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Options for assessing cumulative impact and risk to environmental values in Matters of National Environmental Significance and Australian Marine Parks

Piers K Dunstan and Jeffrey M Dambacher

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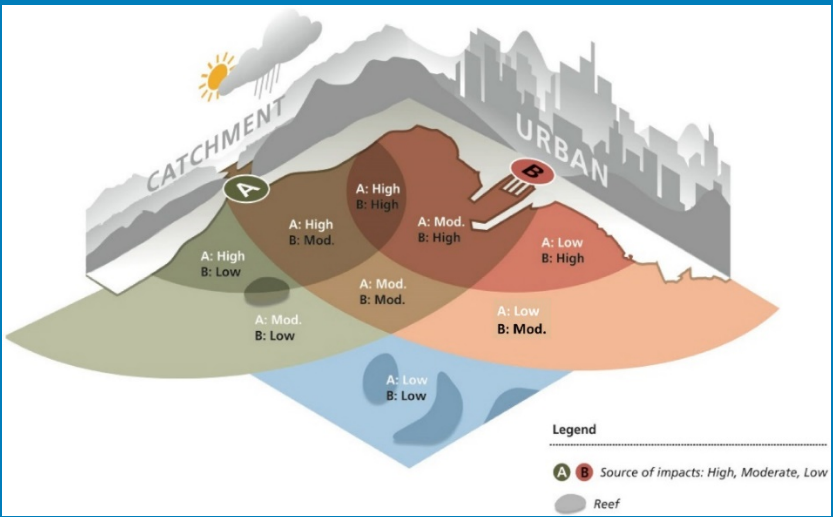

Enquiries should be addressed to:
Piers Dunstan
CSIRO Oceans and Atmosphere
Castray Esplanade, Hobart, Tasmania,
Ph +61 3 6232 5382

piers.dunstan@csiro.au

Distribution list

Kylie Kulper	Department of the Environment and Energy
Amelia Tandy	Department of the Environment and Energy
Amanda Parr	Department of the Environment and Energy

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Important Disclaimer

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1. BENEFITS OF A CONSISTENT APPROACH TO ASSESSING CUMULATIVE IMPACT AND RISK FOR MNES AND CMRS

Understanding the existing impacts and the risks of new impacts on Matters of National Environmental Significance (MNES) and Australian Marine Parks (AMPs) remains a significant challenge for all stakeholders who have an interest in the Marine Environment. Coasts and oceans provide a range of vital services such as food, transport, recreation, waste disposal and cultural inspiration. These services are under a range of pressures, including harvesting, habitat loss, pollution, and climate change, while the demands of a growing human population continue to rise. Managing pressures in this complicated ecological, social and economic environment is challenging and it will not always be possible to achieve agreed objectives. Many coastal environments are expected to degrade given the increasing strength of external factors, including climate change, that cannot be managed locally, which will diminish these ecosystems and the services that they provide. Successful management that can slow or even reverse these trends requires understanding the long-term capacity of ocean ecosystems to respond to increasing or new pressures, identifying appropriate tools that communities, industry and government are able and willing to use to determine sustainable resource use, and providing access to this information. One of the key sets of tools available to ensure that long term outcomes are sustainable are through Environmental Impact Assessments and incorporating tools to assess cumulative impacts into EIA remains a challenge.

To develop approaches to incorporating cumulative impacts into EIA we can separate the problem into two different components:

First, when will an activity trigger an assessment under the EPBC act that may potentially generate cumulative impacts and what are the existing pressures that exist within a region?

Second, if a cumulative assessment is triggered, what information, data and analysis is needed to estimate impact and risk for that activity?

We propose that these components can be met by the following three basic steps:

1. What are the values that people place on the potentially affected marine environment
2. What are the existing and future impacts on those values by human activities, and
3. What management, avoidance or mitigation options can be used to retain those values at an acceptable level?

The problem outlined in step one is the topic of a companion paper “Rethinking Approaches to Valuation in Marine Systems” and options around (3) are the responsibility of the Department of the Environment and Energy (DoEE) and proponents, although science can play a role in comparing options when parties are engaged. This paper will deal exclusively with step two.

1.1 Existing approaches to assessing impact and risk.

Currently, there are two approaches that have been formally undertaken to assess potential impact and risk on MNES and AMPs: either through a Marine Bioregional Plan (MBP) or the State of the Environment report (SoE).

Marine Bioregional Plans

In Marine Bioregional Plans for the North, North West and Temperate East Regions there is standard text that is used to summarise the method used for pressure analysis. While the first MBP, which is for the South West Region, implicitly makes this analysis, it is not described. The SEMR Bioregional Profile that was developed out of sequence with the MBPs does not contain an analysis of the interaction between any Matters of National Environmental Significance (MNES) and pressure/use, and does not seem to have much spatial data on the distribution of pressure associated with the plan.

The Standard text for the development of a pressure profile from the North West, North & Temperate East plans is below:

The pressure analysis considered, for each selected conservation value, information derived from available reports and research about:

a) the spatial location and intensity of the pressure(s), both current and anticipated

b) the location of the conservation value—that is, its distribution and the location of areas important to it

c) current understanding of impacts (at relevant scales) resulting from the interaction between the pressure(s) and the conservation value

d) the effectiveness of current management and impact mitigation measures.

Currently there are both information systems and processes that can be used to identify and capture updated information about conservation values (*i.e.,* a key input to step (b) above). The SPRAT data base and associated species mapping contain the current state of values and the BIA updating protocol and the KEF update protocol (in development) are designed to feed information in. However, there do not appear to be existing DoEE processes to update data and information about pressures or impacts. To support improving the information base, work undertaken in the Marine Biodiversity Hub has updated pressure information and provided this information to DoEE for integration into the National Conservation Values Atlas and the Environmental Matters Search Tool (internal to DoEE). However, there is little information on how the risk matrices in the MBPs were determined and no formal mechanism for updating the risk matrices in the plans as both the values and the pressures in the plans change.

State of the Environment

State of the Environment had no formal, standardised or quantitative approach to either assessing impacts or undertaking the risk assessments across the SoE. Essentially each theme within the report adapted the guidelines depending on context and networks available to the authors. Within the marine report, each assessment was conducted by recognised experts relevant to the subject matter, assessments followed a standard template, and each of these were then made available via the AODN so anyone could then see who did the assessment, how the assessment was done and what it was based on.

A wide range of activities was assessed in the marine SoE. This presented a challenge to implement a standardised approach because the subjects were across a broad scope. For some they are a subjective expert based assessment based on the literature available while others were based on statistical assessment of data to establish trends. This variety is a function of differences in data available for assessments and sometimes the difficulty in summarising variable trends into a single national value of status or trend. SoE was also unable to deal with either indirect or cumulative impacts, instead pointing out that this was an area that required significant further research.

Other International Approaches

Assessment of cumulative impacts remains an area in intense scientific and policy development. Developing processes to incorporate cumulative impacts has been identified in the EU Marine Strategy Framework Directive, and EIA processes, by the Department of Fisheries and Oceans in Canada and the National Oceans and Atmospheric Organisation and appear in the Oceans Policy of many countries (eg Vanuatu). Integrating cumulative impacts into EIA and SEA has also be identified as a key need for the new implementing agreement from UNCLOS.

The science to support these processes has been in development globally and nationally. Approaches such as the assessments underlying the North Sea wind energy projects (Jongnloed *et al.* 2014), Mediterranean Ecosystems (Micheli *et al.* 2013) and long term cumulative fisheries impacts (Foster et al. 2015) suggest that data driven approaches can support more rigorous assessments. However, the key challenge is to link the scientific approaches to the appropriate policy and regulatory frameworks.

2. STEP 1: VALUES IN THE MARINE ENVIRONMENT

There are many ways of valuing coastal and marine areas, including ecological (*e.g.,* biodiversity, productivity), economic (*e.g.,* economic benefits from harvesting and regulation) and socio-cultural values (*e.g.,* spiritual fulfilment, aesthetic enjoyment and recreation). The values that are identified in any survey will reflect the questions asked, the stakeholders involved and their priorities. It is important that the value ascribed to a particular area or asset reflects the importance stakeholders with different spatial outlooks give to these assets – local communities may value an inshore area for fishing, national governments might value the same area for mining rights, while Traditional Owners would have values intrinsic to their cultural heritage.

Conservation values have been defined by the Australian Government as Matters of National Environmental Significance (MNES). MNES are the assets in the environment that have been defined under the EPBC as being important for the continued functioning of marine ecosystems. Australian Marine Parks will also have values linked to local flora, fauna and conditions that need to be protected at a higher level than the surrounding waters.

Assessing interactions between the ecological, cultural and economic values and different uses of the marine environment will help identify scenarios that support mutually compatible activities and provide management options to avoid, mitigate (or offset) activities that are not compatible with the different values identified. For example, activities such as aggregate mining might be incompatible with many ecological values and other uses such as ecotourism. The mix of value and use will be driven by the context of the area, its potential, and the objectives of managers and other stakeholders.

