs) (3)	Flexible vessel availability, aircraft less flexibility, moderate spatial coverage (2)	Mature. Deployment and designs well established (1)	Mature. Biases and limitations well documented and understood (1)	Moderate constraints (7)
R.A_UV	Moderate (vessel costs) (2)	Minimum vessel size restrictions, and limited units in Australia (3)	Maturing. SOPs and designs developing (2)	Data collation well developed. Video analysis methods maturing. Manual processing constraints. (2)	Moderate constraints (9)
DBRUV	Units and cameras relatively cheap. Low (1)	Flexible, most stereo camera housings depth limited < 200m (2)	Mature. SOPs and designs recently established (1)	Maturing. Sampling distribution of MaxN uncertain. Manual processing constraints (2)	Low constraints (6)
PBRUV	Units and cameras relatively cheap. Low (1)	Flexible, most stereo camera housings depth limited < 200m (2)	Maturing. SOPs and designs establishing (2)	Maturing. Sampling distribution of MaxN uncertain. Manual processing constraints (2)	Moderate constraints (7)
S_TV	Moderate (vessel costs) (2)	Minimum vessel size restrictions, limited units in Australia, relatively high image drop-out (3)	Maturing. SOPs and designs developing (2)	Data collation well developed. Video analysis methods maturing. Manual processing constraints. (2)	Moderate constraints (9)
MW_TV	Moderate (vessel costs) (2)	Minimum vessel size restrictions, limited units in Australia (3)	Maturing. SOPs and designs developing (2)	Data collation well developed. Video analysis methods maturing. Manual processing constraints. (2)	Moderate constraints (9)

Table 4: Summary of the current status and key limitations associated with visual- and video-based monitoring methods, when judged against four capacity determining criteria, such as cost, deployment platform flexibility and data analysis procedures. Monitoring methods codes are as follows: DV, DOV = diver visual, diver operated video; AI, SV = airborne imagery, ship-based visual; R.A_UV = remote or autonomous underwater video; DBRUV = demersal baited or un-baited remote underwater video; PBRUV = pelagic baited or unbaited remote underwater video; S_TV = seabed towed video; M_TV = mesopelagic (mid-water) towed video. SOPs = Standard operating procedures.

Method	Relative cost	Sample and deployment platform	Deployment and sampling procedures	Data processing and analysis procedures	Overall relative constraint
MW_A	Moderate (vessel costs) (2)	Minimum vessel size restrictions, limited units in Australia (3)	Pilot. SOPs and designs still developing (3)	Pilot, requires sample-based validation (3)	High constraints (11)
MBS	Moderate (vessel costs) (2)	Flexible, but minimum size restrictions, swath width limited in shallow waters (2)	Mature. SOPs and designs well established (1)	Mature, reliable habitat categorisation limited, validation improving (2)	Moderate constraints (7)
OB_ACM	Moderate to high (3)	Limited units in Australia, low spatial coverage compared to other remote/acoustic methods (3)	Mature, SOPs well established (1)	Mature (1)	Moderate constraints (8)
SB_CM	Moderate to high (3)	Limited units in Australia, moderate spatial coverage compared to other remote/acoustic methods (2)	Mature, SOPs well established (1)	Mature (1)	Moderate constraints (7)
RAPT	Low to moderate (2)	Growing availability of units, base to buoy range restrictions (2)	Maturing, designs still developing (2)	Maturing, data processing well established. Analysis methods developing (2)	Moderate constraints (8)
PA	Low in shelf waters, data download delays (1)	Growing availability of units (1)	Maturing. SOPs and designs developing (2)	Maturing (2)	Low constraints (6)
SOA	Very low after very high initial deployment (1)	Excellent spatio-temporal coverage (1)	Mature, SOPs well established (1)	Mature (1)	Low constraints (4)
MSOCS	Very low after very high initial deployment (1)	Excellent spatio-temporal coverage, coastal analysis limited (1)	Mature, SOPs well established (1)	Mature, localised validation improving (1)	Low constraints (4)
ST	Unit costs decreasing. Low (1)	Growing availability of units & spatial-temporal coverage (2)	Maturing, designs still developing (2)	Mature (1)	Low constraints (6)

Table 5: Summary of the current status and key limitations associated with acoustic and remote monitoring methods, when judged against four capacity determining criteria, such as cost, deployment platform flexibility and data analysis procedures. Monitoring method codes are as follows: MW_A = mesopelagic (mid-water) acoustic sampler; MBS = multi-beam side scan sonar; OB_ACM = ocean-based acoustic current meter; SB_CM shore-based current meter; RAPT = radio acoustic positioning and telemetry; PA = Passive acoustics; SOA = Satellite ocean altimeter; MSOCS = Multi-spectral ocean colour sensor; ST = Satellite tags; SOPs = Standard operating procedures.

processing and analysis procedures of all the methods in this group are mature and well established. Similarly almost all of the deployment and sampling procedure are well established, although in some cases the survey design procedures are unclear (for example the Continuous Plankton Recorder). All of the methods except gliders and surface/sub-surface profiling floats incur moderate vessel charter costs but in all cases the vessel type is flexible, and the spatio-temporal coverage of the traditional sample-based methods is much lower than the newer gliders and profiling floats.

Compound specific isotopes (CSI) are among the newest and mostly highly constrained method in this group. This method can be applied to a variety of marine top predators (Ramos and González-Solís, 2012), and sampling procedures are established, survey designs are unclear and top marine predators are typically migratory hence this method often requires additional monitoring methods, such as satellite tags, to determine foraging grounds and help correct interpretation of the data. Finally CSI requires specialist sample processing facilities, that are currently limited in Australia. Bulk stable isotope analyses are well established and used in exploratory studies (Davenport and Bax, 2002). The level of information, however, is reduced and interpretation can be challenging beyond broad descriptive studies.

6.4. Method priorities by KEF group

The constraints associated with each monitoring method, together with their relevance to the KEF indicators, are indicative of the potential cost-benefit ratio of any one particular method relative to others. Methods that are highly relevant to the indicators in the KEF reporting group, and have low constraints, are likely to provide better information, at a lower cost, than methods that have high constraints and are relevant to only a small proportion of the KEF group indicators.

Figures 32, 31 and 30 plots each of the methods identified in Section 4 within a simple matrix defined by relevance and constraints. Viewing the methods in this manner suggests the following conclusions:

- for the shelf reefs group, diver visual and diver operated video are clearly preferred, whilst within the shelf sea beds demersal trawls and sleds rank highest. Remote and autonomous underwater video, passive acoustics and seabed towed video, are also likely provide good returns for unit cost in both groups, with demersal BRUVs also very important for the shelf reefs group. Importantly both of these KEF groups have a number of methods that rank highly on both axis.
- gliders, followed by water quality and chemistry samplers, multi-spectral ocean colour sensors (Section 6) and surface and sub-surface profiling floats, rank highly in the enhanced pelagic productivity group because all of these methods are capable of sampling ocean properties (including nutrients) as well phytoplankton and (in some cases) zooplankton. Although the CPR captures both phytoplankton and zooplankton, it scores slightly less well in this context because it does not also sample water chemistry.
- for the seamount group only one method – pelagic trawls and lines – ranks amongst the approaches most likely to be cost-efficient. Methods with good relevance thereafter include remote and autonomous underwater video, seabed towed video, mid-water towed video, passive

acoustics and pelagic BRUVS but these have higher associated constraints, implying that they are likely to entail higher collection and/or data processing costs.

- the costs associated with collecting observations of indicators within the canyons and deep sea beds reporting groups are likely to be amongst the highest of all the KEF groups. Importantly there are no highly ranked monitoring methods (relative to the other groups) in either of these two groups. Mid-ranked methods include remote and autonomous underwater video, seabed towed video, demersal trawls and sleds, multibeam sonar, passive acoustics and demersal BRUVs.

Method	Relative cost	Sample and deployment platform	Deployment and sampling procedures	Data processing and analysis procedures	Overall relative constraint
SG	Low to moderate (2)	Flexible, but minimum size restrictions, relatively low spatial-coverage (2)	Mature, SOPs well established (1)	Mature (1)	Low constraints (6)
CTD, XBT, WQC	Low (1)	Flexible vessel availability, low spatial coverage (2)	Mature, SOPs well established (1)	Mature (1)	Low constraints (5)
G, SSPF	Low after moderate initial deployment (1)	Flexible vessel availability, good spatio-temporal coverage (Argo) (1)	Mature, SOPs well established (1)	Mature (1)	Low constraints (4)
OB_ACM, CM_M	Moderate to high (3)	Limited units in Australia, low spatial coverage compared to other methods (3)	Mature, SOPs well established (1)	Mature (1)	Moderate constraints (8)
CPR	Low (1)	Minimum vessel size restrictions, limited units in Australia (3)	Mature, SOPs established, sample biases understood (1)	Mature (1)	Low constraints (6)
PT_L	Low to moderate (2)	Flexible, limited spatial coverage (2)	Mature, SOPs well established, sample biases well understood (1)	Mature (1)	Low constraints (6)
DT_S	Low to moderate (2)	Flexible, limited spatial coverage (2)	Mature, SOPs well established, sample biases well understood (1)	Mature (1)	Low constraints (6)
PP, ZP	Low (1)	Flexible, limited spatial coverage (2)	Mature, SOPs well established, sample biases well understood (1)	Mature (1)	Low constraints (6)
CSI	Moderate (2)	Flexible (1)	Pilot. SOPs and designs still developing (3)	Pilot and limited sample processing facilities in Australia (3)	High constraints (9)

Table 6: Summary of the current status and key limitations associated with sample-based monitoring methods, when judged against four capacity determining criteria, such as cost, deployment platform flexibility and data analysis procedures. Monitoring methods codes are as follows: SG = sediment grab; CTD, XBT , WQC = conductivity, temperature and depth rosettes, expendable bathythermograph, water quality and chemistry samplers (e.g. Niskin bottle); G = Gliders, SSPF = surface and sub-surface profiling floats; OB_ACM = Ocean based current meters; CM_M = Current meters at moorings; CPR = continuous plankton recorder; PT_L = Pelagic trawls and lines; DT_L = Demersal trawls and lines; PP, ZP = Phytoplankton and zooplankton samples (drop nets); CSI = compound specific isotopes.

SHELF REEFS

Relevance to KEF indicators	High (>9)	Moderate (7-9)	Low (4-6)
61 -90%		R.A_UV; S_TV	DV, DOV
31-60%	CSI	RAPT	DBRUV; PA
1-30%	MW_A	AI, SV; PBRUV; MW_TV; MBS	PT_L; SG; CTD, WQC, XBT, G, SSPF

Relative capacity constraint score

SHELF SEA BEDS

Relevance to KEF indicators	High (>9)	Moderate (7-9)	Low (4-6)
61 -90%		R.A_UV; S_TV	DT_S
31-60%		MBS; RAPT	PA
1-30%	MW_A; CSI	MW_TV; PBRUV	DBRUV; SG; WQC; PT_L

Relative capacity constraint score

Figure 30: Summary of the relevance (proportion of KEF indicators that a monitoring method is relevant to) and the current constraints on the deployment of this method, for the Shelf reefs and Shelf sea bed KEF groups. Monitoring method codes are as follows: MW_A = mesopelagic (mid-water) acoustic sampler; MBS = multi-beam side scan sonar; OB_ACM = ocean-based acoustic current meter; SB_CM shore-based current meter; RAPT = radio acoustic positioning and telemetry; PA = Passive acoustics; SOA = Satellite ocean altimeter; MSOCS = Multi-spectral ocean colour sensor; ST = Satellite tags; MW_A = mesopelagic (mid-water) acoustic sampler; MBS = multi-beam side scan sonar; OB_ACM = ocean-based acoustic current meter; SB_CM shore-based current meter; RAPT = radio acoustic positioning and telemetry; PA = Passive acoustics; SOA = Satellite ocean altimeter; MSOCS = Multi-spectral ocean colour sensor; ST = Satellite tags; SG = sediment grab; CTD, XBT , WQC = conductivity, temperature and depth rosettes, expendable bathythermograph, water quality and chemistry samplers (e.g. Niskin bottle); G = Gliders; SSPF = surface and sub-surface profiling floats; OB_ACM = Ocean based current meters; CM_M = Current meters at moorings; CPR = continuous plankton recorder; PT_L = Pelagic trawls and lines; DT_L = Demersal trawls and lines; PP, ZP = Phytoplankton and zooplankton samples (drop nets); CSI = compound specific isotopes

