

Characterising the values and connectivity of the northeast Australia seascape: Great Barrier Reef, Torres Strait, Coral Sea and Great Sandy Strait

Technical Report (Part 1)

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Johanna E. Johnson^{1,2}, David J. Welch^{1,3}, Paul A. Marshall^{4,5}, Jon Day⁶, Nadine Marshall⁷, Craig R. Steinberg⁸, Jessica A. Benthuisen⁸, Chaojiao Sun⁷, Jon Brodie⁶, Helene Marsh¹, Mark Hamann¹ and Colin Simpfendorfer⁹

¹ School of Marine and Tropical Biology, James Cook University

² C2O Consulting, Cairns, Australia

³ C2O Fisheries, Cairns, Australia

⁴ The Centre for Biodiversity & Conservation Science, University of Queensland

⁵ Reef Ecologic, Townsville, Australia

⁶ ARC Centre of Excellence for Coral Reef Studies, James Cook University

⁷ CSIRO Oceans and Atmosphere, Crawley, Australia

⁸ Australian Institute of Marine Science, Townsville, Australia

⁹ Centre for Sustainable Tropical Fisheries and Aquaculture, James Cook University, Townsville



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ACRONYMS

BoM	[Australian] Bureau of Meteorology
CITES	Convention on International Trade in Endangered Species Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEHP	[Queensland] Department of Environment and Heritage Protection
DoEE	[Australian] Department of the Environment and Energy
EPBC	Environment Protection and Biodiversity Conservation Act 1999
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWhA	Great Barrier Reef World Heritage Area
IUCN	International Union for Conservation of Nature
MTSRF	Marine and Tropical Science Research Facility
NERP	National Environment Research Program
NESP	National Environmental Science Program
NOAA	National Oceanic and Atmospheric Administration
PZJA	Protected Zone Joint Authority
SELTMP	Social and Economic Long-Term Monitoring Program
TSRA	Torres Strait Regional Authority
TWQ	Tropical Water Quality Hub
QPWS	Queensland Parks and Wildlife Service
UNCLOS	United Nations Convention on the Law of the Sea

ABBREVIATIONS

ca.	approximately
LWM	low water mark
MHW	marine heatwave
SST	sea surface temperature

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EXECUTIVE SUMMARY

The Great Barrier Reef (GBR) is globally recognised for its Outstanding Universal Value and is an integrated and highly connected part of a larger ecosystem, which includes the Torres Strait, Coral Sea and Great Sandy Strait (herein the northeast Australian seascape). Understanding the values (ecological, cultural, social and economic) of these interconnected systems and characterising the connectivity and inter-dependencies between them is crucial for effective management and conservation. This project aimed to identify and characterise the values of the northeast Australian seascape. By characterising the attributes and processes that influence the values and their connectivity at a regional scale, this report delivers a resource that can inform cross-jurisdictional planning and management.

The need to understand and manage for connections that span jurisdictional boundaries in the GBR region has been recognised for some time, since the Commonwealth of Australia and the State of Queensland signed the Emerald Agreement in 1979 to ensure a complementary approach across the GBR Marine Park and the adjoining State Marine Parks. These marine domains are connected and contain values of national and international significance. However, each domain in the northeast Australian seascape is managed under different legislation, with separate and largely independent management agencies. Yet it is recognised that many of the values that frame the objectives of each management area are not independent or isolated, and their effective protection and management requires a coordinated approach. Despite this recognition, there is still substantial scope for improved coordination in the management of key values across adjacent jurisdictions in the region. A better understanding of the values shared by the connected ecological systems, and the mutual dependency between adjacent systems for maintaining key values, would help identify opportunities and benefits for cross-jurisdictional cooperation.

This project reviewed existing information for the four marine areas in the northeast Australian seascape to identify 10 key values within four categories (Natural, Indigenous, Social and Economic) that are comprised of at least three attributes each, with a total of 62 attributes characterised. The project documented the physical and socio-economic drivers of connections of values between areas, and through a structured approach using expert elicitation, mapped and characterised the different types of connectivity of these 62 attributes. Experts and stakeholders were consulted to identify and score the main threats that influence values and prioritise targets for cross-jurisdictional management based on the strength of connections, current management regimes and future threats.

A new hydrodynamic model for the northeast Australian seascape combined earlier outputs for individual marine areas to document how ocean circulation influences connectivity and drives interdependencies between values. Ocean currents are known to be the major mechanism by which the values across the entire seascape are both defined and connected, for example by facilitating dispersal of larvae and particles and the propagation of climate features (e.g. marine heatwaves that can cause coral bleaching). Social and economic drivers can also connect marine values across jurisdictional boundaries through the networks that exist between people both within and across boundaries and the extent to which ecological values are shared.

By focusing on where values cross borders and connectivity and/or inter-dependencies are strong, attributes were ranked by priority for improved coordination of management across jurisdictions. Importantly, the results provide detail on which jurisdictions should consult to better support management of specific values, and which threats are of most concern. Ultimately, the information can be used to facilitate better engagement between jurisdictions and to develop aligned and collaborative management arrangements. The outputs from this work have been delivered in this technical report, as a spatial tool on the eAtlas that can be used by managers and planners, and in a summary report that highlights the key findings.

1.0 INTRODUCTION

1.1 Description of the project jurisdictions

The northeast Australian marine area has one of the world's most extensive continental shelf areas, and is recognised for its ecological complexity and biodiversity, as well as its social, economic and cultural values. This broad area includes four marine management areas: the Great Barrier Reef (GBR), Torres Strait, Coral Sea and Great Sandy Strait (Figure 1). These areas are managed under complex jurisdictional and regulatory frameworks administered by Australian and Queensland governments, regional Natural Resource Management groups, and international agreements. The northeast Australian seascape is a mosaic of interconnected ecosystems containing a range of habitats, species and processes that extend over large distances. The values of the ecosystems and the pressures and impacts that threaten their values are not confined within jurisdictions. Effective protection of biodiversity and maintenance of social, economic and cultural values requires a “seascape” view that incorporates these connections and cross-jurisdictional linkages.

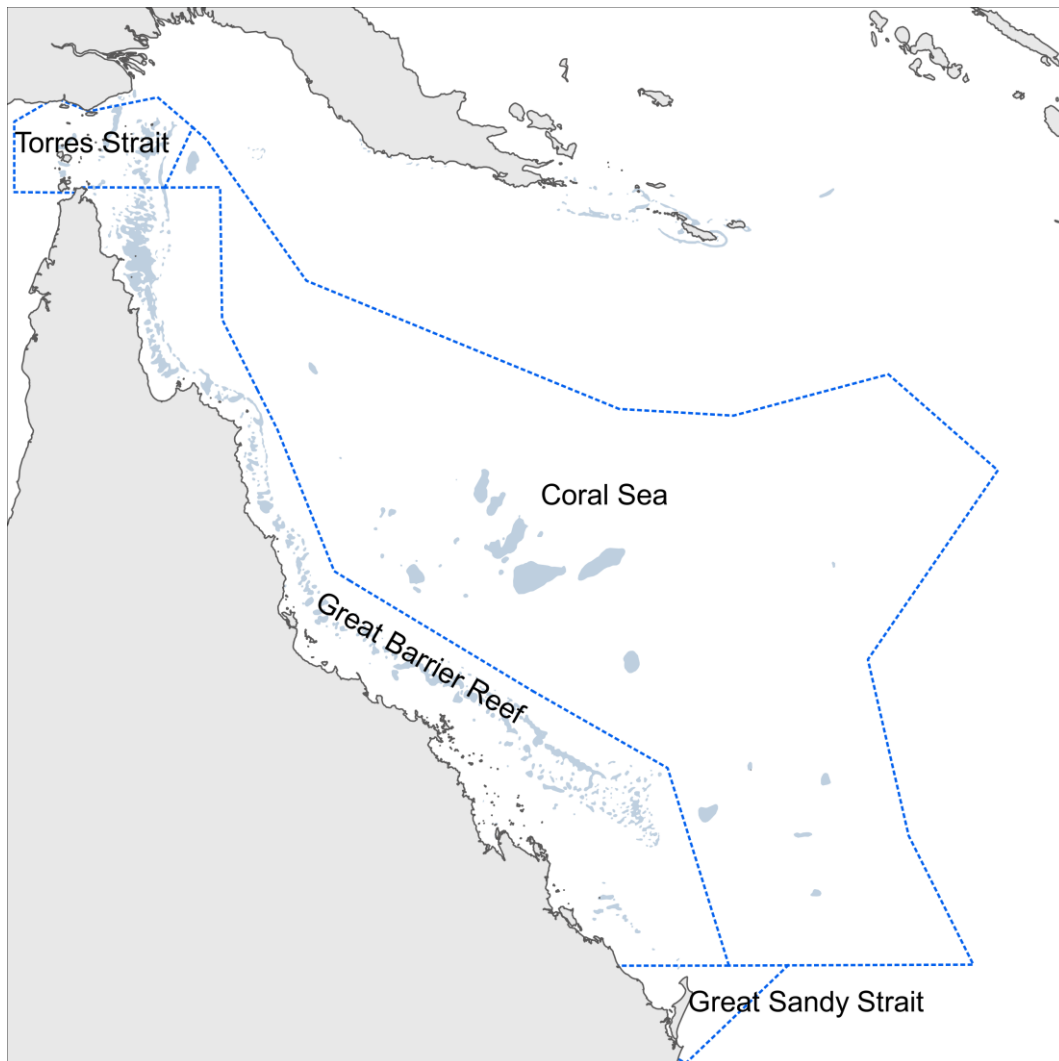


Figure 1: Map of project area: Northeast Australian seascape including the Great Barrier Reef, Torres Strait, Coral Sea, and Great Sandy Strait.