The term ‘values’ is commonly used to refer to many related but different concepts. We provide a simple framework, drawing on Brown (1984), to help distinguish and relate three core value concepts:

- **Held values**: the nature of that relationship is shaped by the values they hold within themselves: for example, their moral compass.
- **Relational values**: primarily, the importance or value of a thing derives from how people experience the thing; the relationship between people and the thing.
- **Assigned values**: things are often described in very specific ways for particular purposes: example to reflect their importance in a value relationship, or connect them to a decision making process.

Approaches to developing a framework to identify social, economic and environmental values that builds on existing approaches can be found in the companion report “Rethinking Approaches to Valuation in Marine Systems”.

Box 1. An illustrative example of analysing and diagnosing a value narrative

We propose developing methods to enable the process of doing such an analyses in a transparent and repeatable way.

Biologically important areas **(assigned)** for Humpback Whale **(thing)** migrations are currently valued for their importance for the viability of the species under the EPBC Act, to reflect society's **(person)** respect for nature **(held)**. These areas are described by scientists (**person**), who study the species and want to ensure (**relationship** and **social context**) that the populations recover to pre-whaling levels (**assigned**). Under the EPBC Act the species is listed as protected (**assigned**), triggering specific protections (**decision contex**t), as they are recovering from whaling (**environmental context**).

However, the same Humpback Whales **(thing**) are also valued by tourism operators (**person**), who run whale-watching (**relationship**) tours for tourists (**person**) and want to have high whale numbers (**assigned**) to ensure a continuing flow of paying (**assigned**) tourists leading to viable businesses and income streams to sustain their livelihoods (**held**). They employ a number of staff (**social context**), but want to ensure (**decision context**) that the species continues to expand (**environmental context**).

3. DISTRIBUTION AND INTENSITY OF PRESSURES

Through the NESP Hub project “Pressures on the Marine Environment” (2015-2017), we have collated and analysed the spatial distribution and intensity of pressures on the marine environment for the Australian EEZ. While the initial emphasis of the project was pressures on the Commonwealth Marine area, we have been extending information into state waters to capture pressures coming from coastal activities. The full set of outputs can be found at https://www.nespmarine.edu.au/understanding-pressures-marine-environment with a companion report summarising the current outputs “Changes in pressures on the Marine Environment over three decades”. Examples of the outputs can be seen in Appendix 1.

4. STEP 2: ESTIMATING RISKS OF SIGNIFICANT IMPACT FROM PRESSURES ON VALUES

4.1 The challenge of complexity and scale in marine ecosystems

Australia's Significant Impact Guidelines for Matters of National Environmental Significance (Department of the Environment 2013) require assessment of an action's total or cumulative impact, which accounts for all direct and indirect effects (including pre-existing effects) that may occur in space (*i.e.*, both on- and off-site) and time. In estimating the risk of a potential impact to a value from a given pressure or activity, there is a series of decisions regarding scope, context and appropriate means of analysis that need to be addressed. A central issue in making these decisions is how to understand and approach the complexity of the ecological, economic and socio-cultural systems in which the value is embedded and how it can be threatened by a pressure or activity. All stakeholders in a system will have a different value basis that they are coming from and will tend to ascribe different risks to the same sorts of activities

Assessing the potential impact of a proposed action requires unravelling causal pathways and processes that sustain, regulate and impact an ecological system, and also to provide a practical means to delimit the spatial bounds applicable to the assessment. Moreover, across the broad spectrum of marine ecosystems within Australia, there is wide disparity of knowledge and data available, making it difficult to provide assessments with an equal level of certainty and precision. The challenge then is to provide a framework that addresses the inherent complexity of human and ecological systems and can be adjusted to deliver rigorous and useful assessments along a spectrum of data-poor to data-rich situations.

We build on experience gained through developing indicators for marine ecosystem health (Dambacher *et al.* 2012, 2013; Hayes *et al.* 2012b, 2015a), and assessment of cumulative impacts for the Great Barrier Reef World Heritage Area (Anthony *et al.* 2013). Underpinning these efforts was a need to provide process-based understanding of how and where the values of concern in complex ecological and socio-economic systems could be affected by multiple anthropogenic pressures and activities. Here a key concept was the definition of a *Relevant Subsystem* (*e.g.,* Fig. 1), which encapsulates the essential dynamics of the system and was tailored to the problem at hand (Dambacher *et al.* 2009, 2015; see also Levin *et al.* 2009). The goal is not to try to account for all species and processes in an ecosystem, but rather to identify a manageable subset of ecosystem components that leads to useful predictions and a general understanding of the system's behaviour and meet stakeholder needs and expectations.

An array of possible modelling approaches is available to develop and analyse cumulative impact assessments for relevant subsystems. Where cause-effect relationships are limited to a relatively simple set of stressors and causal interactions in a system, then conceptual or illustrative modelling approaches are sufficient. But where systems have multiple stressors and complex feedbacks, then mathematical approaches are required, which can include statistical and process-based models (Fig. 2). The main purpose of any of these models is to provide predictions that can be used: to provide causal narratives to inform State of

Environment Reporting; to identify informative indicators; to assess potential effectiveness of management strategies and actions; and also to provide the means to test the validity of the models against observed dynamics of the system (Hayes *et al.* 2015a).

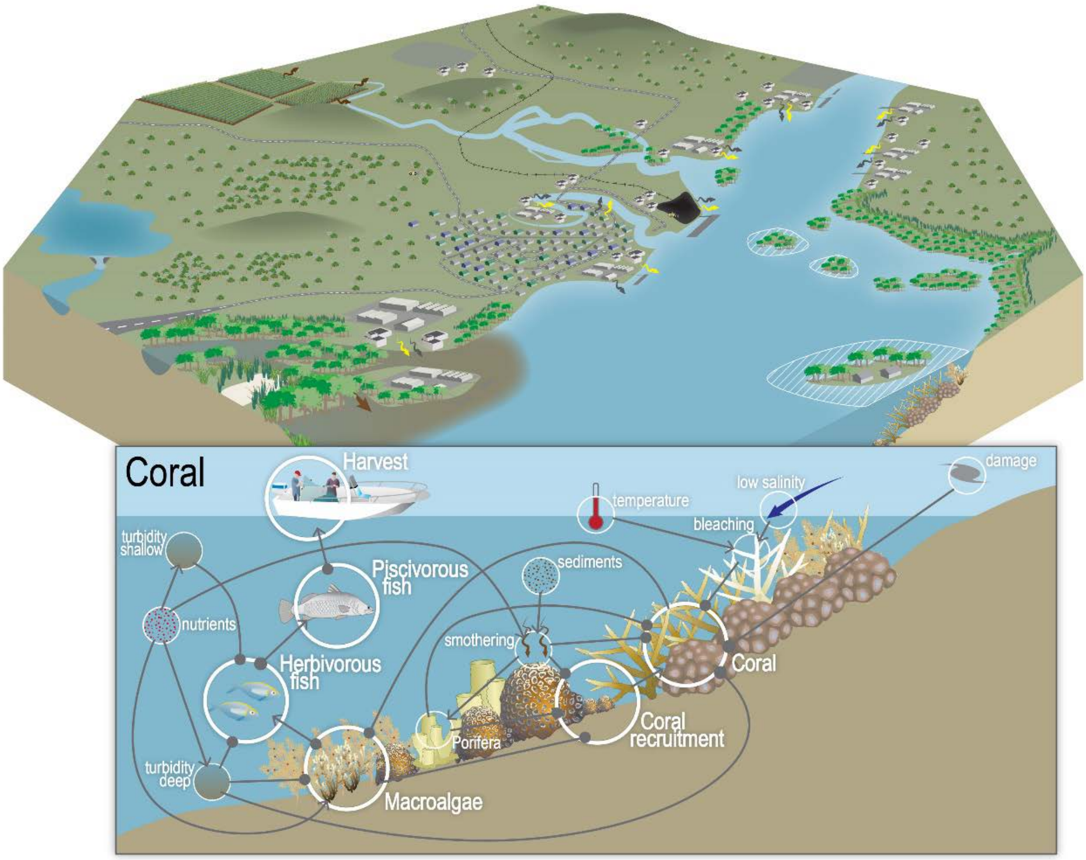
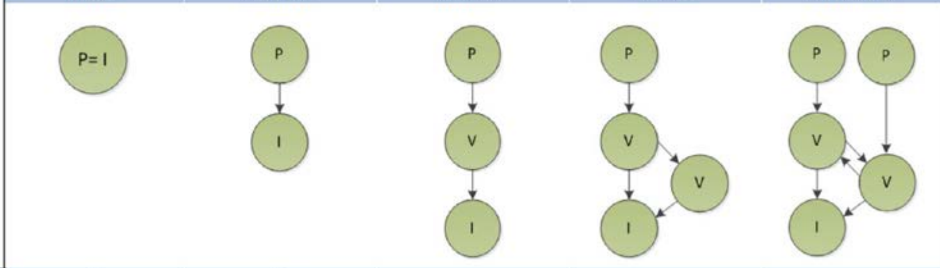


Figure 1. Example of relevant subsystem developed for values and pressures attributed to coral ecosystems within Gladstone Harbour, Queensland. Illustrated diagram of qualitative process model (signed digraph) which includes graph links that depict known direct effects shared between components within the ecosystem (positive direct effect: link ending in arrow, negative direct effect: link ending in filled circle); adapted from Dambacher *et al.* (2013).