		ENHANCED PELAGIC PRODUCTIVITY		
Relevance to KEF indicators	61 -90%			G
	31-60%	CSI		WQC; MSOCS; SSPF; CTD; XBT
	1-30%	MW_A	R.A_UV; S_TV; MW_TV; OB_ACM; SB_CM; CM_M; RAPT; PA; AI, SV; PBRUV	DBRUV; PT_L; SOA; ST; PP; ZP; CPR
		High (>9)	Moderate (7-9)	Low (4-6)
		Relative capacity constraint score		

		SEAMOUNTS		
Relevance to KEF indicators	61 -90%			
	31-60%	CSI	R.A_UV; S_TV; MW_TV; RAPT, PA; PBRUV	PT_L
	1-30%	MW_A	MBS	DBRUV; MSOCS; DT_S; G; WQC, CPR, PP, ST
		High (>9)	Moderate (7-9)	Low (4-6)
		Relative capacity constraint score		

Figure 31: Summary of the relevance (proportion of KEF indicators that a monitoring method is relevant to) and the current constraints on the deployment of this method, for the Enhanced pelagic productivity and Seamount KEF groups. Monitoring method codes are as follows: MW_A = mesopelagic (mid-water) acoustic sampler; MBS = multi-beam side scan sonar; OB_ACM = ocean-based acoustic current meter; SB_CM shore-based current meter; RAPT = radio acoustic positioning and telemetry; PA = Passive acoustics; SOA = Satellite ocean altimeter; MSOCS = Multi-spectral ocean colour sensor; ST = Satellite tags; MW_A = mesopelagic (mid-water) acoustic sampler; MBS = multi-beam side scan sonar; OB_ACM = ocean-based acoustic current meter; SB_CM shore-based current meter; RAPT = radio acoustic positioning and telemetry; PA = Passive acoustics; SOA = Satellite ocean altimeter; MSOCS = Multi-spectral ocean colour sensor; ST = Satellite tags; SG = sediment grab; CTD, XBT , WQC = conductivity, temperature and depth rosettes, expendable bathythermograph, water quality and chemistry samplers (e.g. Niskin bottle); G = Gliders; SSPF = surface and sub-surface profiling floats; OB_ACM = Ocean based current meters; CM_M = Current meters at moorings; CPR = continuous plankton recorder; PT_L = Pelagic trawls and lines; DT_L = Demersal trawls and lines; PP, ZP = Phytoplankton and zooplankton samples (drop nets); CSI = compound specific isotopes

CANYONS

Relevance to KEF indicators		High (>9)	Moderate (7-9)	Low (4-6)
	61 -90%			
	31-60%		R.A_UV; DT_S; S_TV; MBS	
	1-30%	MW_A; CSI	MW_TV; RAPT; AI, SV; PBRUV	MSOCS; SG; WQC, XBT, CTD, G, SSPF; PT_L; DBRUV; PA; ST; PP, ZP, CPR
		Relative capacity constraint score		

DEEP SEA BEDS

Relevance to KEF indicators		High (>9)	Moderate (7-9)	Low (4-6)
	61 -90%			
	31-60%		R.A_UV; S_TV; PA; DBRUV	
	1-30%	MW_A; CSI	PBRUV; MW_TV; MBS; RAPT	PT_L; DT_S; ST; ZP
		Relative capacity constraint score		

Figure 32: Summary of the relevance (proportion of KEF indicators that a monitoring method is relevant to) and the current constraints on the deployment of this method, for the Canyons and Deep sea beds KEF groups. Monitoring method codes are as follows: MW_A = mesopelagic (mid-water) acoustic sampler; MBS = multi-beam side scan sonar; OB_ACM = ocean-based acoustic current meter; SB_CM shore-based current meter; RAPT = radio acoustic positioning and telemetry; PA = Passive acoustics; SOA = Satellite ocean altimeter; MSOCS = Multi-spectral ocean colour sensor; ST = Satellite tags; MW_A = mesopelagic (mid-water) acoustic sampler; MBS = multi-beam side scan sonar; OB_ACM = ocean-based acoustic current meter; SB_CM shore-based current meter; RAPT = radio acoustic positioning and telemetry; PA = Passive acoustics; SOA = Satellite ocean altimeter; MSOCS = Multi-spectral ocean colour sensor; ST = Satellite tags; SG = sediment grab; CTD, XBT , WQC = conductivity, temperature and depth rosettes, expendable bathythermograph, water quality and chemistry samplers (e.g. Niskin bottle); G = Gliders; SSPF = surface and sub-surface profiling floats; OB_ACM = Ocean based current meters; CM_M = Current meters at moorings; CPR = continuous plankton recorder; PT_L = Pelagic trawls and lines; DT_L = Demersal trawls and lines; PP, ZP = Phytoplankton and zooplankton samples (drop nets); CSI = compound specific isotopes

7. MANAGING DATA & PROVIDING INFORMATION

KEY POINTS

1. The Department will require data management arrangements for KEF reporting and associated monitoring and need to clarify its role in managing KEF indicator data.
2. The AODN is an important collaborative network for Australian Government agencies and their stakeholders for developing data management arrangements for sharing and linking KEF indicator data.
3. The Bureau of Meteorology's NEII provides an important reference for enhancing the discovery, access, and use of national environmental information and this should be used to configure data management arrangements for KEF indicator data.
4. Information products for KEF reporting will need to be specified after monitoring priorities have been identified.

Data is the primary asset for reporting on KEF indicators and it needs to be managed effectively to communicate status and trend of KEF indicators. Effective data management relies on data infrastructure and ensuring that the right people are informed about how data is managed and who is involved. Data infrastructure includes facilities, equipment, standards and includes the data itself.

The Department will need to be able to clearly delineate who collects data, how it is stored, discovered, accessed and analysed, and the Department's roles in these arrangements. Information about these arrangements should be made available though a central location that is easily accessible to internal departmental stakeholders and external stakeholders.

To establish the data management arrangements the Department will need to coordinate and cooperate with institutions that collect, manage, analyse and report data. The audit of existing KEF data (Section 4) included data holdings managed by eight marine research and data institutions (i.e. CSIRO, GA, AIMS, UTAS, IMOS, ACEF, AODN and AAD) but did not include marine industries or universities other than UTAS. Governance arrangements for KEF reporting and associated monitoring will be fundamental to providing the necessary oversight and cooperation for effective data management arrangements .

7.1. Existing data management and information outputs

The Department has not determined the data management arrangements for KEF reporting and associated monitoring or its role under these arrangements. There is an established data management infrastructure to manage the Department's environmental data and information. The infrastructure is used to manage a broad range of environmental data, including marine data and information (Figure 33, and provides access to and visualisation of KEF maps (i.e. shape files) through the

National Conservation Values Atlas. The infrastructure has not been configured to support KEF reporting and associated monitoring (i.e. it does not provide for storage, discovery, access, analysis or reporting of KEF indicator data).

The Department is implementing the National Plan for Environmental Information (NPEI) to improve the Australian Government's approach to gather, manage and use environmental information, it includes a number of important initiatives. Firstly, it identifies the Australian Government's environmental information needs (Australian Government Environmental Information Advisory Group, 2012), and these include information for KEFs (conservation values identified in Marine Bioregional Plans).

Secondly, the Bureau of Meteorology has published a reference architecture for managing the nation's environmental information. The reference architecture provides a high level technical description of a system for enhancing the discovery, access, and use of national environmental information. While it does not provide a working system or identify a specific information infrastructure for KEF reporting and associated monitoring it does provide for a common approach among Australian Government agencies and its stakeholders to develop a standards-based approach to sharing and linking KEF indicator data.

Thirdly, advancing the Essential Environmental Measures programme is expected to bring a coherent approach to improving discovery, access and reuse of information and data showing change in the state of the environment. Collectively these initiatives are aligned well to the Department's interests in KEF reporting and associated monitoring.

Australia also has an established and developing national research data infrastructure of facilities, equipment and standards. There are a number of nodes for secure data storage and web portals that provide for discovery and access to marine data, for example AODN, IMOS, TERN, ALA, etc. Some of the existing KEF data (see Section 4) is stored on national data nodes and discoverable using existing portals (e.g. AODN/IMOS portal). Although this marine research data infrastructure is being used to store and access existing KEF data, it has not been configured to support KEF reporting and associated monitoring. The AODN and IMOS have been funded under the National Collaborative Research Infrastructure Strategy and while this has been instrumental in establishing and maintaining these research data management facilities it does not provide secure long-term funding.

The Department also participates in the AODN through its technical committee to develop a standards based approach to sharing and linking marine data. The AODN is also collaborating with the Bureau of Meteorology to implement operational aspects of the NPEI for marine data. These collaborations are important in developing a common approach among Australian Government agencies to develop a standards-based federated approach to sharing and linking environmental data, including KEF indicator data.

There are no specified information outputs to report status and trends of KEF indicators. Information outputs are specified after monitoring priorities are identified. An example of an information output has been developed to communicate status and trends of productivity in areas of enhanced pelagic productivity (Section 5).

7.2. Important gaps

A number of important gaps remain in the Department's information delivery capacity. The data infrastructure of the Department and the research community has not been configured to support KEF reporting and associated monitoring and existing data is being managed by a number of data providers. Furthermore, the current configuration of data infrastructure does not provide a single point of access to data and information associated with KEF indicators. Finally there are no information outputs for KEF indicators because KEF monitoring priorities and specific information outputs are yet to be identified.

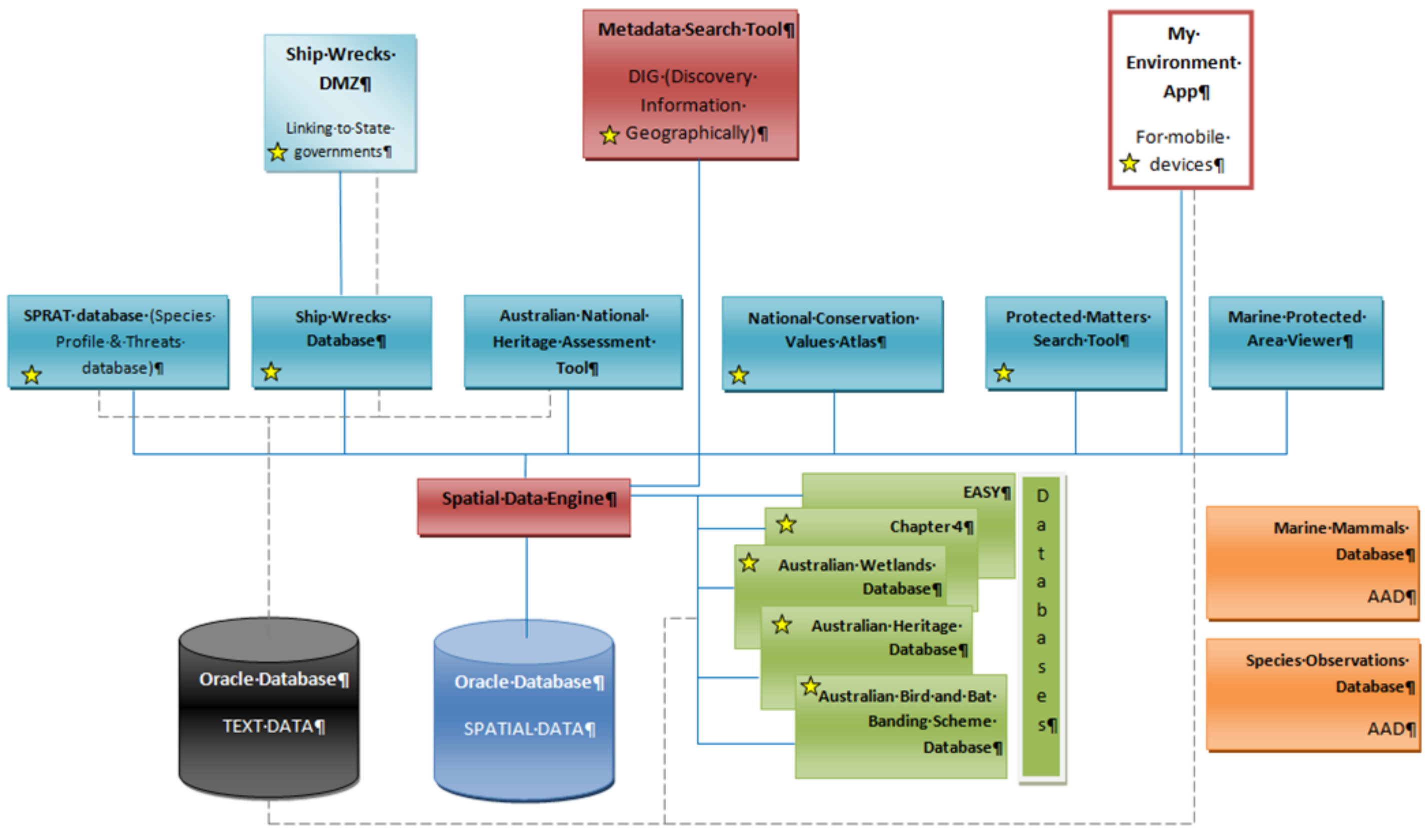

Figure 33: Summary of the Departments current arrangements managing marine spatial data and information