The need to understand and manage for connections that span jurisdictional boundaries in the Great Barrier Reef region has been recognised for some time (e.g. Brodie and Pearson 2016). When the IUCN prepared their evaluation in 1981 for the listing of the GBR on the World Heritage list, they concluded:

"The Committee should also note that the Great Barrier Reef extends beyond the northern boundary of the property nominated, and express a willingness to accept the addition of this area should it become available in the future".

The northeast Australia seascape includes connected tropical marine ecosystems and populations of threatened and vulnerable species, commercially valuable species and migratory species. The area has a multitude of habitats, including coral reefs, inter-reefal areas, mangroves, seagrass meadows, estuaries, islands and cays. The clear waters and coral reefs provide habitat for hundreds of species of plants and animals, and are the basis for Indigenous culture, a thriving tourism industry, recreation and rich fishing grounds. Coastal habitats – estuaries, tidal wetlands, seagrass meadows and beaches – support populations of dugong, marine turtles, cetaceans, and many juvenile fish and invertebrates (Figure 2).



Figure 2: Representation of the high biodiversity of tropical marine ecosystems and the plants and animals they support (Source: nova.org.au).

The northern boundary of the GBR World Heritage Area (GBRWHA) extends to Cape York and excludes the Torres Strait, a relatively pristine environment with an estimated 680 coral reefs (Lawrey and Stewart 2016), spatially extensive areas of seagrass meadows (possibly the largest in the world), the largest population of dugongs globally, and significant green turtle feeding and nesting habitat (Johnson et al. 2015). The Torres Strait region also has one of the highest proportions of Indigenous people in Australia, who maintain strong cultural affiliations with their land and sea. To the east of the GBR is the Coral Sea, a contiguous ecosystem that is remote, relatively distant from direct human influence, has very clear water and isolated oceanic reefs. It supports many species of fish, seabirds, marine turtles, sharks and cold-water corals that are found in deep waters throughout the tropics; with the Coral Sea being one of the few places where they've been documented (Beaman et al. 2016, Webster et al. 2008). Coral Sea reefs may act as stepping-stones connecting western Pacific reefs (e.g. New Caledonia) with the Great Barrier Reef (Ceccarelli et al. 2013). The Coral Sea is another relatively pristine environment that is described to be the 'cradle to the GBR' (UN Chronicle 2017). To the south lies the Great Sandy Marine Park (which includes Hervey Bay, Great Sandy Strait, Tin Can Bay and Cooloola). The Great Sandy Marine Park is a diverse area that includes reefs, seagrass meadows, the most important population of dugongs on the east coast of Australia south of Cape York, important marine turtle and seabird nesting sites, and open water habitats that support migrations of marine megafauna en route to the GBR.

These marine domains are connected and contain values of national and international significance. However, few of the ecological values of the adjacent areas are considered in the current Statement of Outstanding Universal Value for the GBRWHA. Each domain is managed under different legislation, with separate and largely independent management bodies. However, many of the values that frame the objectives of each management area are not independent or isolated, and their effective protection and management requires a coordinated approach. A better understanding of the values shared by these connected ecological systems, and the mutual dependency between adjacent systems for maintenance of key values, will help identify opportunities and benefits for cross-jurisdictional cooperation.

While many of the values and processes in these areas have been identified, for example in the GBR (GBRMPA 2000), Torres Strait (Fuentes et al. 2016, Johnson et al. 2015, Marsh et al. 2015, Waterhouse et al. 2014), Coral Sea (Ceccarelli 2011, Edgar et al. 2015, Beaman et al. 2008, 2012, 2016) and Great Sandy Marine Park (Lee Long and O'Reilly 2009, Ribbe 2017), they have not been characterised in the context of links or interactions within the broader northeast marine ecosystem.

Ocean currents are known to be the major mechanism by which the values across the entire seascape are defined and connected, for example, by facilitating dispersal of larvae and biogeochemical particles, and the propagation of climate features (e.g. marine heatwaves that cause bleaching) (Steinberg 2007, Weeks et al. 2010, Wolanski et al. 2013). While studies have described elements of physical connectivity in parts of the region (e.g. Steinberg 2007, Weeks et al. 2010, Wolanski et al. 2013, Herzfeld 2006, Ganachaud et al. 2014, Sun et al. 2015), there has never been a holistic compilation of this existing knowledge to inform the nature of the connections that link the ecological, cultural, social and economic values across all management boundaries.

1.2 Current management linkages

In terms of management approaches, there are some clear similarities and differences across the four jurisdictions. Some Commonwealth legislation (e.g. EPBC Act 1999, Navigation Act 2012) applies across all four jurisdictions; however, there is also specific Commonwealth legislation that applies only in specific areas (e.g. Great Barrier Reef Marine Park Act 1975 in the Great Barrier Reef). Interestingly, the Great Barrier Reef Marine Park Act 1975 *'...provides precedence over inconsistent provisions of almost all other Federal laws and, under the Australian Constitution, Federal laws have precedence over any inconsistent Queensland State laws within the Great Barrier Reef Region'* (Kenchington and Day 2011).

Queensland legislation clearly applies in the Great Sandy Strait, but some State legislation also applies in the other jurisdictions (e.g. Queensland fisheries legislation in the GBR). For example, all but 70 of the 1,050 islands within the outer boundaries of the GBR are under Queensland jurisdiction and as well as part of the GBR World Heritage Area, and Queensland legislation applies from 'low water mark' (LWM) onto the islands and cays.

In terms of international agreements and conventions, there are some that apply across all four jurisdictions (e.g. Convention on Biological Diversity, UNCLOS, Convention on the Conservation of Migratory Species of Wild Animals [CMS], CITES), whilst others (e.g. World Heritage Convention) only apply in those sites that have been specifically listed in recognition of being of Outstanding Universal Value (e.g. GBR, Fraser Island).

Some thematic issues (e.g. most aspects of shipping) are managed in a consistent way across the four jurisdictions. Other management issues, such as fisheries, are quite specific, not only within jurisdictions but also within specific fisheries within those jurisdictions. Many management tools are therefore specific to a single jurisdiction – however, rather than 're-inventing the wheel' in some jurisdictions, it may be useful to consider existing legislation in other jurisdictions when addressing similar management issues.

There are a number of formal frameworks or arrangements in place to facilitate cross-jurisdictional management, for example:

- The Offshore Constitutional Settlement (Attorney-General's Department 2014) provides a basis for fisheries management within the GBR Region to be undertaken by the Queensland Government, but all fishing activities in the GBR are subject to the federal and Queensland zoning plans;
- The Inter-governmental Agreement (IGA) between Queensland and the Commonwealth in the GBR – the close working partnership between the Federal management agency (the Great Barrier Reef Marine Park Authority or GBRMPA) and the state of Queensland – has been a successful arrangement in terms of collaborative management. This relationship has evolved over 40 years, and includes aspects such as complementary legislation, planning and joint permits. For example, Queensland mirrored the federal marine park zoning plan in the adjoining state waters within 5 months of the federal zoning plan revision coming into effect.
- The Protected Zone Joint Authority (PZJA) in Torres Strait between Australia and PNG.

There are also less formal arrangements for management occurring across jurisdictions (e.g. operations of the Australian Border Force that assist with surveillance in the Torres Strait, GBR and Coral Sea). A range of advisory groups/forums designed to assist managers in one jurisdiction could equally assist management in another. For example, the various advisory committees set up to manage the GBR could also assist the Coral Sea, given that many of the users are the same.

There are many complexities associated with less formal management arrangements. For example, in the Torres Strait shared or overlapping traditional jurisdictional boundaries define nearly every aspect of social, economic and cultural life. Concomitantly, these complexities define how management agencies engage with Traditional Owners in the management of the natural estate of the region. Any future cross-jurisdictional management initiatives involving the Torres Strait will need to engage with and understand these complexities.