Irrespective of the choice of a modelling method, the extent of a model's application is determined by the spatial overlap of the ecosystem in which an environmental value is located and the pressure or activity of concern. For relatively simple, broad-scale analyses, this overlap can be determined through simple pressure-intensity mapping (Hayes *et al.* 2012a), such as those in *Section 3* above. In more complex settings, however, a given activity or pressure can vary in its intensity over space and time, multiple sources can create combined effects and social, economic and regulatory factors may have a broader distribution than the pressure itself. In such circumstances, the concept of a Z*one of Influence* is a useful means for attributing the direct effects of multiple activities or pressures on a component of the ecosystem (Fig. 3). Such a mapping exercise identifies the relationship between the concentration or intensity of a given stressor and the magnitude of an expected stress response for a component of the ecosystem. For instance, in Fig. 3a increased water-column turbidity reduces the growth rate of corals. In Fig 3b low, moderate and high levels of an expected stress response provide overlapping zones of influence.

Analyses of impacts to the entire ecosystem can be assessed through application of a model, such as that of Fig. 1, to zones of influence where the combined intensity of a given pressure exceeds a standard or threshold value.

	COMPLEXITY OF CAUSE AND EFFECT RELATIONSHIP				
	NONE[1]	SIMPLE[2]	DIRECT[3]	DIFFUSE[4]	FEEDBACK[5]



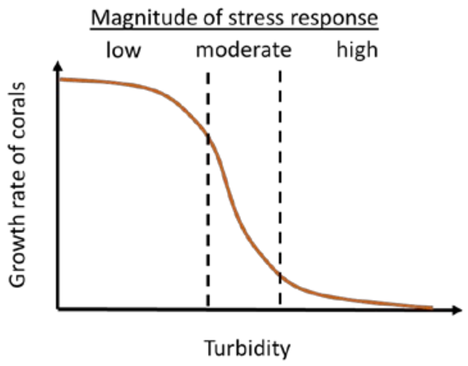
	NONE[1]	SIMPLE[2]	DIRECT[3]	DIFFUSE[4]	FEEDBACK[5]
Unstructured list	•	•			
Objective-indicator matrix	•	•			
Value-impact matrix		•	•		
Structured list		•	•		
Influence diagram or cartoon		•	•	•	
Fuzzy cognitive map		•	•	•	
Bayes Net		•	•	•	•[6]
Statistical model		•	•	•	•[7]
Qualitative process model		•	•	•	•
Quantitative process model		•	•	•	•

[1]No cause-effect relationship, the pressure is the indicator
[2]Pressure directly impacts indicator variable
[3]Pressure directly impacts a variable that has knock-on effects to indicator variable
[4]Pressure indirectly impacts an indicator variable via multiple interaction pathways.
[5]Multiple pressures simultaneously impact complex system with feedbacks between variables
[6]Standard Bayes nets constructed with expert opinion are typically limited to acyclic graph structures. Dynamic Bayes nets can account for feedbacks, but are difficult to parameterize
[7]Feedback not possible with classic statistical techniques (e.g., general and generalized linear models, multilevel models, structural equation models). Incorporation of process models within statistical analyses (e.g., state space modelling) can account for system feedbacks; such techniques, however, require extensive data, especially for large systems

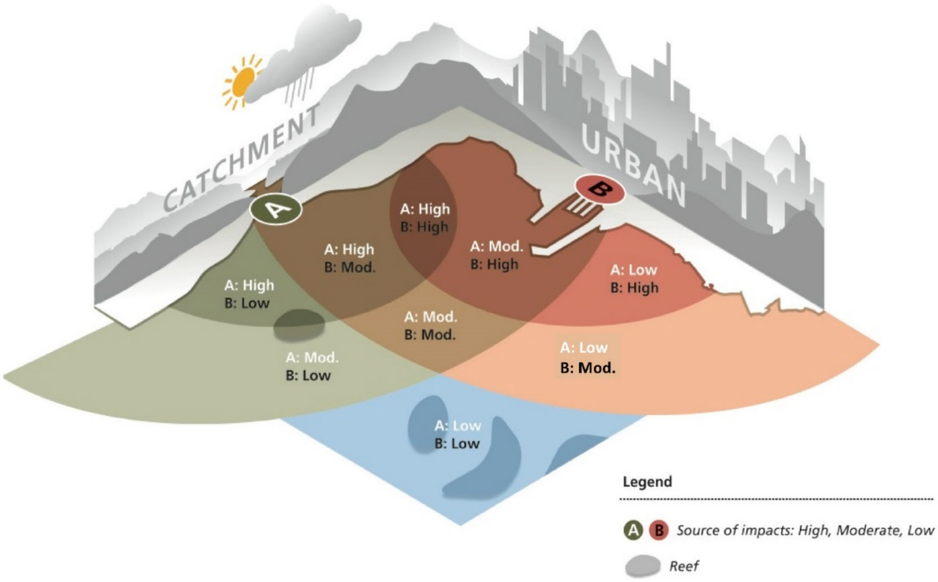
Figure 2. Sufficiency of methods for understanding, predicting and monitoring cumulative impacts in ecological systems across a range of complexity. Simple lists and graphical methods such as influence diagrams are sufficient for simple cause and effect structures, for example where a pressure (P) acts directly on a variable (V) and the indicator (I) is the variable itself. Mathematical approaches, such as Bayes nets, statistical and process-based models are sufficient when one or more pressures act on intermediate variables, which are themselves linked to other variables with ecosystem level feedbacks (adapted from Hayes *et al.* 2015a).

Relevant subsystems and zones of influence are relatively simple concepts, yet can provide a systematic and relatively easily understood approach to address the challenge of complexity and spatial scale inherent in cumulative impact assessments for marine ecosystems. And while the choice of models to support these assessments will necessarily be guided by the purpose and context of the modelling exercise, they will also be constrained by the amount of information available for the modelled system (Hayes *et al.* 2015a). Some marine ecosystems of Australia's EEZ are well studied, but a large fraction can be characterized as data poor (Hayes *et al.* 2015b). Thus, any framework to assess cumulative impacts will also need to be applicable to systems with very different data availability.

Here we propose an integrated strategy for modelling complex marine ecosystems that takes advantage of multiple and complementary modelling approaches (Levins 1966), a hierarchical approach that provides options for data poor to data rich systems. The goal here will be to formally assess risk in data poor systems with support from general non-precise modelling approaches. In well studied and monitored systems, greater data availability allows additional support from quantitative modelling methods, which permit assessments of risk with increased precision. Taken together, these modelling approaches can be used in a complementary manner to more efficiently increase knowledge of the system by focusing monitoring and management programs on most critical information needs.



a.



b.

Figure 3. (a) Expected level of response to a given stressor used to define levels of impact for a component of an ecosystem (e.g., growth rate of corals), which in (b) delineate zones of influence for a point (urban) and non-point (catchment) source; adapted from Anthony *et al.* (2013).

4.2 A hierarchical approach

A framework that can accommodate risk assessments that range in scope from rapid to comprehensive will speed the elimination of low risk pressures and support a graduated response as risk increases. This will focus assessment and management efforts, where risks are greatest or where interventions are likely to have the most effect. Issues of knowledge, data availability, cost, and uncertainty all limit the application of many tools and modelling approaches. A simple hierarchy of tools, moving from simple, rapid and low cost tools to progressively more complex and costly tools across 2 or 3 risk and information levels would support the prioritisation that decision makers and managers will typically require.

The assessment hierarchy we propose (Fig. 4) has three levels with a preliminary scoping step to identify values. The first level is an expert based assessment of the interaction between the values in the relevant subsystem and identified pressures. This first level of assessment is based on a general conceptual model of the system, while assessment levels two and three require an increased use of mathematical models that provide greater understanding, prediction and scope for comparing alternative management interventions. The second level employs qualitative mathematical models that use the information from the first level to build a more robust understanding of the relevant subsystem. The third level combines the use of qualitative and quantitative models that may require extensive data and resources. Each of the previous levels provides the context and justification for further investigation of risk to ecosystems/values/assets (*i.e.,* triggers for progression to the next level in the hierarchy). While the three levels of assessment are laid out as a three-stage progression in Fig. 4, they are, in practice, intended to provide a progressive feedback between modelling, monitoring and management activities (Hayes *et al.* 2015a).