8. BLUE PRINT OPTIONS

KEY POINTS

1. The description of governance options (Section 3), results of the KEF data catalogue (Section 4), and analysis of KEF group/monitoring method relevance versus constraints (Section 6), suggests three options for a KEF monitoring programme. If implemented sequentially these options provide a three-stage implementation strategy.
2. Option 1 has relatively low costs, short time horizons, informal oversight structures and does not commit the Department to a monitoring programme. It focusses on enhancing the value of existing data in the shelf reefs and enhanced pelagic productivity KEF groups, and extending baselines in the former group using high relevance, low constraint monitoring methods.
3. Option 2 has moderate costs, longer time horizons, a formal more collaborative oversight structure and commits the Department to coordinating and/or managing a monitoring programme. It focusses on extending baselines and time series data records but adding moderate relevance, moderate constraint methods to the Option 1 methods/KEF groups.
4. Option 3 has longer time horizons, requires relatively significant funding and needs a formal long-term governance structure. It will require the Department to commit to a KEF monitoring programme and develop new policy proposals to support this. This stage aims to extend time series data and analysis to allow national and regional scale reporting on KEF indicator trends. It builds on the Option 1 and 2 monitoring methods but may also include moderate relevance/high constraint methods.

8.1. Vision, governance and options

The Department has yet to clearly articulate its vision for monitoring marine ecosystems health of the CMA. Nonetheless, marine bioregional plans represent the most comprehensive statement of understanding and priorities for protection, management and research (Section 1 and Figure 2). These plans, and the KEFs identified, inform decision-making not only by the Department but by other agencies and regulators. Similarly, Commonwealth Marine Reserves represent another driver for monitoring and reporting on the health of Commonwealth waters. At a broader scale, Australia has reporting obligations under a range of national (SOE) and international agreements which could also inform prioritisation of focus of national monitoring efforts

The monitoring blueprint brings together information on the data that is needed to inform a monitoring strategy within a KEF reporting group, what to monitor, how to monitor and what is currently possible given the limits of knowledge and technology. This can be used to inform a clearer articulation of the Department's vision.

Governance has not been established to oversee and coordinate monitoring of marine ecosystem health of the CMA. Establishing an initial oversight and coordination group is important for transitioning from research on KEF to an operational KEF monitoring programme that produces time series data to meet the Department's objectives.

Vision, governance and priorities are important for guiding the transition from research on KEFs to operational KEF monitoring. There are also a range of pragmatic questions that will need to be answered to develop the monitoring program. For example, in the context of the priorities, what are the projected stages of maturity for the monitoring program as a whole, what monitoring functions should be developed first, and how quickly does the program need to develop? There are no right answers to these questions and there will be a range of options to consider. This blueprint provides information to help answer these questions.

The KEF data catalogue (Section 4) has provided the first nationwide assessment of current observations within KEF boundaries. This analysis, together with the indicator relevance and method constraint analysis reported in Section 6, and the governance options analysis in Section 3, highlights the potential for three implementation options for a KEF monitoring programme.

These options are summarised in Table 7 and are structured around three broad objectives: (i) enhancing baselines and existing time series; (ii) extending base-lines and new time series; and (iii) implementing a national monitoring programme. If implemented sequentially they provide a staged-implementation strategy that provides proof of concept (on completion of Option 1) and demonstrates the value of monitoring investment (on completion of Option 2), prior to the Department coordinating and/or managing a sustained national monitoring programme (Option 3).

8.2. Implementation options

8.2.1. Option 1: Enhancing existing baselines and time series

Option 1 focusses on enhancing the information value of existing baselines observations and time series data. It has a short term focus (3 to 5 years), does not require the Department to commit to a KEF monitoring programme, has relatively low annual costs ($500k - $1m), and could be completed under the recently announced National Environmental Science Programme (NESP) funding if deemed a Departmental priority.

Option 1 will focus on the existing data within the Shelf reefs and enhanced pelagic productivity KEF groups, and where necessary would enhance these datasets using monitoring methods that have high relevance to the KEF group indicators and low constraints. These methods are identified in Section 6 and listed in Table 7. At this stage additional observations may be available at little or no additional cost to the Department, by increasing co-ordination with, and focus of, existing monitoring regimes, particularly the IMOS Argo float, glider and animal tagging and monitoring programmes.

Programme component	**Option 1: Enhance baselines and time series**	**Option 2: Extend baselines and time series**	**Option 3: National monitoring**
Term Commit to monitor Annual cost Funding sources	Short term research (3-5 yrs) No Low ($500k-$1m) NESP	Short-Med term (3-10 yrs) Yes Moderate ($1m-$5m) NESP + others	Med-long term (10-20 yrs) Yes High ($5m-$10m) New policy proposal
KEF group and method priorities	Pelagic productivity: Existing: CTD, ST, MSOCS, CPR, New: G, WQC, SSPF Shelf reefs: Existing: ST, DV, R.A_UV, DBRUV, New: DV, DOV, R.A_UV, S_TV, DBRUV	Option 1+ Canyons: Existing: CTD, XBT, DT_S, S_TV, New: R.A_UV; DT_S; S_TV; MBS Seamounts: Existing: MBS, MW_A, DT_S, New: PT_L, R.A_UV; S_TV; MW_TV; RAPT, PA; PBRUV	Option 1 +2 + Shelf sea beds: Existing: DT_S, MBS, ST, MW_A, DV, New: DT_S, R.A_UV; S_TV, PA Deep sea beds: Existing: DT_S, New: R.A_UV; S_TV; PA; DBRUV
Survey design target	Extend baselines	Extend baselines, protocols for repeat surveys	Establish and sustain national time series data
Data management	Discovery and access via existing portal such as AODN (consistent with NEII)	Option 1 + Establish central location or single point of access to support KEF monitoring Policies to support collection of time series data	Option 1 + 2 + Integrate data analysis outputs into central location
Data analysis	Survey reports and communication products Time series restricted to existing data	Option 1 + Fit for purpose time series reports Analysis and output expanded to include priority KEFs	Option 1 + 2 + Analysis and outputs expanded to form a balanced suite KEFs
Governance	Informal oversight and coordination group NESP governance (monitoring expertise) + others	Formal oversight and coordination group NESP governance (monitoring expertise)	Formal oversight and coordination group Expert advisory group

Table 7: Summary of blueprint recommendations for progressive implementation of a KEF monitoring programme for the CMA. Refer to Tables 4, 5 and 6 for monitoring method codes.

Survey design considerations at Option 1 should encourage the adoption and implementation of design methods that allow inference to extend to the whole KEF, rather the selected portions, and data management would maintain a focus on extending the KEF data catalogue user case to other data base and/or extending the utility of the ARMARDA tool.

New data analysis in Option 1 would be restricted to providing survey reports to establish baseline status within the shelf reefs KEF group, and trend analysis of existing data within the Shelf reef KEF group (if available) and the enhanced pelagic productivity group. This option should also include improving our understanding of current KEF boundaries, using for example Multi-beam Side Scan Sonar (MBS) to delineate the boundaries of Shelf reefs, and be informed by the KEF review protocol currently being developed by the Department.

Importantly governance arrangements under option 1 could be limited to an informal oversight and coordination group organise under the auspices of the NESP biodiversity hub, with additional expert review and guidance provided by the NESP partners.

Option 1 provides the proof of concept of a KEF monitoring programme and thereby positions the Department to implement the subsequent options that would allow it to move towards a more complete understanding of the status and trends of KEFs, but entails more substantial time and cost commitment. Option 1 also supports a period of development and familiarisation of the KEF approach to ocean health monitoring. This monitoring programme can also be adjusted to deliver more efficiently to the SOE and EEM programs and can be developed to include a larger section of the marine science community.

8.2.2. Option 2: Extending baselines and time series

Option 2 aims to extend the baselines and time series analysis developed in Option 1 by including the seamounts and canyons KEF reporting groups. This will entail analysis of existing data and additional baseline surveys of priority KEFs using the most cost efficient methods. It is anticipated to take between three to ten years to complete, entail a moderate annual cost ($1m to $5m) and while it may initially be developed under the NESP biodiversity hub it will require additional funding sources.

The KEF group and monitoring methods priorities build on and include those identified in Option 1 but also extend to the new method/KEF groups that have high or moderate relevance to the KEF indicators and have low or moderate constraints. These are identified in Section 6 and listed in Table 7. A related recommendation for Option 2 is research and funding directed towards reducing the constraints associated with some of these monitoring methods. For example, investment to increase the number of Autonomous Underwater Vehicles in Australia and their depth limitations to enable them to target indicators associated with Canyons. This type of investment and research will likely require additional collaboration between the Department and Australian marine infrastructure providers, including the Marine National Facility.

Survey designs in Option 2 build on Option 1 and focus on the protocols necessary for repeat surveys with the ultimate aim of providing the basis for new time series data. Data management also builds on Option 1 by centralising KEF data storage and providing a single dedicated point of access for KEF monitoring data. This stage will also likely require additional policies to support the collation and presentation of KEF indicator time series data.

Data analysis in Option 2 shifts emphasis towards time series analysis designed to (in)validate the predictions made in earlier iterations of the scientific method cycle. The analysis would also extent to a larger group of priority KEFs by virtue of the inclusion of moderate relevance/constraint KEF/method groups, as discussed above.

Governance in Option 2 shifts towards a formal oversight and coordinating group. This is anticipated to signal the Department's commitment to transition towards implementation of the objectives and actions articulated in the Marine Bioregional Plans. While the NESP biodiversity can continue to play a governance role in Option 2 it will be important that this role is extended to other bodies, because Option 2 relies more heavily on increased co-ordination and shifting of existing monitoring capacity towards KEF indicators.

By the end of Option 2, we anticipate the Department will be able to report on the status of all of the KEF groups, and the trend of a sub-set of the indicators associated with some of these groups. This positions the Department to demonstrate the value of its investment towards a sustained KEF monitoring programme to meet its environmental reporting requirements under the EPBC Act.

8.2.3. Option 3: Implementing a monitoring programme

Option 3 marks the final transition towards a balanced and sustained KEF monitoring programme by including the last two KEF reporting groups. This stage is anticipated to have a medium to long term time horizon (10 to 20 years minimum), requires Departmental policy proposals, entails relatively significant annual funding ($5-$20m), and importantly requires the Department, and national infrastructure providers, to commit to the programme.

The KEF group/method priorities include all those listed in Stages 1 and 2 but also extend to shelf sea beds and deep sea beds, with monitoring methods that have at least moderate relevance to the KEF group indicators and low to moderate constraints. This option might also entail a shift towards including high constraint techniques such as compound specific isotopes, but this should be contingent on the outcomes and learnings from Stages 1 and 2.

The overall design objectives of Option 3 are to establish and sustain time series data for KEFs that allow environmental reporting on indicator trends at national and regional scales. This will require data analysis to expand to include a wider number of KEFs, and for the results of the analysis to be published in a central, dedicated location.

Option 3 will also require a formal governance structure and expert advisory group. At this point, however, the institutions involved will need to have continuity beyond that associated with the NESP biodiversity hub in order to match the Option 3 time horizon.

8.3. Ancillary recommendations

In addition to the recommendations embedded within the staged implementation strategy outlined above, it will be important for the Department to continue to support fundamental research and analysis to improve our understanding of, and develop predictive models for, KEFs. Our current knowledge is insufficient to develop even a conceptual understanding of 42% of KEFs. This is an important knowledge gap.