There are also examples where the differing jurisdictions have not adopted a common system for representing management arrangements across adjacent areas, complicating interpretation of the rules and regulations and increasing risks of inadvertent non-compliance among stakeholders. For example, the colours used for zone types differ in the Coral Sea and in the adjoining waters of the GBR Marine Park. This is unnecessarily confusing, especially because the users of the two areas are mostly the same, and also perplexing, given the two responsible Federal agencies are within the same portfolio and report to the same Minister. There are also some management requirements that do not fall clearly within one jurisdictional area or the other (e.g. Indigenous 'sea country' sometimes crosses over the jurisdictional boundaries).

1.2.1 Jurisdictional Boundaries

Virtually all of the jurisdictional boundaries are literally 'lines on a map' that have little, if any, relationship to the ecological boundaries and connectivity that occurs on and in the water. Their location and definition often dissect ecological habitats, and management is fraught with challenges, as illustrated by the following examples:

- The approximately 550 coral reefs in the Torres Strait are part of the same reef system that comprises the GBR, yet the boundary was chosen as an east-west line from the tip of Cape York.
- The boundary between the eastern GBR and the Coral Sea cuts across deep-sea habitats in those waters, and many of the ocean currents that are critical for GBR connectivity originate in the Coral Sea.
- The Australian and Queensland Governments each have differing definitions of LWM, so the boundary between state and federal waters on the landward side of the GBR is not clear (this is not a problem, however, as both jurisdictions apply complementary management either side of the jurisdictional boundary). Furthermore, the position of the LWM constantly moves because of erosion and accretion, so mapping it is impractical. This issue has been exacerbated because there are no clear or agreed principles for defining the internal waters of Queensland (i.e. which parts of bays, channels, river mouths or estuaries are internal waters). Also, LWM is often covered by water making it unworkable as a boundary from an enforcement perspective.

- International transboundary pollution, e.g. plastics, litter, sediment is not considered in the legislation. While both the *GBRMP Act* and the *EPBC Act* allow for the management of pollution originating from outside the boundaries of the GBRWHA, this is restricted to sources within Australian jurisdiction. This therefore allows for the management of pollution from rivers in Queensland, but not pollution from the Fly River in PNG.

1.3 Defining connectivity

Connectivity between physically isolated habitats can be strong, often spanning large distances, because many marine organisms have a pelagic life stage. Therefore, despite the predominantly sessile nature of foundational habitat species, e.g. reef-building corals or seagrass plants, there is a need to consider the potential for connectivity across jurisdictions when designing or implementing management measures for these values.

For example, connectivity between separate coral reefs or reef patches varies in strength and direction, and the importance of connectivity for any one reef or reef patch will differ among species. In general, however, connectivity can be considered at two scales. Demographic connectivity generally occurs on scales of kilometres, up to tens of kilometres. Evolutionary connectivity, in contrast, can span hundreds or even thousands of kilometres (Sale et al. 2010).

What is connectivity?

Connectivity, or connecting processes, are ecological and biophysical processes that “link two or more realms and allow for the movement of species (i.e. biological connectivity) and the associated or independent transfer of energy and matter (i.e. geo-physical connectivity). Biological connectivity is mainly concerned with the movement of individuals between habitats diurnally, seasonally, or during their life cycle for feeding or reproduction. Geo-physical connectivity occurs as a result of gravity, meteorological phenomena, and the water cycle. Despite this distinction, biological and geo-physical processes are not necessarily independent.”

Beger et al. (2010)

Types of connectivity

1) Evolutionary (genetic) connectivity: the amount of gene flow occurring among populations over a timescale of several generations. It determines the extent of genetic differences among populations.

2) Demographic (ecological) connectivity: an exchange of individuals among local populations that can influence population demographics and dynamics. It can include:

- Exchange of offspring between populations through larval dispersal;
- Recruitment of juveniles and survival of these juveniles to reproductive age;
- Any large-scale movement of juveniles and adults between locations.

Sale et al. (2010)

Both evolutionary and demographic connectivity are relevant when considering the need for cross-jurisdictional management, and it is important to match the appropriate population paradigm with the management or conservation objectives (NOAA 2008). Maintaining genetic connections is important in long-term conservation planning, but demographic connectivity is important for informing day-to-day management. Therefore, demography is relevant to short-medium term management targets and evolutionary connectivity patterns are relevant to longer-term objectives (and require ongoing monitoring). Thus, the type of connectivity that is relevant to management depends on the management objectives and how the population unit is defined. For example, two demographically independent populations can be genetically similar, since it only takes a few individuals to create genetic exchange. If management objectives and the definition of population units differ between adjacent jurisdictions, agencies are likely to adopt a different management approach. It is therefore important that management is consistent in terms of how connectivity is considered in the objectives and approaches, and ideally these should be based on demographically independent populations (Wallace et al. 2010).

From a management perspective, the role and definition of connectivity also depends on what value is being considered. For highly mobile species, how a stock is treated under different legislation – the stock concept – can influence management effectiveness. For corals and other species where connectivity depends on currents for movement of a life stage, this can be highly directional, and can lead to the situation where a reef can be predominantly a source reef or a sink reef. The need to manage for connectivity across borders is likely to be most acute when reefs close to jurisdictional borders are strongly dependent on source reefs that are upstream in an adjacent jurisdiction.

In the context of the marine area of northeast Australia, there is strong commonality in the species composition of the reef-building communities, indicating strong evolutionary and demographic connectivity across all four marine areas. Demographic connectivity is likely to be important across all of the area interfaces, supporting the argument for strong cooperation in the management of coral reefs, especially for reefs close (kilometres to tens of kilometres) to shared boundaries. The specific location of source and sink reefs that are connected across jurisdictional boundaries could be estimated through larval connectivity modelling using information on the larval duration and behaviour of representative reef-building species

and fine-scale oceanographic models. Such information would be useful for understanding the connectivity of populations to inform marine spatial management and planning (e.g. Treml and Halpern 2012).

1.4 Social and economic drivers of how values are connected

Social and economic drivers can connect marine values across jurisdictional boundaries through the networks that exist between people within and across boundaries, and the extent to which ecological values are shared. Typical economic drivers include market drivers such as the price of marine products, demand for product and demographic factors such as the rate of population increase and education. Typical social drivers include the perceptions, attitudes, beliefs and judgements that people make about the marine resource that reflect the extent to which the marine resource is valued – either for its products or its services. What people value is a strong predictor of behaviour and decision-making. Social values – or what is important to people – can therefore act as important drivers of change. We also know that social values are generally stable over time, and knowledge of social values can underpin effective engagement processes as part of planning and management (Curtis et al. 2014).

The extent to which ecological values are shared across boundaries provides insight into the strength of social drivers for marine conservation or use. For example, if communities on either side of a boundary similarly value turtles for their intrinsic qualities, then turtles act to connect the two communities, and the social drivers for turtle conservation become strong as they flow across jurisdictional boundaries. Problems arise, however, when communities differ in how they value ecological assets. One community may value the turtle for its intrinsic qualities, whilst another community may also value turtles for hunting and eating. In these instances, whilst there may still be considerable overlap in the intrinsic and cultural values of turtle, some of the social drivers are different and in conflict, where the hunting and eating of turtle in one jurisdiction can perceptibly impact on the benefits that turtles provide in the other jurisdiction. The social drivers for turtle conservation and turtle use thus becomes entangled and polarised across jurisdictional boundaries. Where values cross jurisdictional boundaries and are not aligned across boundaries, effective management of values requires additional investment in negotiations and cross-jurisdictional agreements, underpinned by clear visions and strong leadership.

Social and economic drivers can also be in conflict within a region and at any scale. People in the GBR region are known to value the marine resource predominately for its aesthetic qualities and for its biodiversity (SELTMP 2014). These attitudes act as strong drivers of decision-making within the region, even though they can conflict with economic drivers. While economic drivers can dominate some decision-making processes, in general they are not as strong as social drivers, even among commercial fishers and tourism operators (which are both financially dependent on the GBR). Stakeholders from both of these groups consistently rate aesthetic and biodiversity values more highly than economic values (Marshall et al. 2016). In these instances, the social and economic drivers can be in conflict within individuals, households, communities and regions. For example, coastal residents may treasure the aesthetic experience of snorkelling in clear blue water and appreciate the ecological diversity provided by coral reefs, however they may also treasure the economic benefits of working in a land-based occupation such as agriculture, which directly impacts on

water clarity and ecological diversity. Similarly, one member of a household may hold strong conservation values, whilst another member may be particularly attached to their income from farming. When social drivers are similar across scales, then decision-making at each scale is relatively easy. Problems arise when social and economic drivers are non-compatible and this can occur at any scale. Negotiations, local agreements and strong vision and leadership become important when managing incompatibility between social and economic drivers.