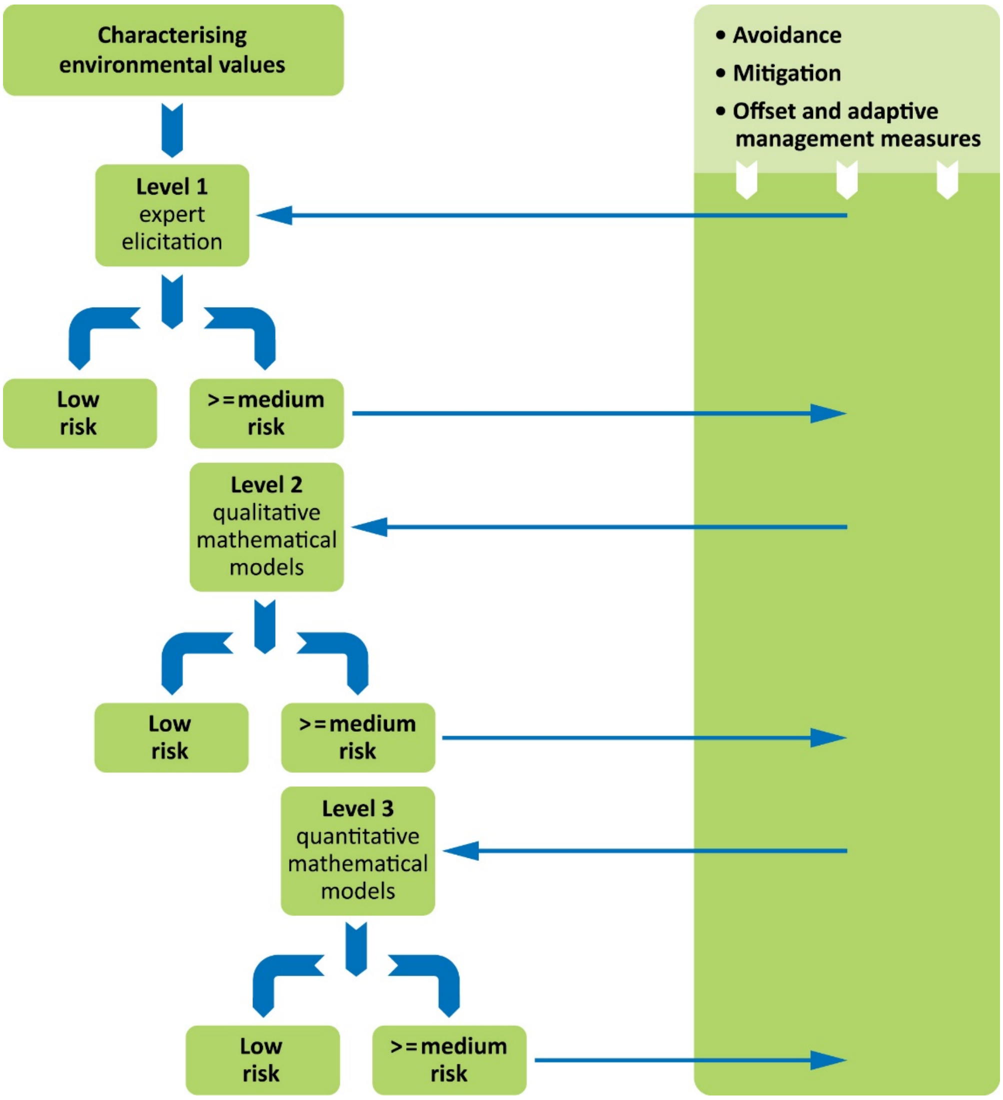


Figure 4. Proposed framework for hierarchical ecosystem risk assessment.

4.2.1 Modelling approaches and trade-offs

In this framework, we are guided by a strategy of model building that recognizes a practical trade-off between realism, generality and precision when building and analysing models of complex systems (Levins 1966, 1998). To obtain a manageable and useful model, one typically sacrifices one attribute for the other two. Qualitative process models emphasize generality and realism, but lack precision, while quantitative process models (*e.g.,* ecosystem models) can be both precise and realistic but are not generalizable (*i.e.,* application of model to changed circumstance requires re-parameterization). A third approach is through statistical models, which emphasize precision and generality. Here there are precise insights into the general pattern of correlations among variables, but at the cost of causal understanding of the processes involved. In practice, a robust strategy considers all three approaches, such that models are mutually informative and build upon the strengths and insights that each provides.

4.2.2 Scoping stage-Identify location and scale of values

There is considerable experience in identifying the relevant species (*e.g.,* Hobday et al. 2011 assessment of risk to commercially fished species), but identifying areas of interest is less well developed. A pragmatic approach is to identify areas that contain the well identified, ecologically coherent systems that contain features that could be both responsive to management (and impacted by activities) and perform an ecologically or biologically important function. This is also an acknowledgement that there are significant areas of the ocean that we do not have sufficient scientific information to actively manage based on evidence. We are choosing to focus on the areas where there is sufficient information to articulate the values for that area (*i.e.,* to at least level 1 in our hierarchy).

The term ‘values’ is commonly used to refer to many related but different concepts. We provide a simple framework, drawing on Brown (1984), to help distinguish and relate three core value concepts:

- *Held values*: the nature of that relationship is shaped by the values they hold within themselves: for example, their moral compass
- *Relational values*: primarily, the importance or value of a thing derives from how people experience the thing; the relationship between people and the thing. .
- *Assigned values*: things are often described in very specific ways for particular purposes: example to reflect their importance in a value relationship, or connect them to a decision making process.

Of particular interest to the management of ecological and social systems is using relational and assigned values as the basis for decision making. We have experience in describing values of areas – *e.g.,* Key Ecological Features (KEF; Dambacher *et al.* 2012), Biologically Important Areas (BIA), Ecologically or Biologically Significant Marine Areas (EBSA; CBD (2008), Dunn *et al.* 2014), but these can also be extended (see the companion report on values). The unifying attribute, however, is the identification and delineation ecological features that are valued for their productivity or biological diversity. For KEFs, these elements are described as the relevant subsystem, which is a description that applies equally well to

EBSA, KBA and all the other area-based descriptions, as well as attributes described as values (Dunstan *et al.* 2016).

The information sources that can be used to identify productivity and biodiversity values are diverse and will depend on the regional, national and local capacity. An important component of understanding the values will frequently be the knowledge held as traditional/local knowledge by communities and the processes described here could equally be applied to community-level management efforts (*e.g.,* Community Based Fisheries Management; CBFM, SPC 2010). In areas with more scientific capacity, existing and future research surveys will provide significant sources of information to identify biodiversity values. As this is an adaptive approach, identifying the biodiversity values to be considered should be based on best available scientific information.

4.2.3 Level 1 - Identification of hypotheses about interactions between pressures and values.

Description of Process

Once a process of identifying the spatially bounded values has been completed, level one identifies hypotheses about where and when pressures are affecting the relevant subsystem (Fig. 4). This identifies perceived interactions between the pressures and values, guiding conceptual models of the relevant subsystem. Conceptual models play an important role in organising understanding and communicating the links between different components in the system. They formalise what may otherwise remain in an individual expert's head and provide a shared level of understanding by all parties (Gross 2003).

Tools used

There are a number of tools and approaches, remembering that the expectation around a level 1 analysis is that it is a simple and rapid filtering of risks, it does not need to be particularly quantitative or quantitatively complex. The simplest means of analysis is the direct examination of the interaction of the ecosystem values identified in the relevant subsystem and the pressures thought to interact with that subsystem. There are two key components to this. First, the pressures that occur within the area need to be identified and assessed to see if there is possible interaction between the pressures and the area identified within the relevant subsystem. If there is no possible spatial overlap and if the pressures could not reasonably be expected to interact with the values of interest then the pressure should be considered a low risk with no further consideration required. Second, expert elicitation can be used to identify and rank the potential risk of impact from pressures on the values in each relevant subsystem. The elicitation can be either structured or unstructured. Structured elicitation is preferred (as it confers some degree of consistency, ref), but it is not always possible and so unstructured elicitation should not be ruled out if alternatives are not available.

Unstructured elicitation may involve a consensus process where a group of experts identify the potential interactions between pressures and values on a scale of consequence (*e.g.,* pressures are "of concern", "of potential concern", "of less concern", "not of concern", "data deficient or not assessed").This type of approach has been used in many fora (*e.g.,* Marine

Bioregional Plans (DSEWPaC 2012), Community Ecosystem Approach to Fisheries Management (SPC 2010)). While this provides a quick simple answer it does not allow for ranking the pressures beyond the 4 levels, and it limits the ability to compare between different areas. It also makes it difficult to prioritise in a consistent manner, particularly across different relevant subsystems. In contrast, a structured process of expert elicitation allows for the relative ranking of the interactions between pressures and values (*e.g.,* Garthwaite and O'Hagan 2000, Garthwaite *et al.* 2005, Kadane and Wolfson 1998, Kynn 2008). It also allows for the scoring of the interactions relative to each other and provides a quantitative estimate of the experts' understanding of the relative impacts on the values identified in the areas of interest. A relative ranking will identify the risk of different pressures relative to the pressures within the same relevant subsystem.