The Department should also require that all NESP project partners, and encourage other relevant institutions, to publish web feature services for existing and new data on publicly available geoservers. This is an important pre-requisite step of efficient data discovery.

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A. KEF REPORTING GROUPS

To date 54 Key Ecological Features have been identified in the Commonwealth Marine Area. 32 of these KEFs are sufficiently well understood to model and predict their response to a range of anthropogenic pressures. These KEFs have been grouped into 6 key reporting groups by virtue of their process and systems commonality. The groups and KEFs within them are as follows:

1. Canyons – grouping: (i) Albany Canyon Group and Adjacent Shelf Break; (ii) Big Horseshoe Canyon; (iii) Canyons Linking the Argo Abyssal Plain and Scott Plateau; (iv) Canyons Linking the Cuvier Abyssal Plain and the Cape Range Peninsula; (v) Canyons on the Eastern Continental Slope; (vi) the Perth canyon and adjacent shelf break and other west coast canyons; and, (vii) the West Coast (Tasmania) Canyons.
2. Deep sea beds – grouping: (i) the Diamantina Fracture Zone; and, (ii) the Norfolk Ridge.
3. Areas of enhanced pelagic productivity – grouping: (i) the Bass Cascade and upwelling East of Eden; (ii) the Bonney Coast Upwelling; (iii) the Cape Mentelle Upwelling; (iv) the East Tasmanian sub-tropical convergence zone; (v) the Kangaroo Island Pool and Eyre Peninsula upwellings; (vi) Meso-scale eddies of the Leeuwin Current; (vii) the small pelagic ecosystems off-shelf of the Bonney and Eyre coast; (viii) the Tasman Front and Eddy Field; and, (ix) the upwelling off Fraser Island.
4. Seamounts – grouping: (i) the Lord Howe Seamount Chain; (ii) the Seamounts south and east of Tasmania; and, (iii) the Tasmantid Seamount chain.
5. Shelf reefs, divided into three categories: (a) tropical, (b) sub-tropical, and (c) temperate – grouping: (i) Ashmore and Cartier Island and surrounding Commonwealth waters; (ii) Mermaid Reef and Commonwealth waters surrounding Rowley Shoals; (iii) Plateau and saddle North-West of the Wellesley islands; (iv) the Reefs, Cays and herbivorous fishes of the Marion Plateau; (v) the Reefs, Cays and herbivorous fishes of the Queensland Plateau; (vi) the Seringapatam Reef and Commonwealth waters in the Scott Reef complex; (vii) the Submerged Coral Reefs of the Gulf of Carpentaria; (viii) Commonwealth marine environment surrounding the Houtman-Abrolhos Islands; (viii) the Elizabeth and Middleton Reefs; (ix) the Commonwealth marine environment surrounding the Recherche Archipelago; (x) the Commonwealth marine environment within and adjacent to the west-coast inshore lagoons; (xi) the Rocky Reefs and Hard Substrate of the south-east marine region; and, (xii) the shelf rocky reefs of the temperate East region.
6. Shelf sea beds – grouping: (i) the benthic invertebrate communities of the eastern Great Australian Bight; (ii) the Commonwealth marine environment within and adjacent to Geographe Bay; (iii) and the Gulf of Carpentaria basin.

B. ORIGINS OF THE BLUEPRINT

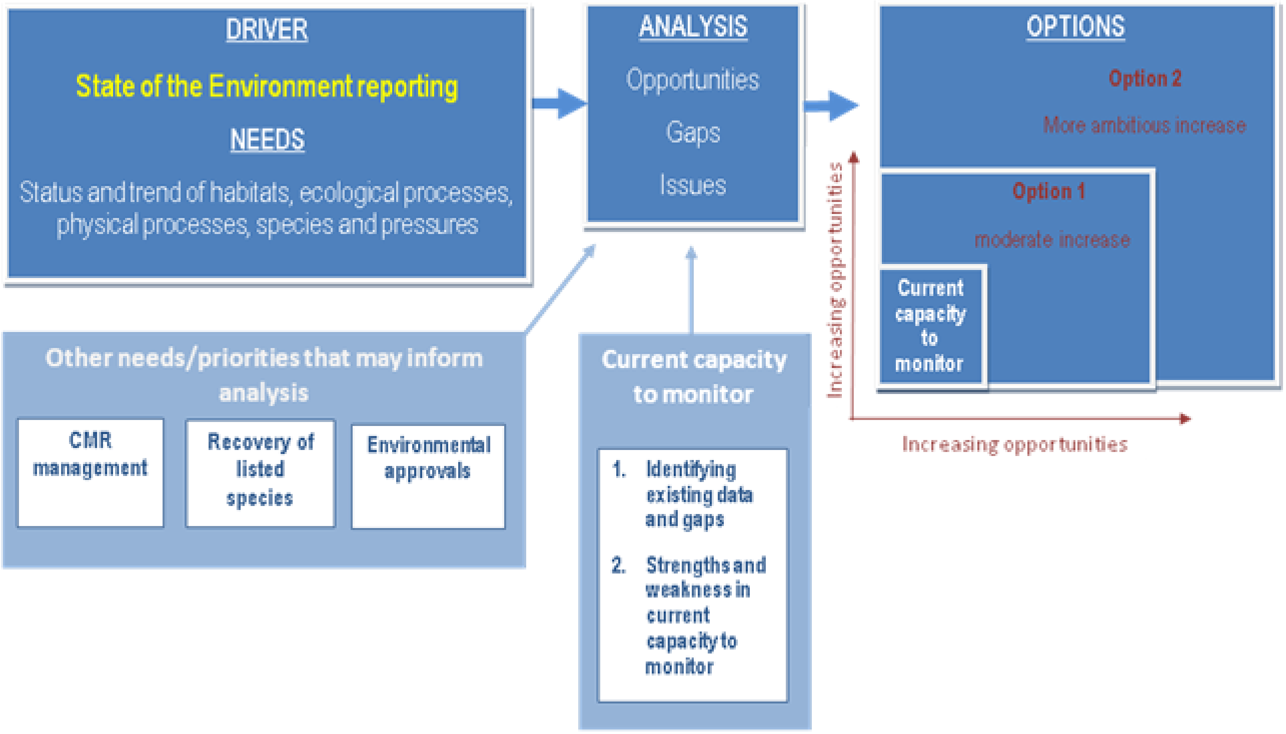

Figure 34: Summary of the agreed outcomes of the discussions between the Department and the NERP Marine Biodiversity Hub regarding options for developing a KEF monitoring programme, highlighting the Department's drivers and needs in relation to the programme, and other needs and priorities that may inform the implementation options.

C. KEF DATA CATALOGUE USER-CASE DESCRIPTION

The task of data discovery is a significant challenge because of the vast scale of the CMA and because data sets are maintained by a diverse set of institutions. Recent efforts to improve access to marine data sets by AODN and the widespread adoption of ANZLIC meta-data standards have, however, made the task more manageable by enabling direct internet-based access to many relevant databases. Critical barriers remain, however, despite these recent improvement in data access.

Surveys of the marine environment are strongly organized along ship- or gear-based programs operating over large and variable spatial scales. Data queries to centralised databases currently require the user to either specify a data type from particular cruises or deployments, or use a free-text search query to search for matching terms in meta-data records. Where the data is geo-referenced, the user may also nominate a "bounding box" and retrieve records within this box.

These types of queries are straightforward, and may meet the needs of any one research institution or discipline. They are, however, highly inefficient and ineffective for the purposes of cataloguing all data within KEFs, for several reasons:

- Users attempting to catalogue data held across multiple institutions will not typically know before hand what data types are present within an area of interest.
- Free text searches are time consuming and return both false-negative and false-positive records because naming conventions are not uniform or consistent across (or even within) institutions. For example a free text search of the AODN (`http://portal.aodn.org.au/aodn/`) with the text string "NERP biodiversity hub" retrieves only nine records three of which appear to be unrelated to the hub's activities.
- Bounding box searches are typically limited to regular latitude-longitude boxes and are not suitable for retrieving records within an individual irregular-shaped polygon, or sets of these polygons, that are necessary to represent KEFs and CMRs.
- Bounding box and free text searches return lists of meta-data records often with little (if any) indication of the spatial distribution and temporal resolution of the observations.

For these reasons data queries with standard search tools result in inefficient and incomplete summaries that did not conform to the spatial domain of KEFs. Hence, the following relatively simple "user case" – (i) a data user that does not *a priori* know what data records exist in a given area of interest; (ii) the area of interest is an irregularly shaped polygon, or a set of these polygons; and, (iii) the user wishes to know the spatial distribution and temporal resolution of the data within the area of interest – is not met by currently available tools that access marine databases.

D. ARMADA LIMITATIONS AND FUTURE IMPROVEMENTS

ARMADA was designed to meet the basic requirements of the KEF data catalogue user case. In its current stage of development, however, it is subject to a number of limitations and should be considered as a proof of concept. Future improvements should include:

- Increasing the breadth and depth of retrieved data sets. While all of the major (national) marine research institutions are contributing to ARMADA, additional repositories of data could be obtained from smaller or regional institutions (e.g., universities, museums). Additional progress can be made by ensuring that all existing marine data has a been entered with geo-referencing, and where possible, that embargoed data is made publicly available as soon as the relevant time period has expired.
- Expanding the public domain. A major source of data, which is currently not publicly available, are the data holdings of private organisations, such as surveys conducted by consultants for the oil and gas industry. Augmenting national data collections with these data would add considerable information, especially in data poor but "industry rich" regions such as the Northwest shelf.
- Improving compliance to existing data standards. Considerable increases in access and utility to data can be achieved through adherence to existing and evolving marine domain standards for meta-data, common vocabularies and web services so that data can be harvested from data providers in a more efficient manner. Ideally all new data, acquired for example under the CERF/NERP/NESP programs, should be made available as linked open data and therefore discoverable as a web service.
- Refining the functionality of data queries with respect to gear types and their deployment. Currently there is only a limited capacity to distinguish attributes for some broad categories of data types. For instance, it would be useful to be able to distinguish among sample sites for catch data from bottom benthic trawls, mid-water trawls, or benthic sleds. Doing so across all institutional datasets will require a more sophisticated database structure, analysis and display along with the encouragement of data providers to enhance their datasets by conforming to emerging language standards such as the pan-European infrastructure for ocean and marine data management (`http://seadatanet.maris2.nl/v_bodc_vocab_v2/welcome.asp`).
- Refining the functionality of data queries with respect to taxonomy or functional traits of organisms. Currently there is only limited capacity to discern characteristics of organisms that were sampled, and it would be very useful to base queries on attributes relevant to previously identified biological indicators (i.e., species or functional groups such as herbivorous fishes or mid-sized predators, or demersal versus pelagic species). This will require a more sophisticated database structure, analysis and display along with the encouragement of data providers to enhance their datasets to conform to standard taxonomy descriptions such CAAB codes or CATAMI nomenclature (`http://catami.org/`)

- While progress is being made in making new research data available online, agencies are still struggling to make some of their older data holdings available electronically. An expert-based process to help identify data currently not available electronically should be considered.