The social and economic drivers – or importance of values – within each of the four regions of this study are documented to varying degrees. There are some data describing the social drivers within the Coral Sea, Torres Strait and Great Sandy Strait. Most data, however, describe the social and economic drivers within the Great Barrier Reef through information collected in the Social and Economic Long Term Monitoring Program (SELTMP). Drivers are described as the importance that people place on each of the following social values associated with the Great Barrier Reef: identity, pride, place attachment, aesthetic appeal, biodiversity appreciation, lifestyle appreciation, seafood, heritage and agency. These social values were important to local residents, Australians, tourists, commercial fishers and tourism operators. On average, Australians rated the role of the Reef in their identity even more highly than local residents to the region. Domestic tourists, local residents, indigenous residents and tourism operators highly rated their agreement with the SELTMP statement, “I feel proud that the GBR is a World Heritage Area”. Indigenous residents, commercial fishers and tourism operators stated that they would be particularly affected if the condition of the Reef declined. People particularly appreciated the aesthetic qualities of the Reef, its heritage opportunities, lifestyle and biodiversity (Marshall et al. 2016). Indigenous residents and local residents also particularly valued the seafood provided by the Reef. SELTMP data showed that 41% of local residents, 76% of tourism operators and 65% of fishers lived in the region because of the Reef. Together, these data provide an overview or indication of the strength of the social drivers within the region. Until similar work is conducted within each of the other three regions in this study, the extent to which social and economic drivers are compatible across the four jurisdictions remains unclear.

1.5 Objectives

This project aims to provide accessible and relevant information on ecosystem values and their connectivity between jurisdictions. The information gathered and synthesized will support informed decision-making and management for the northeast Australia seascape and will broadly support steps towards holistic “seascape” management.

This project has four main objectives:

1. Synthesise existing information on values and their connectivity for all jurisdictions in the broader northeast Australian seascape (GBR, Torres Strait, Coral Sea, Great Sandy Strait), including established values already described for particular areas, e.g. Coral Sea and Ramsar wetlands.
2. Synthesise existing information about the physical drivers of the inter-connections, between and across the regions.

3. Define the known spatial scale of key influencing processes, impacts and connectivity between and within the jurisdictions of the broader northeast Australian marine region.
4. Provide recommendations to relevant managers that guide future management cooperation across jurisdictional boundaries, where necessary.

2.0 METHODS

2.1 Characterising key values in the northeast Australia marine area

There are many approaches to characterising ecosystem values, including through the lens of goods and services (e.g. biodiversity, productivity), economic revenue (e.g. income from fishing and tourism) and socio-cultural benefits (e.g. spiritual fulfilment, aesthetic enjoyment). While it is important that characterising ecosystem values reflects the held values of communities and stakeholders, the most useful information is that required by managers and planners to maintain ecological, social and cultural values across different scales.

Values can be *held*, *relational* or *assigned*, and each can be associated with an individual or shared amongst a group or community (Gorrdard et al. 2017). The Oxford Dictionary defines value as “...the importance, worth, or usefulness of something or one’s judgement of what is important in life.” While ecological value is defined as “the worth attributed to an organism, ecosystem, product, resource or activity, in terms of benefits to the environment.” For this project, standard definitions were applied with the project objectives in mind. **Values** fall into four broad categories: Natural Heritage, Indigenous Heritage, Social & Historic Heritage, and Economic. These values have ‘**components**’ that are *a feature of the system that is of significance for ecological function and/or society and people*. Each component is made up of ‘**attributes**’ that are features that can be mapped and managed (Figure 3). For example, coral reefs are a component of Natural Heritage and include four attributes: hard corals, crustose coralline algae, *Acropora* larvae and macroalgae. We used this concept to develop a *values characterisation framework* for identifying the key attributes of values that are important for managers across the four marine domains.

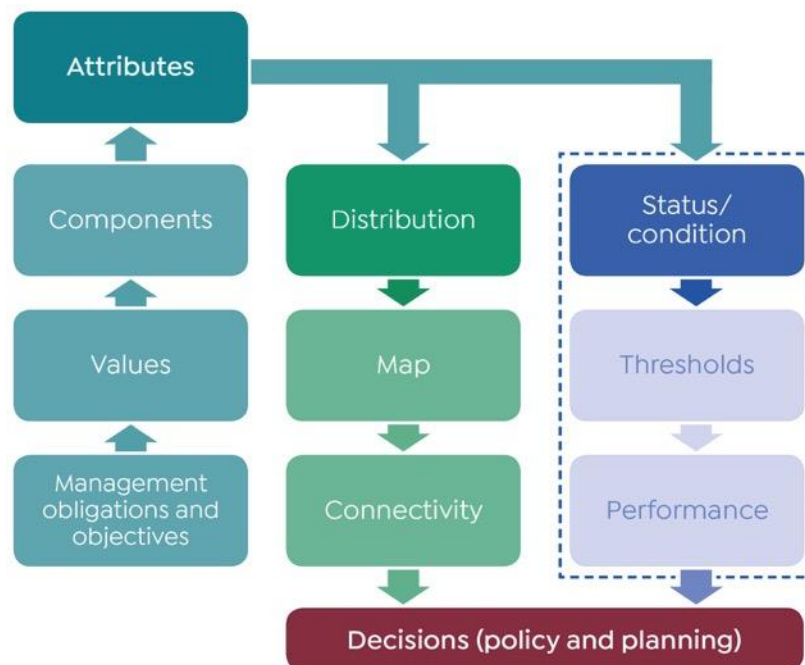


Figure 3: Conceptual framework outlining the hierarchy of values and attributes, and how characterising and mapping values and connectivity will inform decision-making. Purple boxes represent additional key considerations for management decision-making that were outside the scope of this report.

2.1.1 Identification of key values

To identify the key attributes for all four of the value categories among the respective jurisdictions, we first carried out a desktop synthesis that examined relevant literature (see *NESP Project 3.3.3 Supplementary Synthesis Report: Part 2*). From this we were able to provide a substantive list of key attributes for analysis. However, a key part of the project was for comprehensive stakeholder inclusion in the process of further identifying the key attributes and their characteristics. Therefore, we also conducted a participatory workshop approach that included a range of stakeholders, including managers from a range of relevant agencies, scientists, marine park rangers, and Traditional Owners. Participants were introduced to the values characterisation framework and asked to comment and contribute to the identification of key attributes, the characterisation of their connectivity across adjacent jurisdictions, threats to the values and attributes, and the prioritisation of particular attributes for management action.

2.1.2 Characterising connectivity

Connectivity can vary in strength and directionality. Together, these characteristics describe the relative importance of a jurisdiction in the maintenance (or erosion) of a value/attribute in another jurisdiction through their connectivity. Understanding strength and directionality helps managers to identify and prioritise the importance of another jurisdiction in achieving management goals of a value. It also helps managers identify when their management of a value is likely to affect another jurisdiction. Workshop participants were asked to describe the connectivity of attributes across jurisdictions and to characterise that connectivity in terms of the main driver of movement. A simple system was used of arrows to indicate direction and strength of connectivity, each with a descriptive title. Through this simple characterisation we were able to represent five general connectivity vectors (Figure 4).

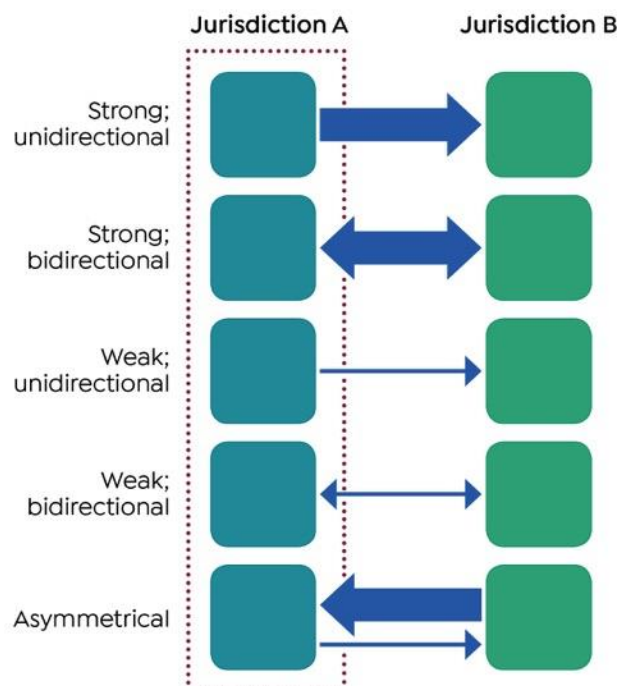


Figure 4: Strength and directionality of connections between jurisdictions.