Transition to level 2

Before transitioning to a higher level of analysis it may be appropriate to consider whether sufficient information is already available to identify suitable management options and monitor their success. If all the risks are identified as low then progression may not be necessary. Alternatively, it may be decided that there is no acceptable level of risk for values identified in the relevant subsystem and the pressure would be managed to remove its impact over part of or all of the relevant subsystem, in which case progression is again unnecessary as a decision can already be made (Fig. 4).

If the pressure cannot be removed from all or part of the relevant subsystem and the assessment has identified the pressure is a concern (*i.e*., greater than an acceptable and preferably predefined threshold) then there are two options. Either the pressures of concern can be managed based on the information made available through level 1 (*i.e*., avoidance, mitigation, offset in an adaptive management approach) or it might be appropriate to transition to a higher level of analysis (*i.e*., level 2) that would increase the understanding of the risk posed on the relevant subsystem and improve the identification of the scale or type of management intervention that could be used to minimise or remove the pressure at an acceptable cost to society. However, this desire for more information must be weighed against the cost of the increased information requirements and increased duration to complete assessments at higher levels. Level 2: Qualitative mathematical models of ecosystem impact and risk.

Description of Process

A more complex understanding of the dynamics and structure of the relevant subsystem within an ecosystem and its components can be developed using qualitative mathematical models (Fig. 4). With increased understanding of the biodiversity values and ecosystem components, it is possible to construct ecosystem models that allow for a more informed, albeit qualitative, estimate of the cumulative impacts of pressures on ecosystem values (*e.g.,* Dambacher *et al.* 2009, Dambacher *et al.* 2010, Hosack and Dambacher 2012, Anthony *et al* 2013). A semi-quantitative process is also used within level 2 analysis of the Ecological Risk Assessment for the Effects of Fishing (ERAEF, Hobday *et al.* 2011). The ERAEF uses a semi-quantitative productivity susceptibility analysis (PSA), scoring fisheries on the productivity of species and the susceptibility of each species to the types of fisheries gear used. Both approaches take elements of the information gathered as part of level 1 and incorporate them into a more quantitative information-rich framework.

Tools used

Qualitative mathematical models incorporate components and processes of an ecosystem without the need to measure or estimate them precisely. They can be constructed and analysed relatively rapidly, thus allowing for comparison of alternative models based on different understandings or beliefs about how the system works. These models contain only the sign (+, –, 0) of species interactions, and not their precise magnitude or strength. In this approach, one sacrifices precision in a model for generality and realism (Levins 1966). The principal goal of this approach is to understand how the structure of a system (*i.e.,* the variables and the signs of their connecting links) affects its dynamics. This is achieved through analysis of a system’s feedback properties in predicting how it will respond to a perturbation.

In Fig. 5 is an example analysis of cumulative impacts from qualitative models of coral reef ecosystems in Gladstone Harbour (Fig. 1). The model results have been translated into a Bayes net, which gives the probability for an increase, decrease or no change in the level or abundance of variables given a sustained input or perturbation, here by way of an increase in sediments delivered to the coral reef ecosystems.

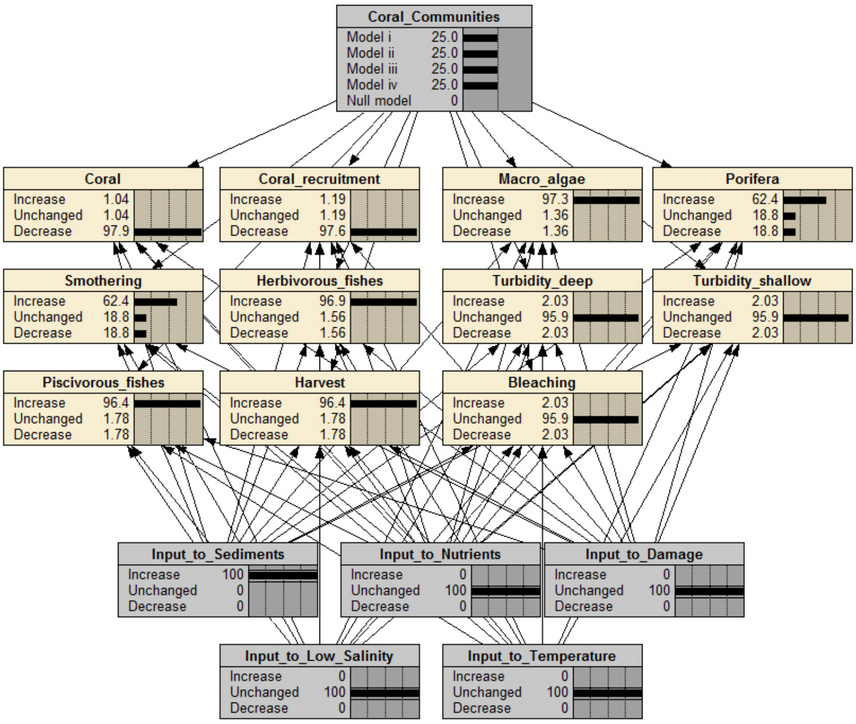


Figure 5. Bayes net of qualitative models of Fig. 1 giving predictions for cumulative impacts to coral reef ecosystems of Gladstone Harbour. Predictions indicate likelihood for a directional or qualitative change (+, -, 0) for ecosystem variables for increase in sediments in system.

The strength of the qualitative modelling approach is that the models can formally capture information about the structure of the relevant subsystem, particularly for components that are difficult to measure, and can draw information from knowledge bases that are hard to access quantitatively (*e.g.,* social or cultural knowledge). Because they are derived from our current understanding of the system they can be developed, analysed and updated rapidly as new information becomes available. The dynamics of the system can be understood and predicted through examining the system's qualitative structure and feedback properties. In this way the level two approach provides qualitative predictions about how cumulative risk and impact are likely to affect the specific components of relevant subsystems and which components would need to be monitored to unambiguously detect and attribute impacts to the different pressures. Different stakeholders' perception of how things work can be explored to see how this would change outcomes.

Transition to level 3

The need to transition from level 2 to 3 can be assessed based on similar conditions to the transition from 1 to 2. If pressures can be removed or managed based on information obtained at level 2 then progression to level 3 is unnecessary, unless formal monetary valuation is required for offsetting?. If the pressure cannot be removed, reduced or restricted from the relevant subsystem and the assessment identifies pressures that are of concern (*i.e.,* cause negative or uncertain outcomes for the system values of interest) then there are two options. Either the pressures of concern can be managed based on the information made available through level 2 or a transition to a higher level of analysis (*i.e.,* level 3) may be appropriate, as that would increase the understanding of the risk posed on the relevant subsystem. This decision must be made with the clear understanding that a transition to level 3, a fully quantitative analysis, implies significantly more expense and complexity.

4.2.4 Level 3: Quantitative Analysis of Ecosystem Impact and Risk.

Description of Process

In some of situations a more quantitative understanding of the risk of different pressures will be needed to decide on thresholds and trigger points for actions, or provide managers with an increased knowledge of how to manage towards potential future scenarios. This will be particularly relevant when previous levels have indicated that activities may be high risk and there is insufficient information to mitigate pressures as a result of the assessments at previous levels (Fig. 4). This is the only level where a fully quantitative analysis is undertaken and where information from all levels should be integrated and used.

There are a significant number of analytical options that exist to address ecosystem level analyses and the challenge is choosing the approach that meets the objectives of the assessment and the time and budget constraints. The first constraint for this approach is the availability of data or the ability to obtain additional data. Numerical data is expensive both in terms of cost and time to analyse and if there is existing data that can be used to address the objectives of the assessment then it is possible to shorten this aspect of the process. Alternatively, additional information may be obtained through a monitoring program (Hayes *et al.* 2015a, 2015b) or scientific surveys that explore the response of the system with adaptive management. The implementation of a monitoring program would be a reasonable response to the absence of data, using information obtained in levels 1 and 2. The program would need to clearly identify how the additional information would be used to update management options, appropriate trigger points and a process for updating the analysis of the monitoring data.

Tools used

Statistical models emphasise generality and precision, they are more easily tested and will provide thresholds with estimates of uncertainty. These are critical to setting quantitative thresholds and trigger points and providing the analysis needed to refine ecosystem level analyses. However, they have difficulty in describing the complexity of ecosystems, and more particularly, are less able to address questions of causation. Statistical models have been used to address questions around single sector activities and outcomes – such as fisheries impacts (*e.g.,* Trenkel and Rochet 2010, Rochet *et al.* 2010) and acoustic impacts (Pine *et al.* 2014). In Fig. 6, for example, is a statistical analysis of the impact of cumulative trawl effort to groups of fishes on the continental slope off south-eastern Australia. Statistical models are most useful when there is a direct measure of the value of interest and monitoring data can be collected quickly and cheaply and the response of the system to the pressures is sufficient to clearly detect the signal of change.