E. STATISTICAL MODEL RESULTS

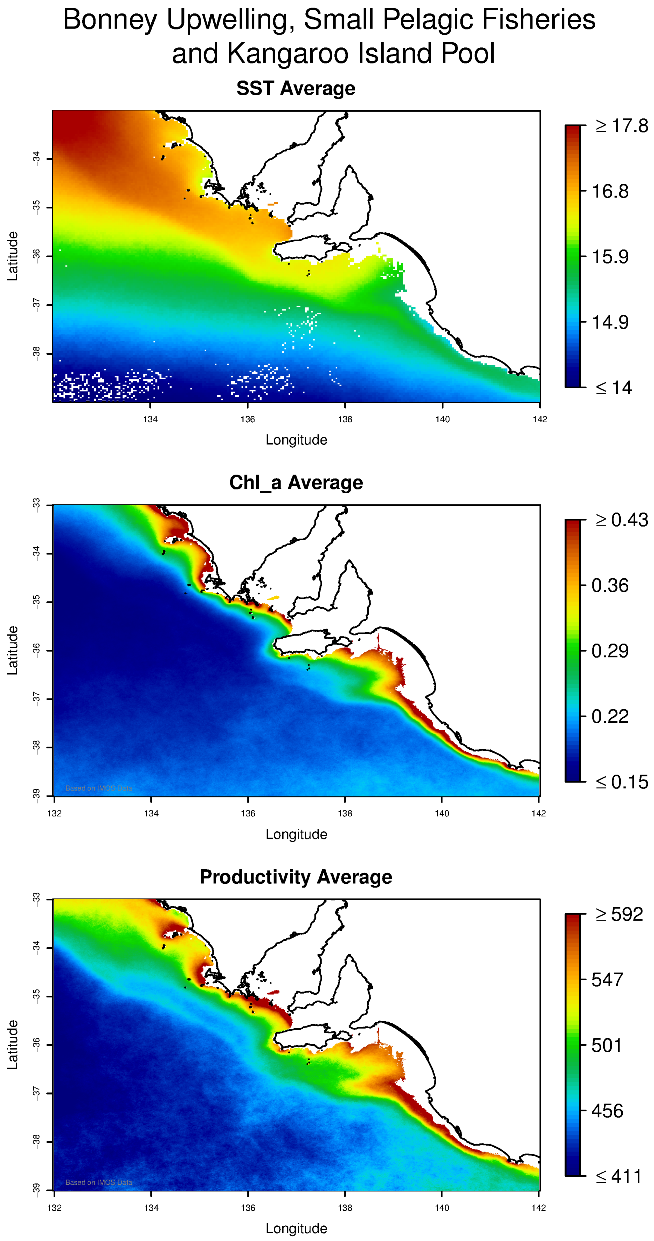

Figure 35: Overall estimated mean of SST, Chlorophyll-a and Net Primary Productivity in the three Enhanced Pelagic Productivity KEFs on the continental shelf between Portland, Victoria and Ceduna, South Australia.

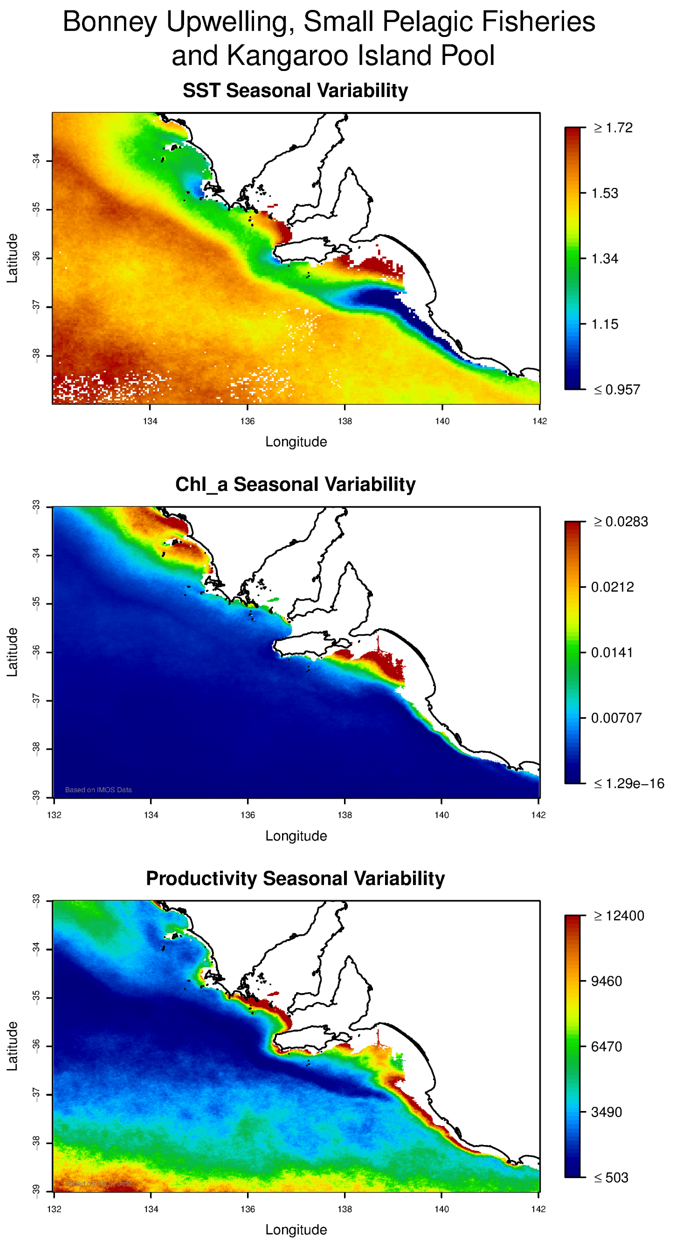

Figure 36: Estimated annual variability of SST, Chlorophyll-a and Net Primary Productivity in the three Enhanced Pelagic Productivity KEFs on the continental shelf between Portland, Victoria and Ceduna, South Australia.

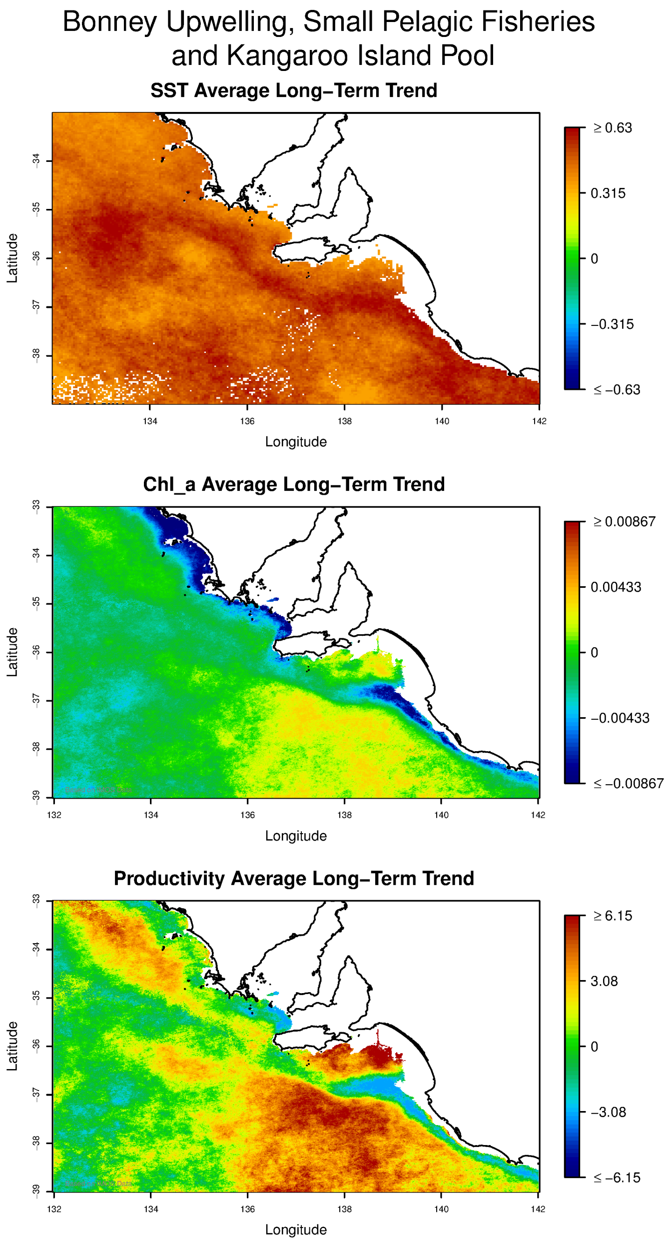

Figure 37: Estimated average long term trend in SST, Chlorophyll-a and Net Primary Productivity in the three Enhanced Pelagic Productivity KEFs on the continental shelf between Portland, Victoria and Ceduna, South Australia.

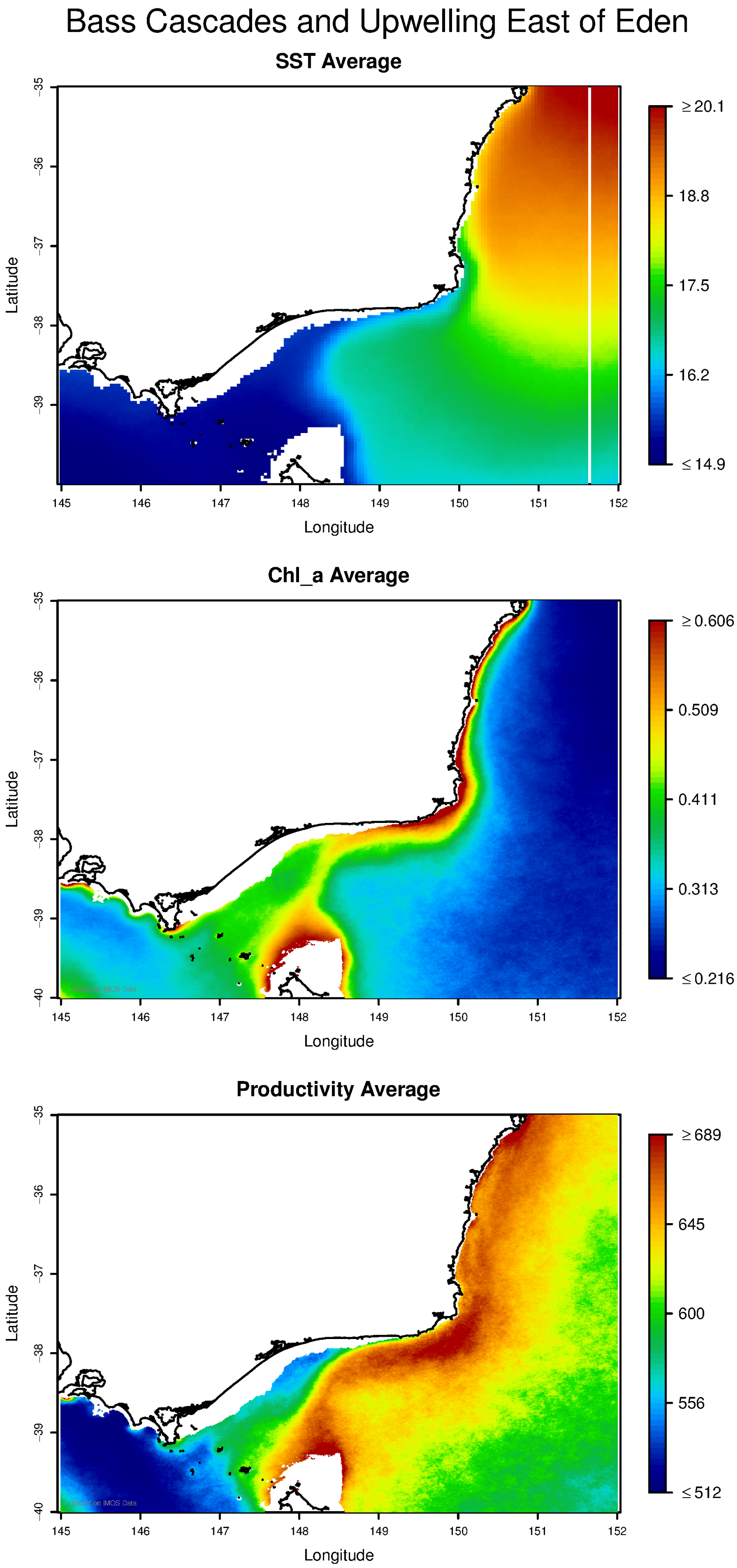

Figure 38: Overall estimated mean of SST, Chlorophyll-a and Net Primary Productivity of the Bass Cascade and upwelling East of Eden KEFs.