Green turtles are an example of an attribute that has asymmetrical connectivity between jurisdictions. Individuals from the northern GBR population commonly move between, and through, the GBR and Torres Strait in the course of their lives (strong connectivity). They move in both directions, creating a distinctly bi-directional connectivity across the two jurisdictions. However, the strength and type of connectivity is different in each direction. From the GBR to Torres Strait the connectivity is heavily dependent on maintenance of reproductive output from GBR nesting beaches, while from Torres Strait to the GBR it is mostly associated with movement of adults. This bi-directional connectivity creates a strong case for cross-jurisdictional management of the northern population of green turtles, while the asymmetrical nature suggests different management strategies (or priorities) in each jurisdiction may be appropriate.

The strength and directionality of connections can also vary across space and time. Connections can be homogenous, patchy, ephemeral or fluctuating, or chaotic (Figure 5). Understanding variability in space and time can help managers in adjoining jurisdictions to identify whether connections are more important along some parts of a shared boundary than others, and whether cross-jurisdictional management is a constant requirement, or might be seasonal or triggered by particular events.

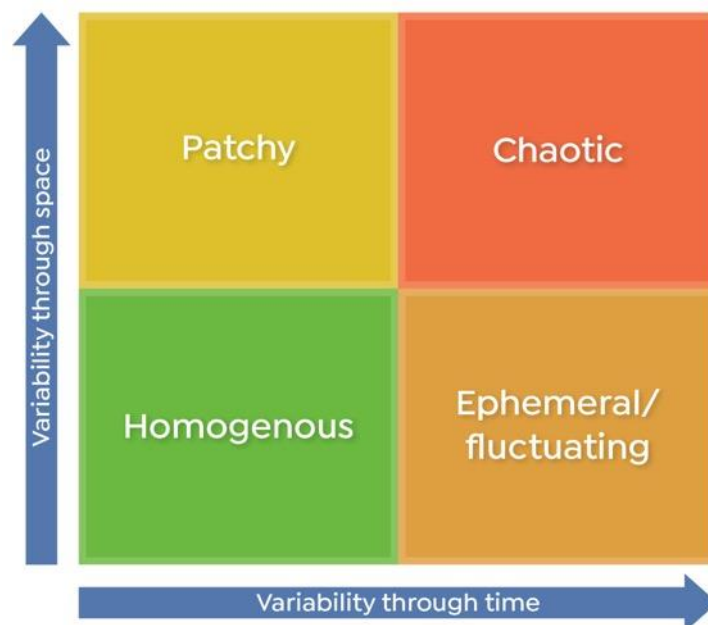


Figure 5: Categories of connectivity based on variability in space and time.

The northern GBR population of green turtles can also be used to illustrate the importance of connectivity variability. The most important processes for the maintenance of this attribute are reproduction and survival of adults. In the northern GBR, reproductive output is heavily concentrated at Raine Island and Moulter Cay (patchy) during the breeding season (ephemeral). An objective to protect the contribution of GBR green turtles to the maintenance of turtle populations in the Torres Strait, as well as the northern GBR, could be achieved by focusing management effort to protecting breeding turtles and improve hatchling production at Raine Island and Moulter Cay.

2.2 Oceanography and physical models

The following sections details the sources of modelled and observational data used in this review of oceanography and the physical drivers of connectivity.

2.2.1 Remotely sensed and in situ observations

OceanCurrent (<http://oceancurrent.imos.org.au/>) is an Integrated Marine Observing System (IMOS) product that fuses observational data from a variety of sources onto a daily map. This product is useful in that it is readily comparable to any model data for verification and validation purposes. The data utilised are comprised of Advanced Very High Resolution Radiometer (AVHRR) satellite SST data, gridded observations of sea surface height from multiple satellite missions along with tide gauges to make maps of sea surface height anomaly and the geostrophic surface current velocity derived from them, current meters that are deployed and operated by the IMOS Australian National Moorings Network (ANMN), temperature and salinity from Argo profilers and gliders, and surface currents from the drifting buoy programme.

The data used for the marine heatwave analysis are from the National Oceanic and Atmospheric Administration's Optimum Interpolation Sea Surface Temperature version 2, which is the AVHRR satellite data (NOAA OISST V2; Reynolds et al. 2007). The SST data are daily with 0.25° horizontal resolution, and we use data from 1 September 1981 to 31 December 2016.

2.2.2 Regional hydrodynamic models

The two main hydrodynamic models developed for shelf-scale modelling of northeastern Australian waters are the eReefs and SLIM models. The marine modelling component of eReefs was tasked to deliver numerical models capable of simulating and predicting the physical hydrodynamic state, sediment transport, water quality and basal ecology of the Great Barrier Reef lagoon and reef matrix. Together, these models represent a capability to simulate the transport and fate of waterborne material, of either oceanic or terrestrial origin, and its impact on Reef water quality.

The eReefs models (<http://ereefs.org.au>) include hydrodynamic, sediment, wave and biogeochemistry models for the Great Barrier Reef ecosystem. An issue with the GBR model is that it only models half the Torres Strait, limiting its utility in that region. However, the model covers the Coral Sea and the Great Sandy Strait regions adequately. The model has been applied to the Torres Strait for an earlier study by Saint-Cast and Condie (2006). The hydrodynamic eReefs model is based on the Sparse Hydrodynamic Ocean Code (SHOC; Herzfeld 2006) with 1 km (GRB1) and 4 km (GBR4) horizontal resolution. The GBR1 grid has a size of 510 x 2390 and 48 vertical layers. The GBR4 grid has a size of 220 x 500 with 44 vertical layers. The model uses a curvilinear orthogonal grid in the horizontal and a choice of fixed 'z' coordinates or terrain-following σ coordinates in the vertical. The 'z' vertical system allows for wetting and drying of surface cells, which is useful for modelling regions such as tidal flats where large areas are periodically dry.

The depth-averaged version of Second-generation Louvain-la-Neuve Ice-ocean Model (SLIM) hydrodynamic model (www.climate.be/slim) has been applied in the GBR and Torres

Strait (Lambrechts et al. 2008, Wolanski et al. 2013). The Coral Sea and Great Sandy Strait are not in the domain of the model. SLIM uses the finite element method and solves two-dimensional primitive equations on an unstructured mesh. Using an unstructured mesh allows the spatial resolution to be made locally higher in shallow areas and near coastlines, where small-scale flow features are important, and lower resolution in areas where flow varies over greater length scales. This approach allows the model to resolve a wide range of scales of motion, from regional flows to eddies behind reefs and islands, and tidal jets that develop between reefs and islands (Wolanski 2016).

2.2.3 Climate modelling hindcast and forecast

The climate scenario downscaling experiments were run with the near global, 1/10 degree resolution Ocean Forecasting Australia Model version 3 (OFAM3) (Oke et al. 2013) from 1979 to 2100. An eddy-resolving ocean hindcast has been carried out over a 36 year time period from 1979-2014. The model was forced by atmospheric conditions from the Japanese 55-year Reanalysis (JRA-55) (Kobayashi et al. 2015). The air-sea fluxes that force the model were derived from the bulk formula. For detailed information about the hindcast runs, the reader is referred to Zhang et al. (2016). The future projections (2006-2100) were forced with multi-model-mean climate change signals from 17 CMIP5 models under the greenhouse gas concentration trajectory of Representative Concentration Pathway 8.5, which assumes greenhouse gas emissions continue to rise throughout the 21st century (Zhang et al. 2016, Zhang et al. 2017).

3.0 RESULTS

3.1 Physical drivers of connectivity

Ocean currents are known to be the major mechanism by which the values across the entire northeast Australian seascape are both defined and connected. For example, ocean currents facilitate dispersal of larvae and particles and propagate climate features (e.g. marine heatwaves that can cause bleaching). While a range of research outputs have described elements of physical connectivity in parts of the region (e.g. Steinberg 2007, Weeks et al. 2010, Wolanski et al. 2013, Herzfeld 2006, Ganachaud et al. 2014, Sun et al. 2015, Wolanski 2016), there has not been a holistic review and compilation of this existing knowledge to inform the nature of the connections that link the ecological and other values across management boundaries.

In 2007, the GBRMPA initiated a comprehensive assessment of the vulnerability of the GBR to climate change (Johnson and Marshall 2007) and included a range of ecological and social systems expected to be affected by projected climate change. This publication coincided with the implementation of the Integrated Marine Observing System (IMOS) that sought to improve the monitoring network with the GBR as the primary focus, and later an expansion into southeast Queensland to monitor the East Australian Current (EAC) and shelf waters off North Stradbroke Island. Unfortunately, there remain significant gaps in the observing network and some of the northeast marine seascape remains on the periphery, though there have been some weather, oceanographic and reef observations in the Torres Strait supported by TSRA, the Queensland Government, AMSA, and other Australian Government research programs (e.g. MTSRF, NERP).