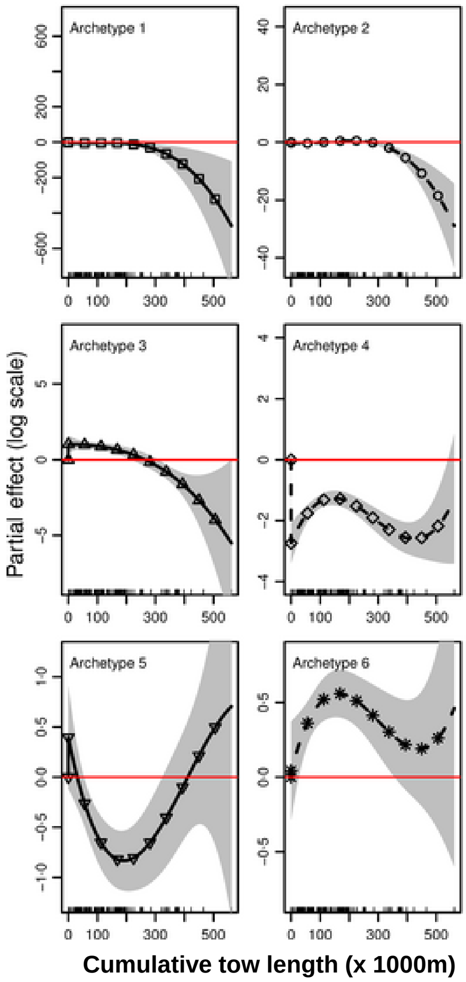


Figure 6. Statistical analysis of the responses of fish species abundance to cumulative trawl effort (tow length) on the continental slope off the coast of south-eastern Australia for 6 archetype models of fish groups; grey regions are the 95% confidence regions; adapted from Foster *et al.* (2014).

In contrast, numerical simulation models are able to capture a significant amount of ecological complexity of the systems and can also incorporate the dynamics of human activities, they are, however, less easily tested and may require significantly more data. Initially these models have focused primarily on fisheries and their trophic interactions with other biological elements of marine ecosystems, though some of the more sophisticated represented the gross pressure of other activities (such as coastal development and catchment based nutrient flows) as background to the fisheries work (Fulton 2011, Fulton *et al.* 2014).

For example, Fig. 7 shows the data required to run a complex coupled model including fisheries, biophysical, assessment and management submodels, which were used to inform performance measures to evaluate the effectiveness of a set of proposed management options for marine protected areas in the Gulf of Carpentaria. This work highlighted trade-offs among values associated with biodiversity, commercial fisheries and economic and sustainability objectives.

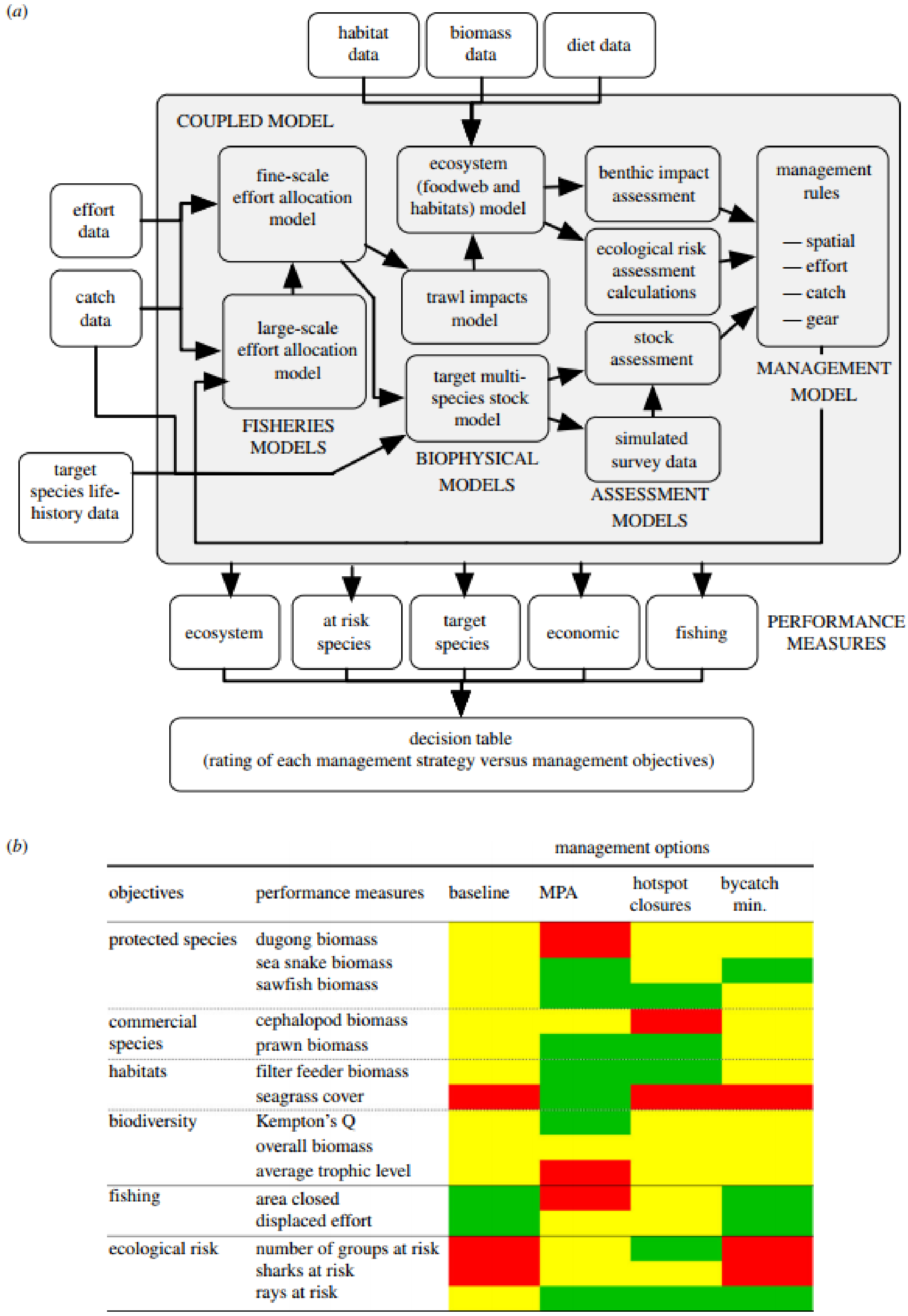


Figure 7. Coupled model for marine protected areas in the Gulf of Carpentaria. (a) Schematic diagram of data used, with the components of the coupled model shown in the shaded area. (b) An example output decision table, with colours indicating how well the management objectives were met (red, failure; yellow, partial; green, full) for the four management options considered: baseline (status quo) management arrangements in place in the region in 2008; a conservation network of MPAs across the region; adaptive closures triggered in fishing effort hotspots; and new management arrangements (including targeted area closures) focused on fisheries bycatch minimization; adapted from Fulton *et al.* (2015).

A diversity of approaches have been applied, from multispecies models with environmental and social drivers to full end-to-end (or whole of system) ecosystem models that include the physical environment, habitats, food webs and all the human uses (Little et al 2006, Fulton et al 2011, Plagányi *et al.*, 2011, 2014). Simulation models require significant amounts of data, for all parts of the model, to support the specification of parameters and to support assumptions about the functional forms of ecological relationships. They have an advantage that they can portray the ecosystem in a way that resonates with stakeholders. This in itself can lead to an improved and shared understanding that can remove disagreements on potential management actions. However, while representation of the uncertainty around simulation model results is improving, unless large scale ensemble-modelling approaches are used, it is still difficult to determine the confidence in the models in terms of structural and parametric uncertainty. Moreover, simulation models can be good at describing the current state of the ecosystem, but may have limited skill in distinguishing the relative probability of future states. One approach showing significant potential is the ‘minimum realistic’ or intermediate complexity approach (*i.e.,* MICE, Plagányi *et al.* 2014). By focusing only on the relevant subsystem, statistically proven model fitting methods can be used and skill assessments can be undertaken, providing greater confidence in model results for some loss of generality.

5. SUMMARY AND FUTURE STEPS

Understanding the current impacts and risks of impact to marine biodiversity remains a major challenge for all stakeholder of the marine environment. Where impacts are direct and easily measured there are clear tools and guidance for the analysis of that impact. However, where there are indirect impacts, such as downstream, upstream and the plethora of possible cumulative impacts there is less clarity and no guidance on the types of approaches and analysis that can be used to ensure that stakeholders can understand how to analyse impact and where it will be critical to manage those impacts. The consequences of this lack of guidance can be seen in the different approaches taken in the Marine Bioregional Plan and the Marine chapter of the State of the Environment.