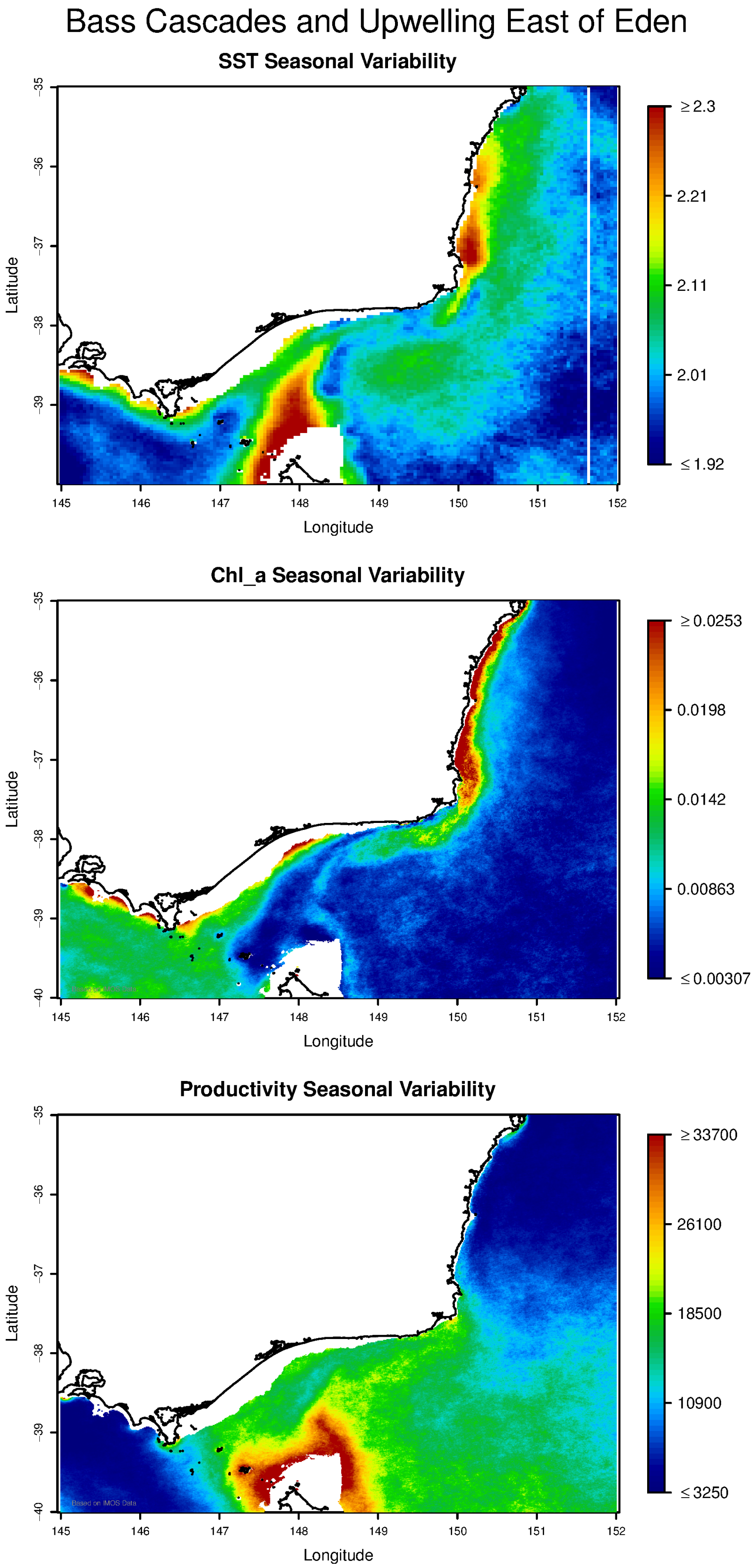

Figure 39: Estimated annual variability of SST, Chlorophyll-a and Net Primary Productivity of the Bass Cascade and upwelling East of Eden KEFs.

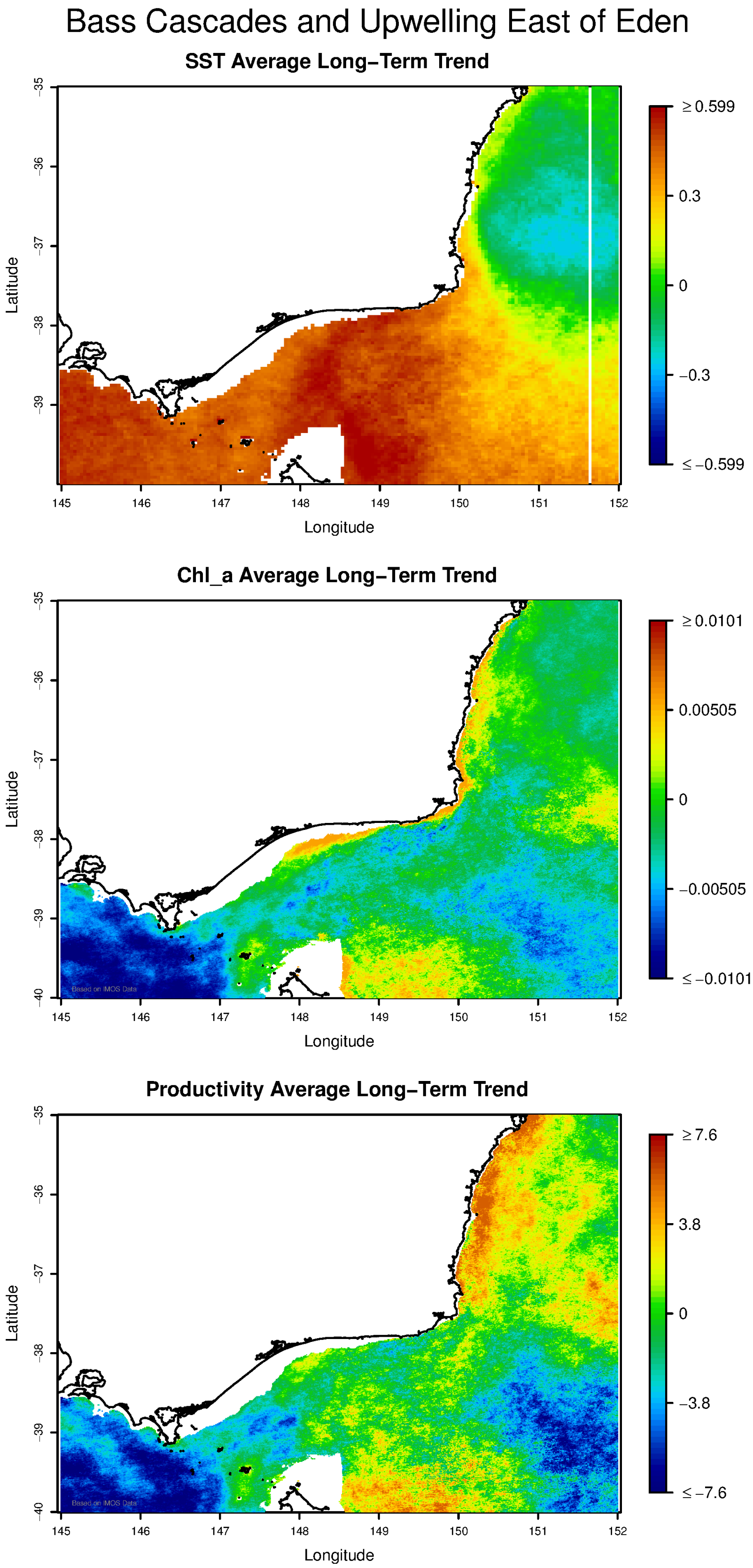

Figure 40: Estimated average long term trend in SST, Chlorophyll-a and Net Primary Productivity of the Bass Cascade and upwelling East of Eden KEFs.

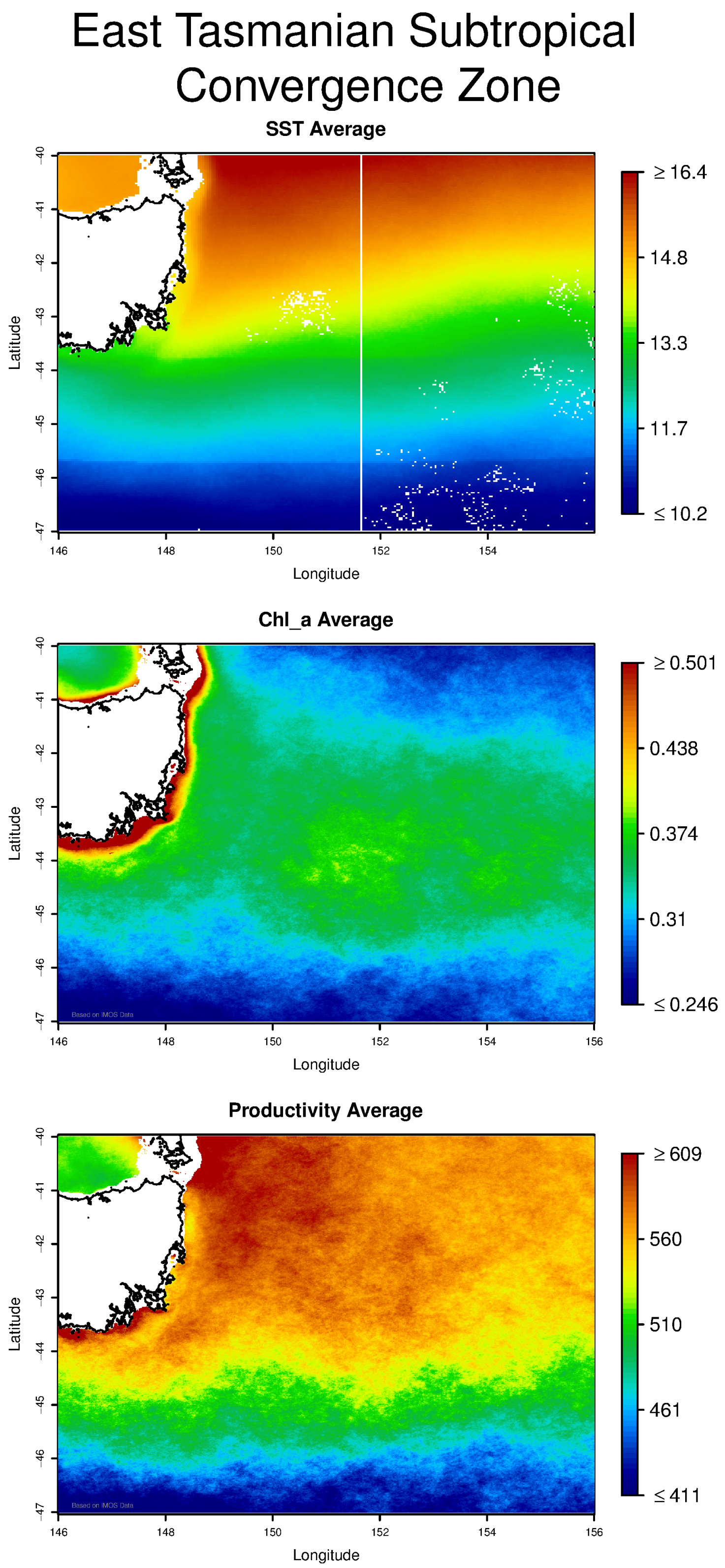

Figure 41: Overall estimated mean of SST, Chlorophyll-a and Net Primary Productivity of the East Tasmanian Subtropical Convergence Zone KEF.