Ten years on, a wealth of information has been collected and published. This information presents decadal oceanic and GBR variability, moving beyond the reliance on shorter term process based studies and the calibration and validation of a number of hydrodynamic models. Significant progress has been made with the continued development of the Bluelink model (Brassington et al. 2007) from regional to near global scale, with improved near surface resolution (Zhang et al. 2016) and operationalised by BoM as OceanMAPS. The three-dimensional eReefs model builds on the Bluelink effort to bring the model spatial resolution from 10 km to 4 km and 1 km, with far more vertical resolution allowing tides and baroclinic processes to be analysed. A parallel model has also been implemented and operationalised for research by BoM.

The two-dimensional SLIM model has also been used extensively to investigate reef processes, including reef circulation and connectivity issues along the GBR and Torres Strait, at even finer spatial scales (e.g. Thomas et al. 2014, Critchell et al. 2015, Delandmeter et al. 2017, Wolanski et al. 2017).

This project draws on the results of these models, *in situ* observations and remotely sensed satellite data analyses recently published. Discussions begin at the larger Coral Sea scale that is of relevance to the Coral Sea and then focus on adjacent regions – the GBR to the west (divided into northern, central and southern), the Torres Strait in the north and Great Sandy Strait in the south.

3.1.1 Circulation

Ocean topography is a major determinant on where and how water can circulate and mix; this makes it a component of any circulation modelling study. Beaman (2010) has produced a high-resolution interpolated product from all the available data for the regions of interest.

Coral Sea

In the Coral Sea, there has been a focus on understanding current variability and the significant role of eddies that can be embedded in the major inflows, and on occasion significantly change ocean circulation. The broad westward flowing Southern Equatorial Current (SEC), which is the northern arm of the South Pacific Gyre, is forced through the many island archipelagos and coral reef complexes on the way toward the GBR. The current splits into jets to the north and south of these topographic barriers, effectively creating multiple pathways flowing toward the west. As they approach the Queensland continental shelf, they are deflected to the north or south to contribute to the Gulf of Papua Current or East Australian Current, respectively (Figure 6).

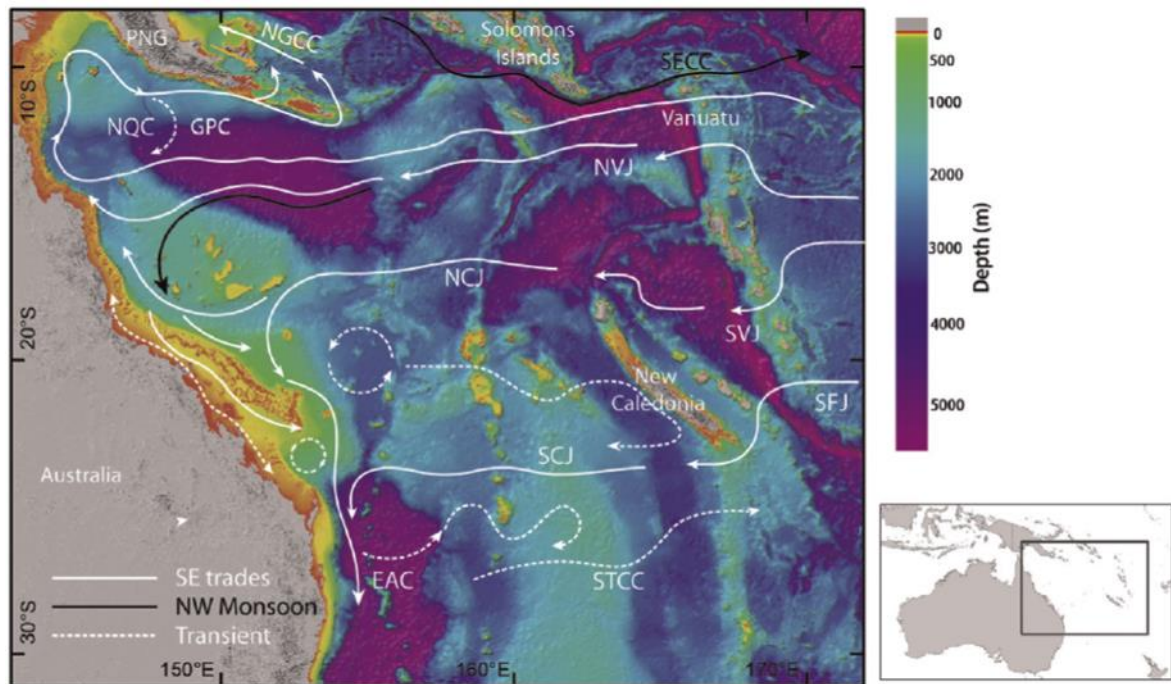


Figure 6: Bathymetry and currents in the northeast Australian region. NGCC: New Guinea Coastal Current, mirroring the deeper New Guinea Coastal Undercurrent; NQC: North Queensland Current, that is part of the Gulf of Papua Current (GPC); SECC (black line): South Equatorial Counter current; Jets of South Equatorial Current (SEC): NVJ: North Vanuatu Jet; NCJ: North Caledonia Jet; SVJ: South Vanuatu Jet; SFJ: South Fiji Jet; SCJ: South Caledonia Jet. EAC: East Australian Current; STCC: Subtropical Counter current; A wind-driven coastal current runs parallel to the coast along the inner shelf (bathymetry data: deep.reef.org, Beaman (2010), figure adapted from Schiller et al. 2015, Steinberg 2007).

Recent studies by Hristova et al. (2014) have also investigated the eddy fields in the region. Eddies can be cyclonic or anti-cyclonic and are generated by flow instabilities (Figure 7).

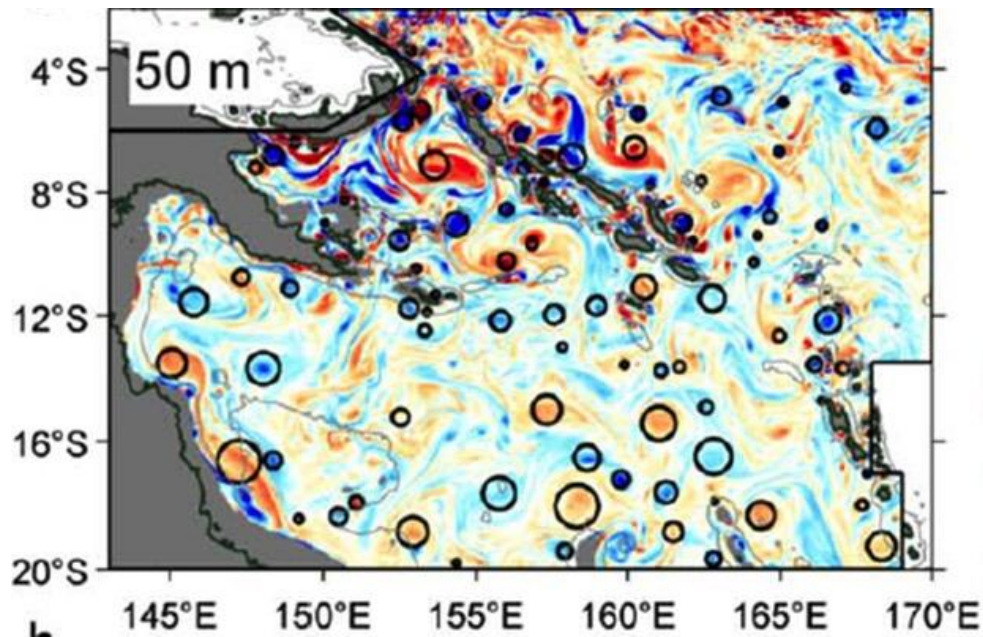


Figure 7: Modelled eddy vorticity (red is anti-cyclonic vorticity, blue is cyclonic vorticity) (Adapted from Figure 9a in Hristova et al. 2014).

This is further evidence that whilst the classic view of the SEC is seen as a series of eastward flowing braided jets, formed as they manoeuvre past the various island archipelagos, they in fact have significant eddies embedded in their flow that can cause significant meanderings of the jets themselves, and even reversals can occur in the form of countercurrents. Rousselet et al. (2016) tracked an anti-cyclonic eddy from *in situ* and satellite observations over 3 months, moving southwest away from the North Vanuatu Jet and into the North Caledonia Jet. This complexity in the flow means that connectivity pathways can vary significantly over a range of timescales.