This report has proposed a framework that could be used to analyse and triage activities to ensure that those that will have a significant impact can be identified. However, like so many other initiatives, this can only go forward with the support and participation of a broad range of stakeholders. These ideas should be tested and, where necessary, modified by researchers in the Marine Biodiversity Hub to ensure that they can be broadly applied to provide a practical and robust approach to analyse potential impacts to Australian marine resources.

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7. APPENDIX 1

7.1 Shipping

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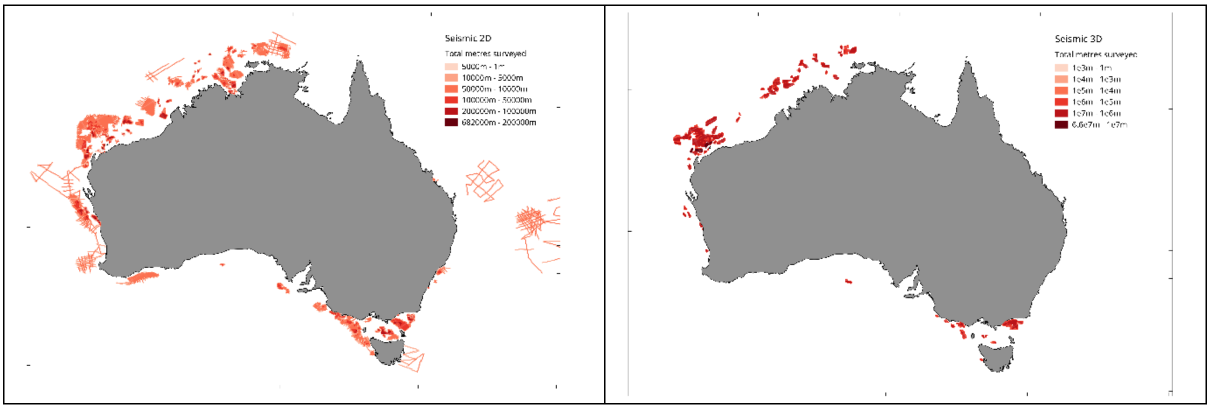

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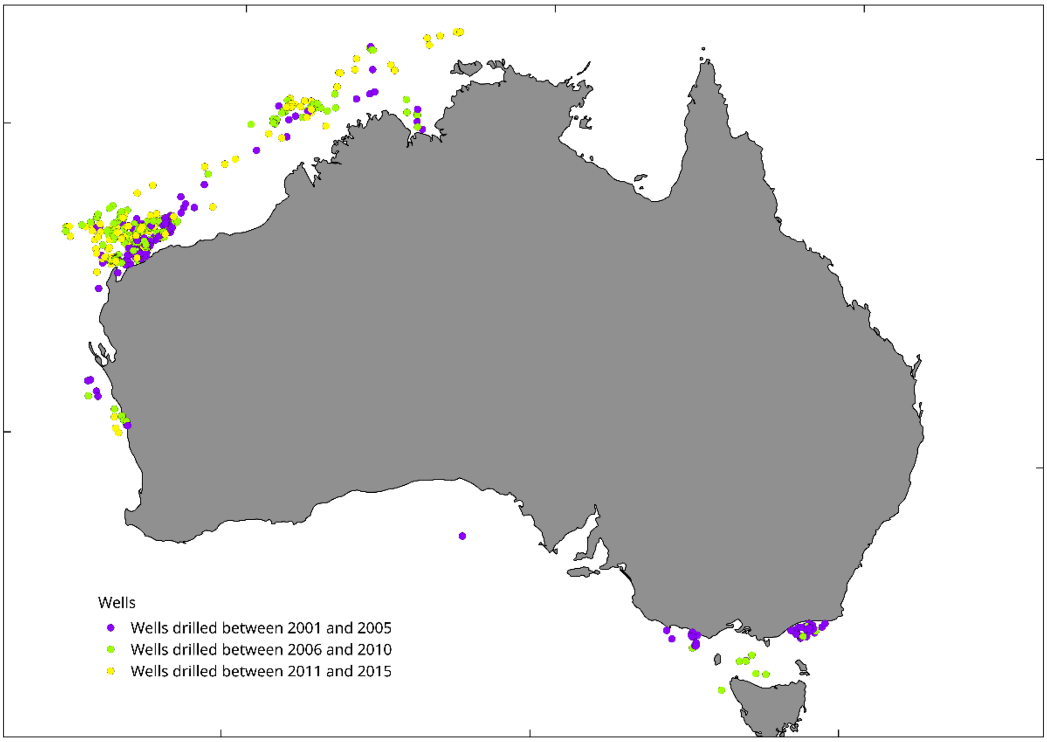

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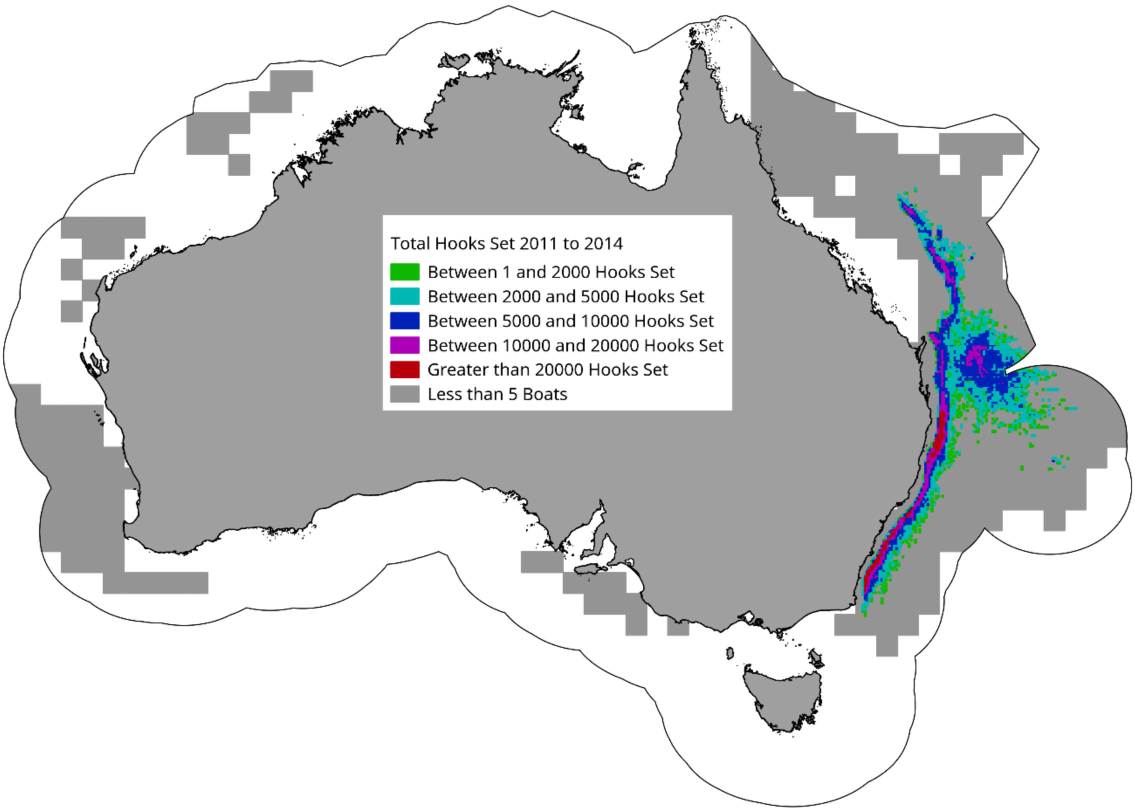

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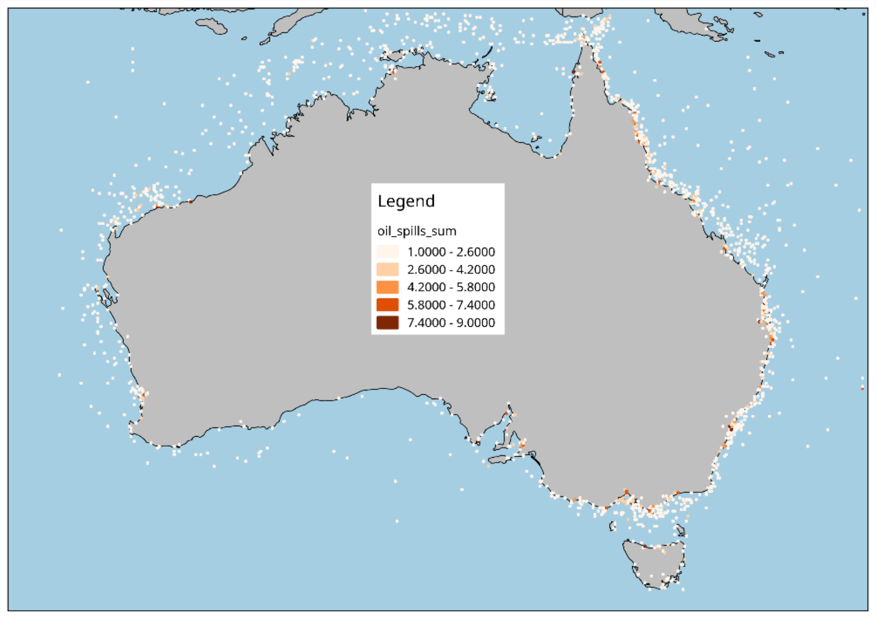