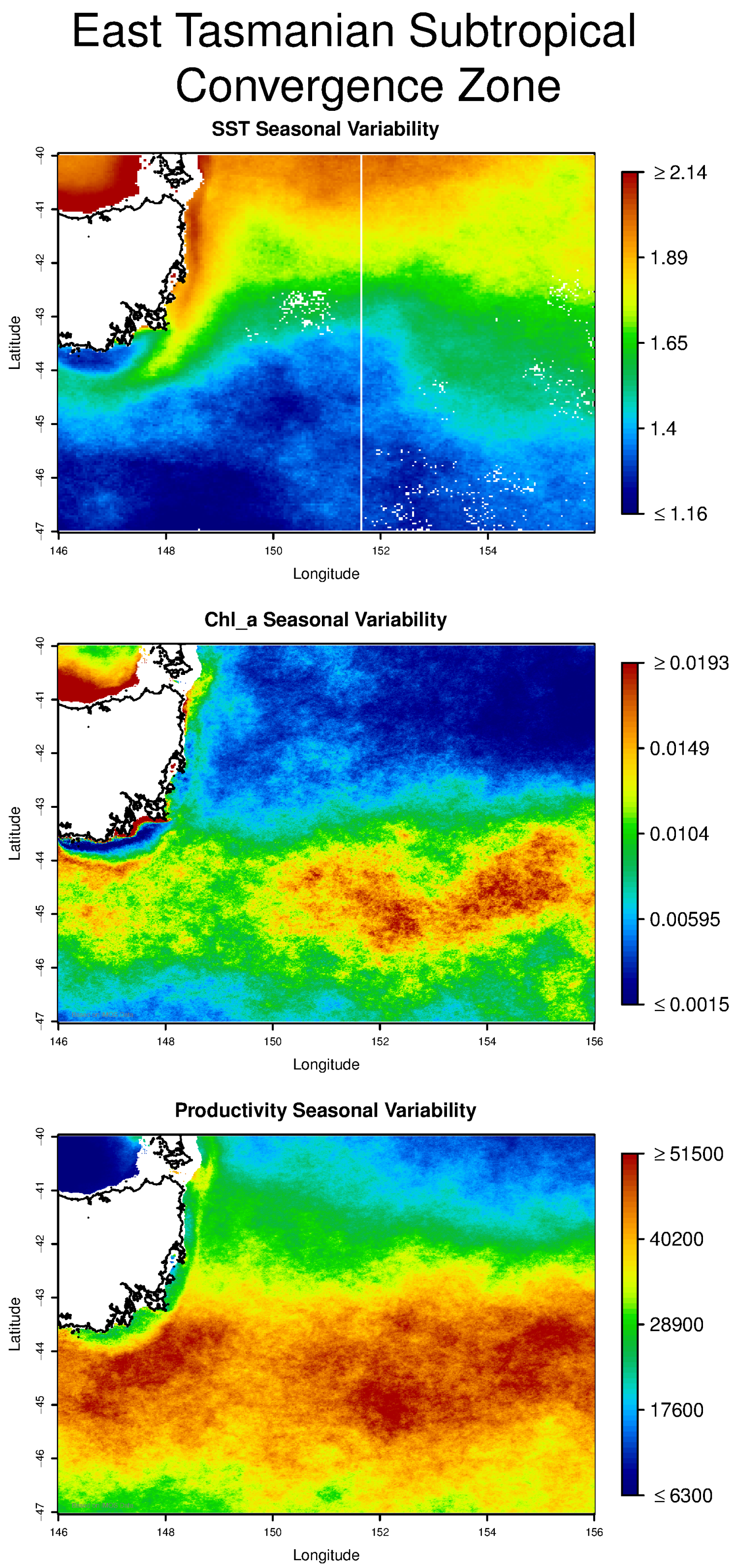

Figure 42: Estimated annual variability of SST, Chlorophyll-a and Net Primary Productivity of the East Tasmanian Subtropical Convergence Zone KEF.

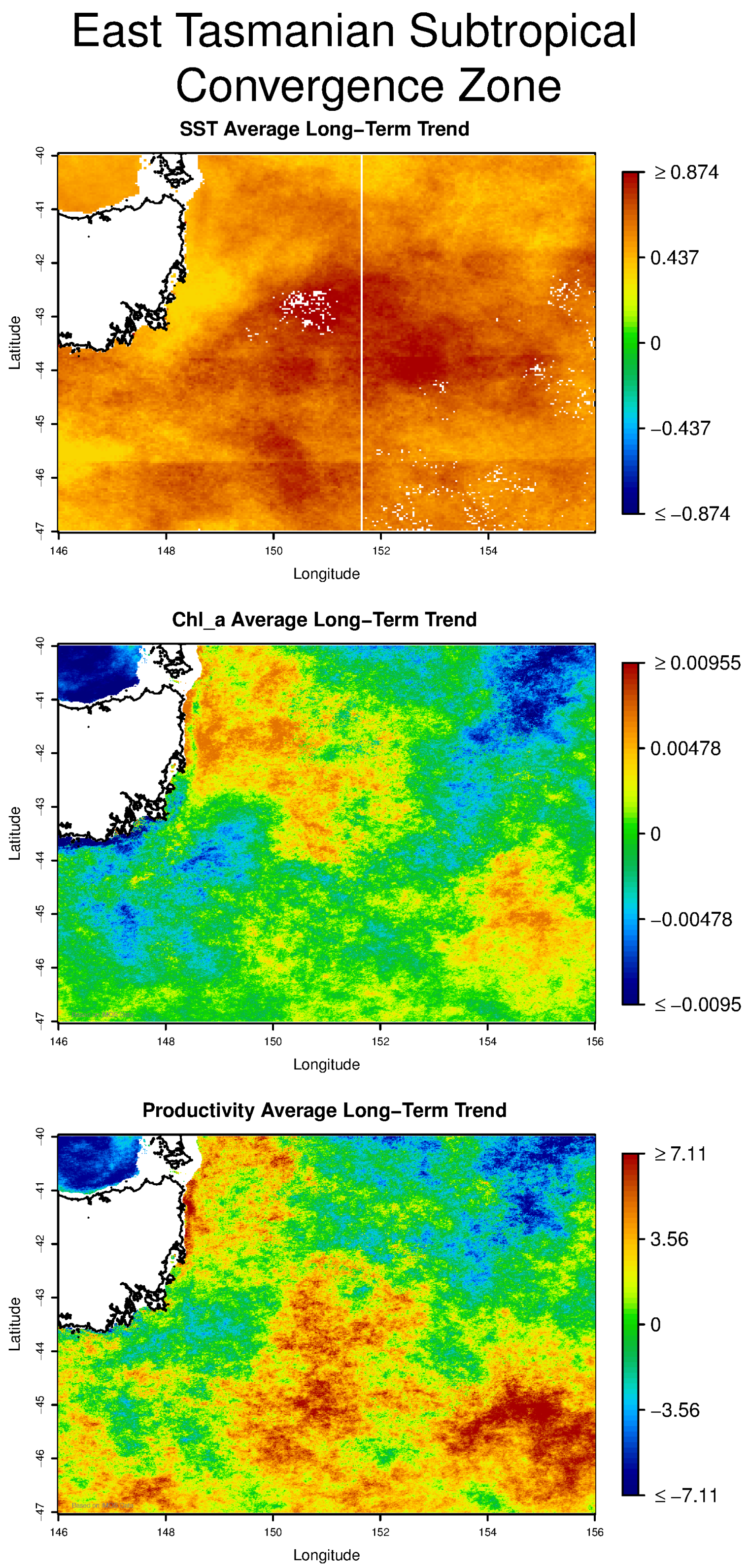

Figure 43: Estimated average long term trend in SST, Chlorophyll-a and Net Primary Productivity of the East Tasmanian Subtropical Convergence Zone KEF.

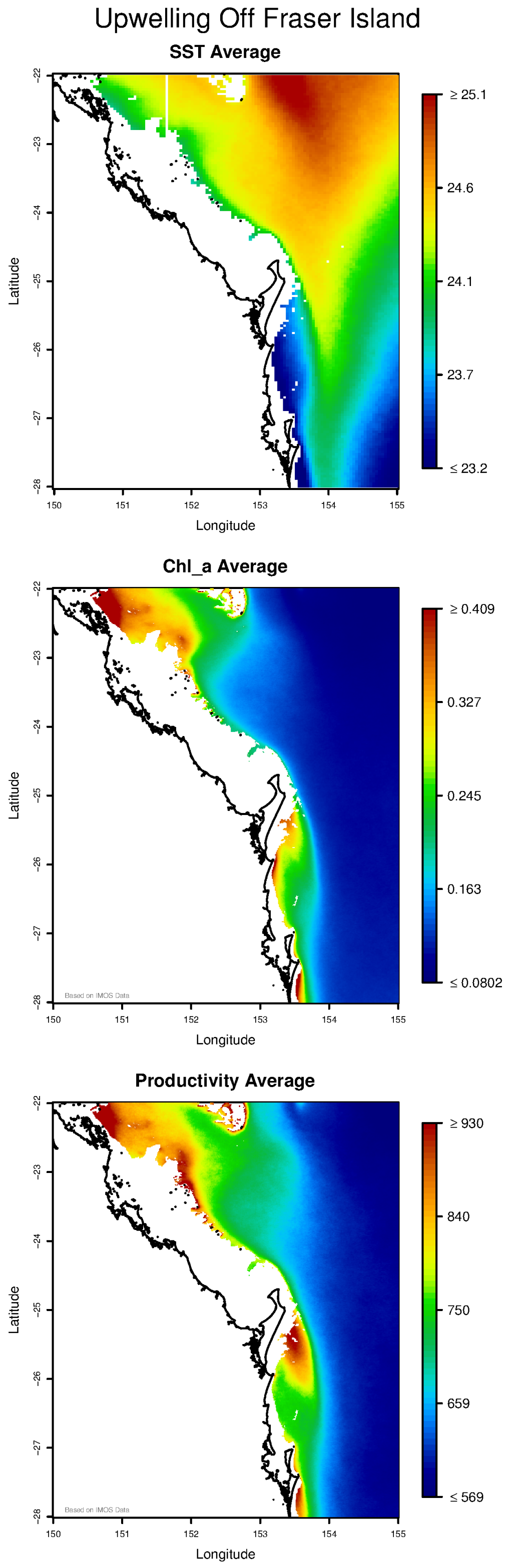

Figure 44: Overall estimated mean of SST, Chlorophyll-a and Net Primary Productivity in the Upwelling off Fraser Island KEF.

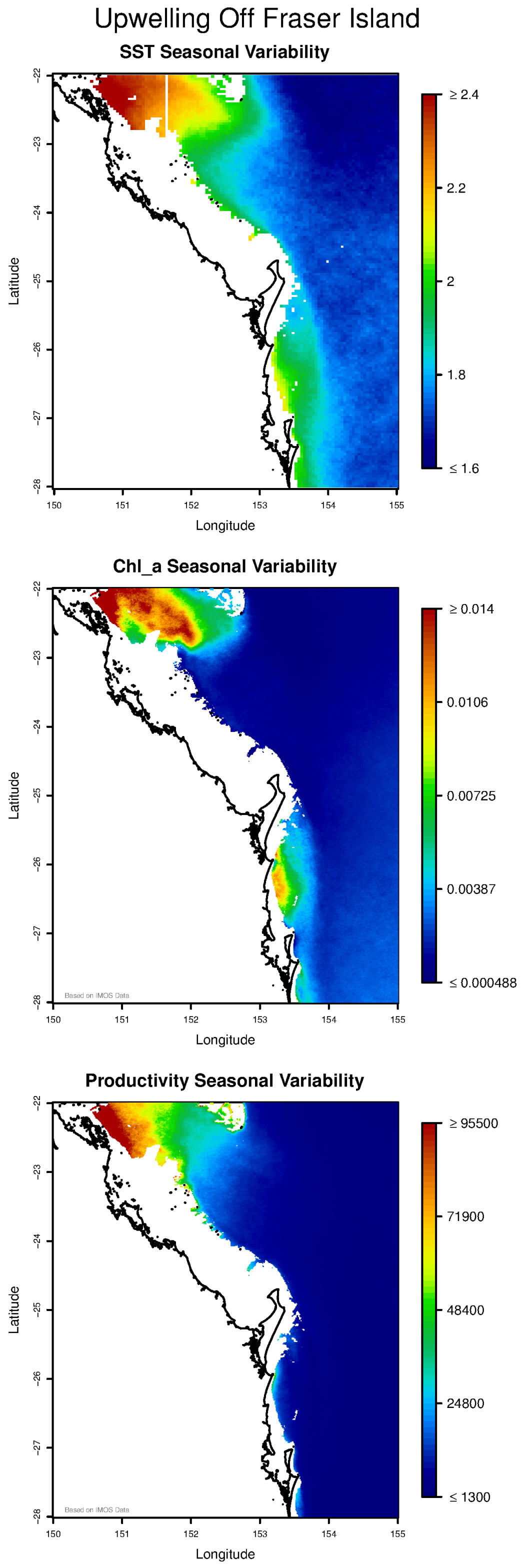

Figure 45: Estimated annual variability of SST, Chlorophyll-a and Net Primary Productivity in the Upwelling off Fraser Island KEF.