Circulation in the northern Coral Sea is dominated by the clockwise Gulf of Papua Current that forms from a bifurcation of the North Vanuatu Jet off Lizard Island. As the current approaches Papua New Guinea, it diverges eastward and passes through the Louisiade Archipelago. A closed gyre can exist in the Gulf of Papua, forming a closed loop for any propagules to recirculate in this area. During summer, the strength of this circulation is reduced and can even reverse as anti-clockwise eddies form in the Gulf of Papua (Figure 8). The implications of this are significant, as the poleward boundary current near the shelf break allows the thermocline to lift and so upwelling of cool, nutrient rich waters are more readily available to occur on the shelf of the eastern Torres Strait.

Torres Strait

The net flow through the Torres Strait is deemed to be highly seasonal. It is primarily driven by sea level gradients, which are caused by the build-up of waters in the northern Coral Sea by the southeast trade winds from April to November, and the northwest monsoon in the Gulf of Carpentaria from December to March. Wolanski et al. (2017) hypothesised that during the 2015/16 summer a significant amount of hot water from the Gulf moved through the Torres Strait, further exacerbating the coral bleaching event in 2016.

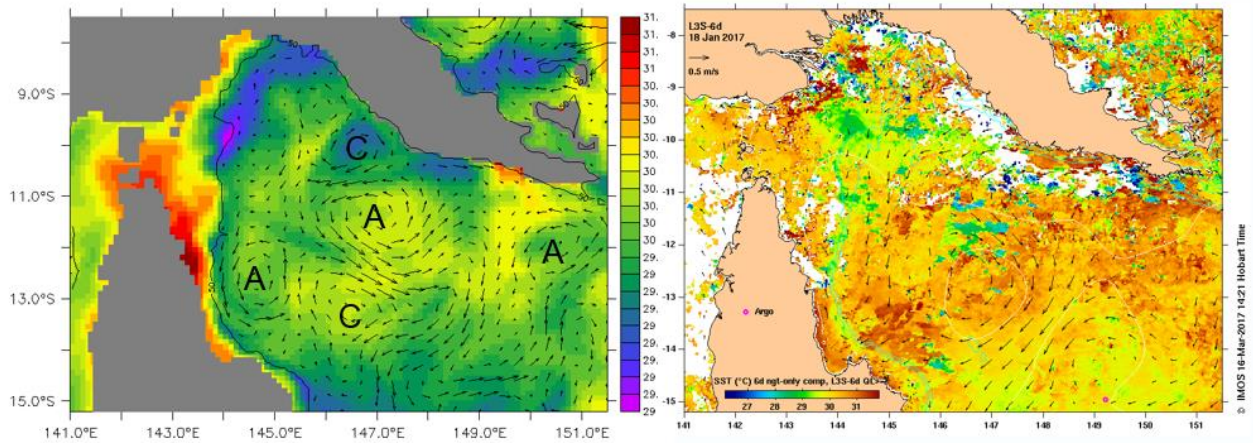


Figure 8: Snapshot of OFAM3 model (left) and OceanCurrent satellite product (right) of the Gulf of Papua and Torres Strait regions on 18 January 2017. Label A indicates anti-cyclonic rotation and C indicates cyclonic rotation.

Great Sandy Strait

This region is dominated by the poleward flow of the East Australian Current that is nearly at full strength as a western boundary current after the confluence of the jets in the Coral Sea and the traversing of the Marion Plateau. Upstream of Fraser Island, the Capricorn Eddy can form, enhancing the northwest flow from the southeast trade winds on the outer shelf of the Capricorn Bunker Group of reefs at the southern end of the GBR (Weeks et al. 2010). This can allow a northward coastal boundary current to form, facilitating south to north connectivity. South of Waddy Point, an eddy can form in the lee of Fraser Island inshore of the EAC, causing significant upwelling and resulting in a phytoplankton bloom (Brieva et al. 2015; see Figure 9).

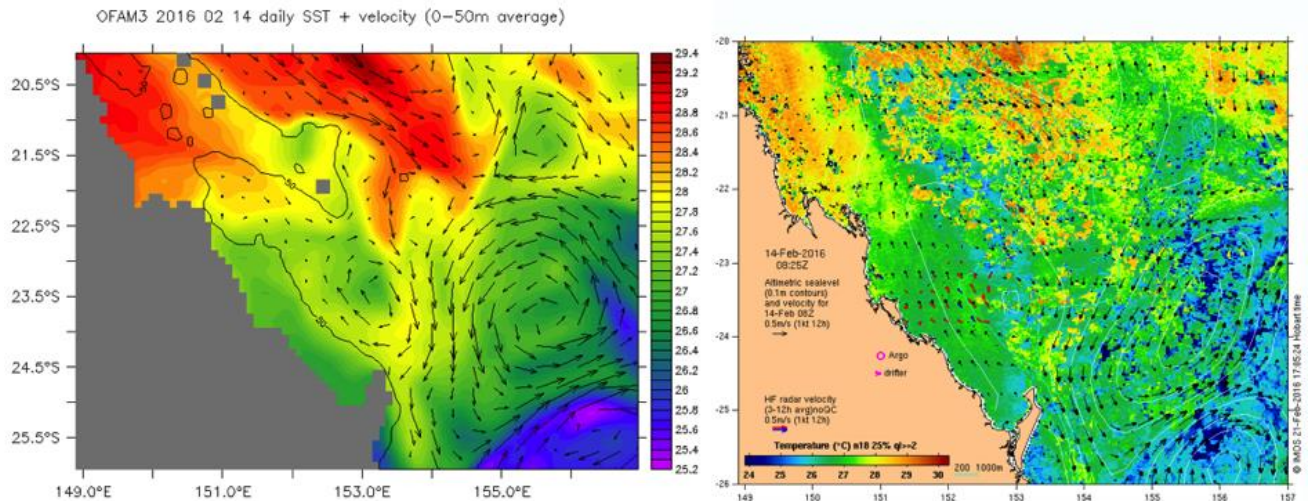


Figure 9: Snapshot of the OFAM3 model (left) and OceanCurrent satellite product (right) of the Great Sandy Strait and the Southern GBR on 14 February 2016.

3.1.2 Climate change scenarios

Sun et al. (2012) downscaled future climate scenarios to explore the potential effects on the major boundary currents around Australia. The results revealed an expected strengthening of the EAC off the Great Sandy Strait, but did not focus on the more northern regions. This report presents some preliminary results of a more recent downscaling model under a high emission climate scenario (Zhang et al. 2016). See Methods section 2.2.3 for more detail.

The 0-1000 m total transport from the downscaled current and future climate model scenarios for northeast Australia and the western Pacific region is shown in Figure 10. The net transport by the current is represented by the magnitude of depth-integrated velocity from the sea surface to 1000 m depth. The model results reveal a strengthening of combined net transport by the southward flowing EAC and northward flowing GPC (Figure 10).

The surface current field is consistent with the 0–1000 m currents with a strengthening of the Gulf of Papua gyre, however the EAC slightly weakens in the top 50 m (Figure 11).

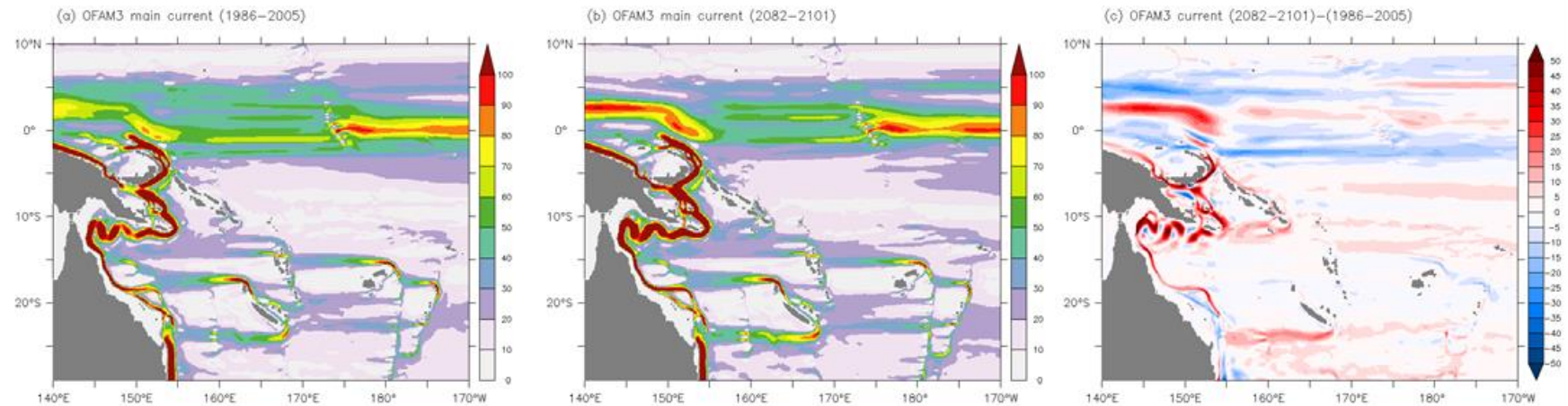


Figure 10: Current magnitude of the 0-1000m depth-integrated velocity from the OFAM3 model: (a) hindcast 1986-2005; (b) climate scenario 2082-2101; (c) the difference.