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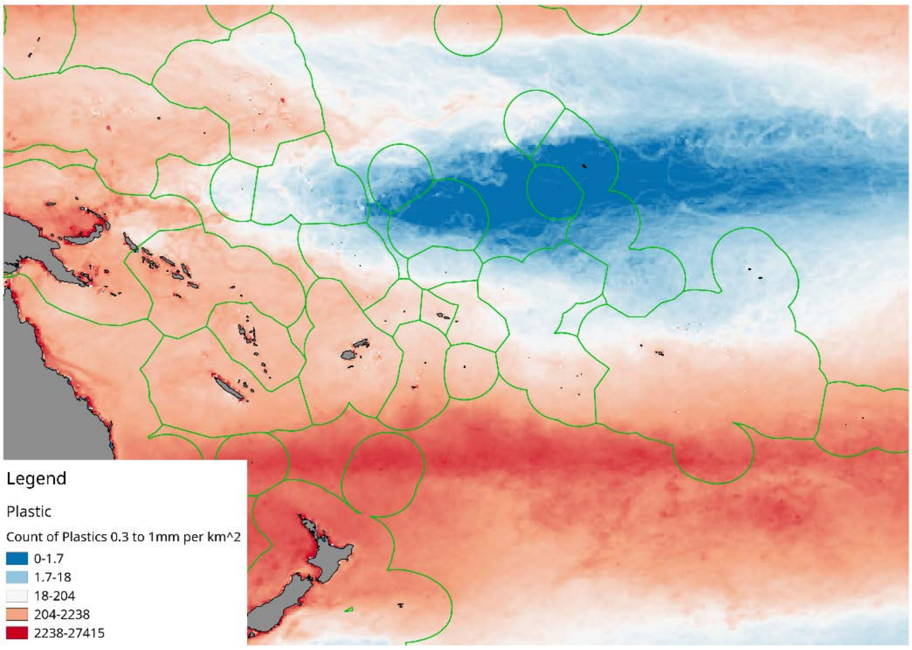

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7.8 Climate

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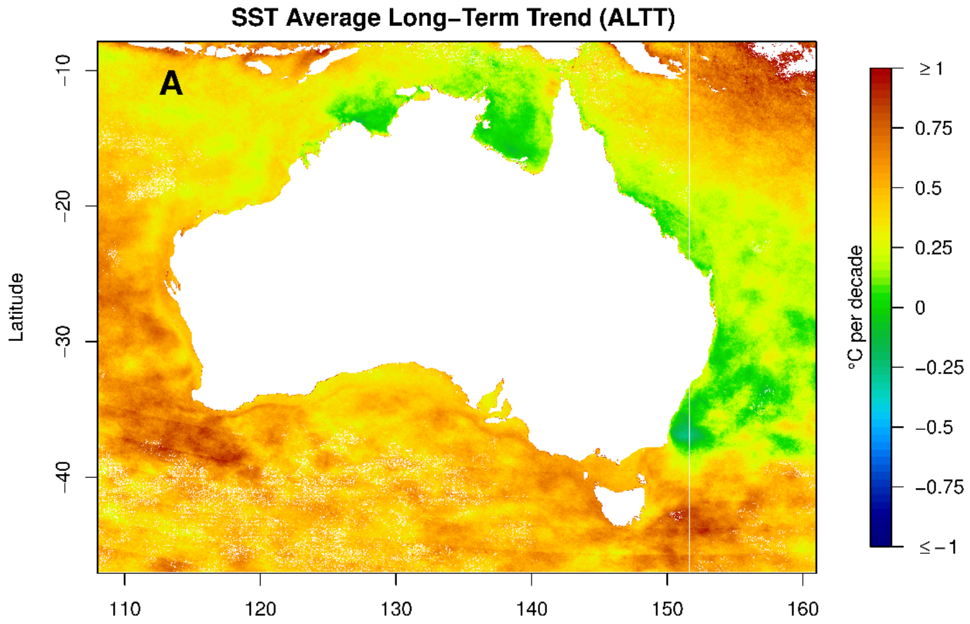

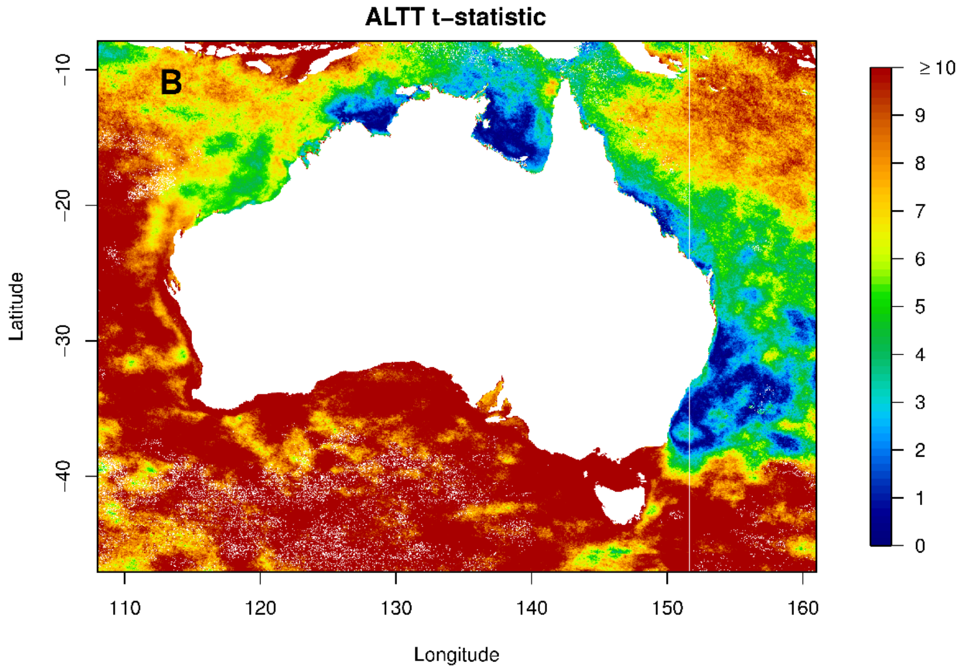

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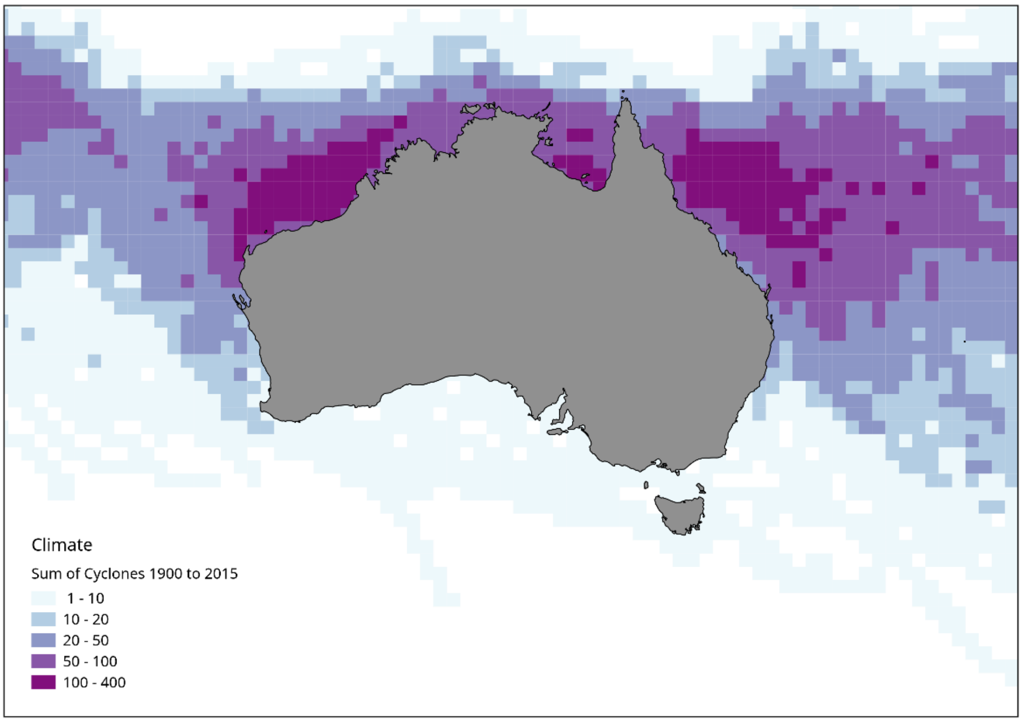

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Contact:
Piers Dunstan
CSIRO

Castray Esplanade, Hobart, Tasmania
Piers.Dunstan@csiro.au | tel +61 3 6232 5382