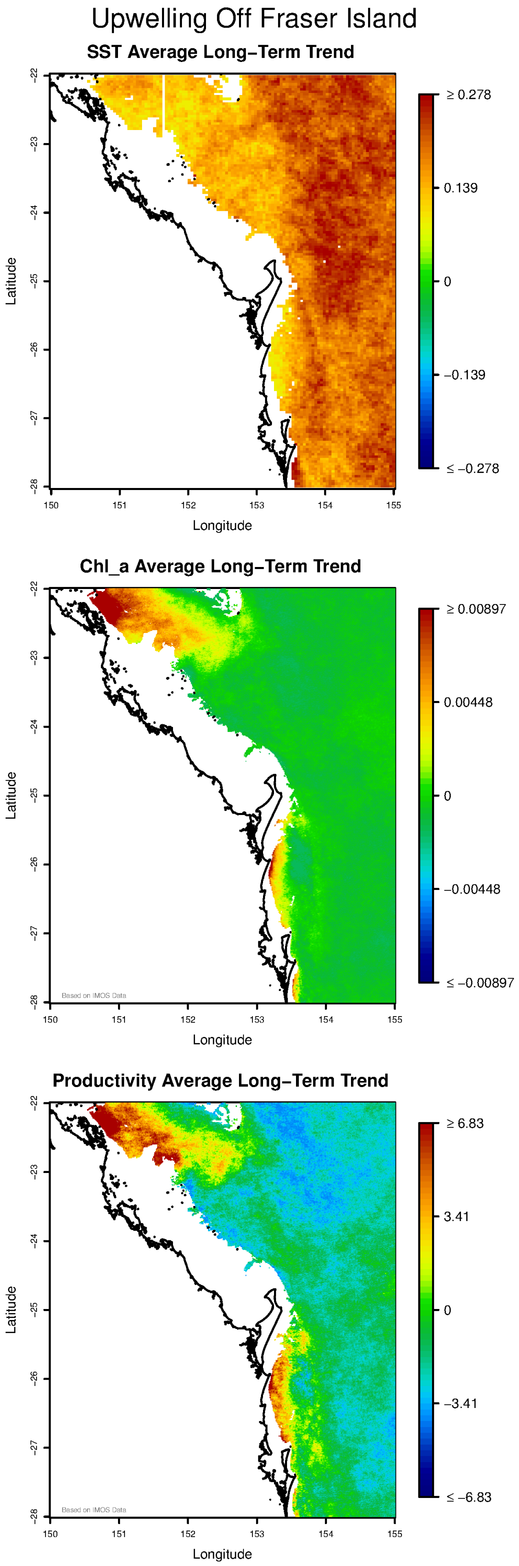

Figure 46: Estimated average long term trend in SST, Chlorophyll-a and Net Primary Productivity in the Upwelling off Fraser Island KEF.

F. MONITORING METHOD LOOK-UP TABLES

	VISUAL AND VIDEO						
Group	DOV, DV	AI, SV	R.A_UV	DBRUV	PBRUV	S_TV	MW_TV
Macro-algae	1	1	1	0	0	1	0
Bacteria	0	0	0	0	0	0	0
Bentho-pelagic predatory fishes	1	0	1	1	1	1	1
Marine mammals	1	1	0	0	1	0	1
Coral	1	1	1	0	0	1	0
Demersal fishes	1	0	1	1	0	1	0
Demersal herbivorous fishes	1	0	1	1	0	1	0
Demersal infauna bioturbators	0	0	0	0	0	0	0
Demersal infauna invertebrates	0	0	0	0	0	0	0
Demersal invertebrates	1	0	1	1	0	1	0
Demersal invertivorous fishes	1	0	1	1	0	1	0
Demersal mid-sized predators	1	0	1	1	0	1	0
Demersal planktivorous fishes	1	0	1	1	0	1	0
Demersal predatory fishes	1	0	1	1	0	1	0
Demersal predatory invertebrates	1	0	1	1	0	1	0
Detritus	0	0	0	0	0	0	0
Euphausids	0	0	0	0	0	0	1
Habitat feature	0	0	1	0	0	0	0
Large pelagic predatory fishes	1	1	0	0	1	0	1
Nutrients	0	0	0	0	0	0	0
Oceanographic feature	0	0	0	0	0	0	0
Pelagic predatory fishes and invertebrates	1	0	0	0	1	0	1
Phytoplankton	0	0	0	0	0	0	0
Seabirds	0	1	0	0	0	0	0
Seagrass	1	1	1	0	0	1	0
Sessile demersal invertebrates	1	0	1	0	0	1	0
Small pelagic fishes	0	0	0	0	1	0	1
Turtles	1	0	1	1	1	1	0
Zooplankton	0	0	0	0	0	0	0

Table 8: Indicator variables to identify the relevance of visual and video-based monitoring methods to establish the status and trends of KEF indicator groups. Method codes are given in Table 2 and 3

	ACOUSTIC AND REMOTE								
Group	MW_A	MBS	OB_ACM	SB_CM	RAPT	PA	SOA	MSOCS	ST
Macro-algae	0	0	0	0	0	0	0	0	0
Bacteria	0	0	0	0	0	0	0	0	0
Bentho-pelagic predatory fishes	0	0	0	0	1	1	0	0	0
Marine mammals	0	0	0	0	1	1	0	0	1
Coral	0	1	0	0	0	0	0	0	0
Demersal fishes	0	0	0	0	1	1	0	0	0
Demersal herbivorous fishes	0	0	0	0	1	1	0	0	0
Demersal infauna bioturbators	0	0	0	0	0	0	0	0	0
Demersal infauna invertebrates	0	0	0	0	0	0	0	0	0
Demersal invertebrates	0	0	0	0	0	0	0	0	0
Demersal invertivorous fishes	0	0	0	0	1	1	0	0	0
Demersal mid-sized predators	0	0	0	0	1	1	0	0	0
Demersal planktivorous fishes	0	0	0	0	0	0	0	0	0
Demersal predatory fishes	0	0	0	0	1	1	0	0	0
Demersal predatory invertebrates	0	0	0	0	1	1	0	0	0
Detritus	0	0	0	0	0	0	0	0	0
Euphausids	1	0	0	0	0	0	0	0	0
Habitat feature	0	1	0	0	0	0	0	0	0
Large pelagic predatory fishes	1	0	0	0	1	1	0	0	1
Nutrients	0	0	0	0	0	0	0	0	0
Oceanographic feature	0	0	1	1	0	0	1	0	0
Pelagic predatory fishes and invertebrates	0	0	0	0	1	1	0	0	0
Phytoplankton	0	0	0	0	0	0	0	1	0
Seabirds	0	0	0	0	1	1	0	0	1
Seagrass	0	0	0	0	0	0	0	0	0
Sessile demersal invertebrates	0	0	0	0	0	0	0	0	0
Small pelagic fishes	1	0	0	0	0	0	0	0	0
Turtles	0	0	0	0	1	1	0	0	1
Zooplankton	0	0	0	0	0	0	0	0	0

Table 9: Indicator variables to identify the relevance of acoustic and remote monitoring methods to establish the status and trends of KEF indicator groups. Method codes are given in Table 2 and 3

	SAMPLE												
Group	SG	CTD	XBT	WQC	CM_M	G	SSPF	CPR	PT_L	DT_L	PP	ZP	CSI
Macro-algae	0	0	0	0	0	0	0	0	0	0	0	0	0
Bacteria	0	1	1	1	0	0	0	0	0	0	0	0	0
Bentho-pelagic predatory fishes	0	0	0	0	0	0	0	0	1	1	0	0	1
Marine mammals	0	0	0	0	0	0	0	0	0	0	0	0	1
Coral	0	0	0	0	0	0	0	0	0	0	0	0	0
Demersal fishes	0	0	0	0	0	0	0	0	0	1	0	0	1
Demersal herbivorous fishes	0	0	0	0	0	0	0	0	0	1	0	0	1
Demersal infauna bioturbators	1	0	0	0	0	0	0	0	0	0	0	0	0
Demersal infauna invertebrates	1	0	0	0	0	0	0	0	0	0	0	0	0
Demersal invertebrates	0	0	0	0	0	0	0	0	0	1	0	0	?
Demersal invertivorous fishes	0	0	0	0	0	0	0	0	0	1	0	0	1
Demersal mid-sized predators	0	0	0	0	0	0	0	0	0	1	0	0	1
Demersal planktivorous fishes	0	0	0	0	0	0	0	0	0	1	0	0	1
Demersal predatory fishes	0	0	0	0	0	0	0	0	0	1	0	0	1
Demersal predatory invertebrates	0	0	0	0	0	0	0	0	0	1	0	0	?
Detritus	0	1	1	1	0	0	0	0	0	0	0	0	0
Euphausids	0	0	0	0	0	0	0	0	1	0	0	0	0
Habitat feature	0	0	0	0	0	0	0	0	0	0	0	0	0
Large pelagic predatory fishes	0	0	0	0	0	0	0	0	1	0	0	0	1
Nutrients	0	1	1	1	0	1	1	0	0	0	0	0	0
Oceanographic feature	0	1	1	1	1	1	1	0	0	0	0	0	0
Pelagic predatory fishes and invertebrates	0	0	0	0	0	0	0	0	1	0	0	0	1
Phytoplankton	0	1	1	0	0	1	1	1	0	0	1	0	0
Seabirds	0	0	0	0	0	0	0	0	0	0	0	0	1
Seagrass	0	0	0	0	0	0	0	0	0	0	0	0	0
Sessile demersal invertebrates	0	0	0	0	0	0	0	0	0	1	0	0	0
Small pelagic fishes	0	0	0	0	0	0	0	0	1	0	0	0	1
Turtles	0	0	0	0	0	0	0	0	0	0	0	0	1
Zooplankton	0	1	1	0	0	0	0	1	0	0	0	1	0

G. KEF MONITORING METHODS

	nInd	DOV, DV	AI, SV	R.A_UV	DBRUV	PBRUV	S_TV	MW_TV
Canyons	25	0	1	14	3	2	12	3
Deep sea beds	6	0	0	4	2	1	4	1
Enhanced pelagic productivity	45	0	10	3	3	9	3	8
Seamounts	9	0	0	4	2	3	4	3
Shelf reefs	160	139	41	132	94	17	130	12
Shelf seabeds	8	0	0	5	2	1	5	1

Table 11: Number of KEF indicators where visual- and video-based monitoring methods are relevant for assessing status and trends, grouped under each of the 6 key reporting questions. Monitoring methods codes are as follows: DV, DOV = diver visual, diver operated video; AI, SV = airborne imagery, ship-based visual; R.A_UV = remote or autonomous underwater video; DBRUV = demersal baited or un-baited remote underwater video; PBRUV = pelagic baited or unbaited remote underwater video; S_TV = seabed towed video; M_TV = mesopelagic (mid-water) towed video. Diver based methods restricted to shallow KEFs. The number of indicators (nInd) in each KEF group is shown in the first column.

	nInd	MW_A	MBS	OB_ACM	SB_CM	RAPT	PA	SOA	MSOCS	ST
Canyons	25	2	11	0	0	3	3	0	1	2
Deep sea beds	6	1	1	0	0	1	2	0	0	1
Enhanced pelagic productivity	45	5	0	9	9	13	13	9	20	12
Seamounts	9	2	2	0	0	3	3	0	1	1
Shelf reefs	160	0	21	0	0	83	83	0	0	18
Shelf seabeds	8	1	3	0	0	3	3	0	0	1

Table 12: Number of KEF indicators where acoustic and remote monitoring methods are relevant for assessing status and trends under each of the 6 key reporting questions. Monitoring method codes are as follows: MW_A = mesopelagic (mid-water) acoustic sampler; MBS = multi-beam side scan sonar; OB_ACM = ocean-based acoustic current meter; SB_CM shore-based current meter; RAPT = radio acoustic positioning and telemetry; PA = Passive acoustics; SOA = Satellite ocean altimeter; MSOCS = Multi-spectral ocean colour sensor; ST = Satellite tags. The number of indicators (nInd) in each KEF group is shown in the first column.

	nInd	SG	CTD	XBT	WQC	CM_M	G	SSPF	CPR	PT_L	DT_L	PP	ZP	CSI
Canyons	25	5	1	1	1	0	2	1	2	2	10	1	1	3
Deep sea beds	6	0	0	0	0	0	0	0	1	1	2	0	1	2
Enhanced pelagic productivity	45	0	18	18	18	9	29	18	12	6	0	11	1	14
Seamounts	9	0	0	0	1	0	1	0	1	3	2	1	0	4
Shelf reefs	160	7	4	4	5	0	4	4	0	11	97	0	0	92
Shelf seabeds	8	1	0	0	1	0	0	0	0	1	5	0	0	2

Table 13: Number of KEF indicators where sample-based monitoring methods are relevant for assessing status and trends under each of the 6 key reporting questions. Monitoring methods codes are as follows: SG = sediment grab; CTD, XBT , WQC = conductivity, temperature and depth rosettes, expendable bathythermograph, water quality and chemistry samplers (e.g. Niskin bottle); CM_M = Current meters at moorings; G = Gliders; SSPF = surface and sub-surface profiling floats; CPR = continuous plankton recorder; PT_L = Pelagic trawls and lines; DT_L = Demersal trawls and lines; PP, ZP = Phytoplankton and zooplankton samples (drop nets); CSI = compound specific isotopes. The number of indicators (nInd) in each KEF group is shown in the first column.