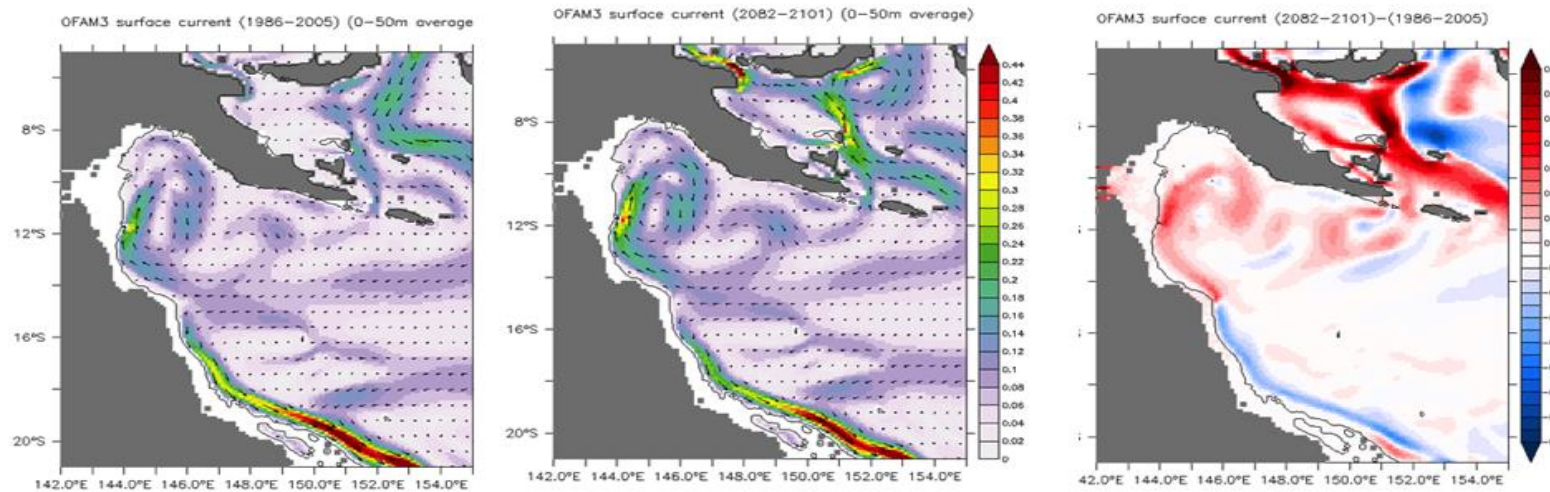


Figure 11: Current magnitude of the depth averaged 0-50m surface currents from the OFAM3 model: (left) hindcast 1986-2005; (middle) climate scenario 2082-2101; and (right) the difference.

The bifurcation latitude of the South Equatorial Current is predicted to follow the trend of the last 60 years and continues to move poleward (not shown). Below 200 m, the bifurcation latitude moves further south but becomes shallower, with the EAC undercurrent that feeds the northward flowing GPC shallowing and the southward flowing EAC shoaling. These changes have implications for the dispersal of larvae in key locations. Reefs in the vicinity of Lizard Island may have an increased role as a source reef to the north than is currently the case, and the closed circulation of the Gulf of Papua will enhance the transfer of larvae between PNG and the northern GBR and vice versa.

3.1.3 Marine heatwaves

Over the past two decades, the coastal waters off northeast Australia have experienced periods of anomalous warming coinciding with coral bleaching and mortality. Determining the frequency and spatial variability of warming events is important to understand and predict where extreme thermal stresses impact marine ecosystems. Areas adjacent to these regions may harbour marine life less affected by these thermal disturbances. For coral reefs, these less affected areas may serve as refugia (Hughes et al. 2017), offering a potential source of coral larvae and, through larval dispersal, providing a mechanism for coral recovery. Hence, there is a need to understand the spatial and temporal span of affected areas off northeast Australia. This section aims to identify the regional connections in extreme warming events, known as marine heatwaves, throughout northeast Australia.

We investigate the occurrence of marine heatwaves from the Torres Strait, GBR, Great Sandy Strait and Coral Sea. A marine heatwave (MHW) is defined as “a discrete prolonged anomalously warm water event” (Hobday et al. 2016). Following this definition, we use an algorithm¹ in which a MHW is identified when temperature exceeds a threshold for at least five days (with gaps of less than two days considered one event). The threshold and climatological mean are calculated for each calendar day using an 11-day window centred on that day, and the threshold is based on the 90th percentile climatology.

We apply this MHW definition to sea surface temperature (SST) from the NOAA OISST V2 (Reynolds et al. 2007). The SST data are daily with 0.25° horizontal resolution, and we use data from 1 September 1981 to 31 December 2016. The climatology base period is from 1 January 1982 to 31 December 2015. MHW metrics are calculated for the maximum intensity (greatest anomaly relative to the climatological mean) and the duration (number of days) of each event. Based on these metrics, we present results from the spatial variations in MHW metrics from major coral bleaching events (1998, 2002, and 2016) and temporal variations in MHW metrics for the main regions across northeast Australia.

For the major coral bleaching events of 1998, 2002, and 2016, thermal stresses had distinct spatial patterns throughout and extending beyond the GBR (e.g. Berkelmans et al. 2004, Hughes et al. 2017). During the austral summer of 1998, the maximum SSTs were confined mostly to near-coastal regions, with severe bleaching in the central and southern GBR (Berkelmans et al. 2004, Hughes et al. 2017). During the summer of 2002, the maximum SSTs were confined to the central GBR, with coral bleaching impacting both inshore and offshore reefs (Berkelmans et al. 2004). The summer of 2016 was profoundly different from these past two events, with maximum SST anomalies reaching from the Torres Strait (Wolanski et al. 2017) and northern GBR into the central GBR (Hughes et al. 2017,

Benthuisen et al. 2018). There was also a bleaching event in 2017, however, the pattern of that event was different again, with the central section of the GBR between Lizard Island and Townsville most affected.

Based on the MHW metrics, we re-examine these events based on 1 July – 30 June for each period 1997-98, 2001-02, 2015-16. The most intense MHW at each location across all regions generally exceeded +1.5 to +2°C during these years (Figure 12a,b,c). The most intense MHWs were concentrated in the southern GBR and parts of the Coral Sea in 1997-98 and included the Central GBR in 2001-02. In contrast, in 2015-16, the most intense MHWs were concentrated in the Torres Strait, northern GBR, and western side of the Coral Sea. The total duration, or number of days, in which temperatures exceeded the 90th percentile threshold reflected similar patterns to the maximum intensity (Figure 12d,e,f). The regions with the most days experiencing a MHW tended to also have the most intense MHWs. Notably, for 2015-16, the extensive total duration in the northern and central GBR occurred after the peak in summer temperatures and was due to prolonged MHWs in the austral autumn and winter.

To determine the temporal and spatial variations in MHWs, we averaged the SST over each bounded region shown in Figure 13. The most intense MHW experienced in each region varies spatially, potentially due to ocean dynamics. For example, the Coral Sea region encompasses a much broader area, and ocean processes may feed back and limit the amplitude of fluctuations that are experienced in the shallower regions, such as in the Torres Strait (Figure 13a). In terms of total duration, in the past two decades there have been years with pronounced peaks in total duration compared with the 1980s and early 1990s (Figure 13b), meaning that marine heatwaves are lasting longer. Importantly, there is not a single region that consistently shows the most intense MHW or highest total duration. Instead, different regions are affected in any given year.

To examine the regional connections in MHW occurrences, we apply linear regression to the annual time series for the most intense MHW and total duration. The coefficient of determination, R^2 , measures the fraction of variation in a region's MHW metrics with respect to the metrics in the neighbouring regions. For both maximum intensity and total duration, the greatest R^2 values tend to occur with the immediate neighbouring regions along northeast Australia and decline with increasing distance. For the most intense MHWs, the greatest connections occur between the central and northern GBR, while the Coral Sea's maximum intensity has the weakest relationship with variations in other region's maximum intensity. For the total duration of MHWs in each region, the R^2 values are overall much greater, with the strongest connections between the northern GBR and the Torres Strait and the Coral Sea. The weakest connections are between the Great Sandy Strait and the Torres Strait and northern GBR, owing to the distance separating them. Hence, off northeast Australia, regional connections occur in MHWs that emerge during each year, especially in the duration of the events, providing an indication of the spatial footprint of events. Further examination of MHW occurrences and changes in other ecological values will improve our understanding of those linkages during periods of anomalous warming.

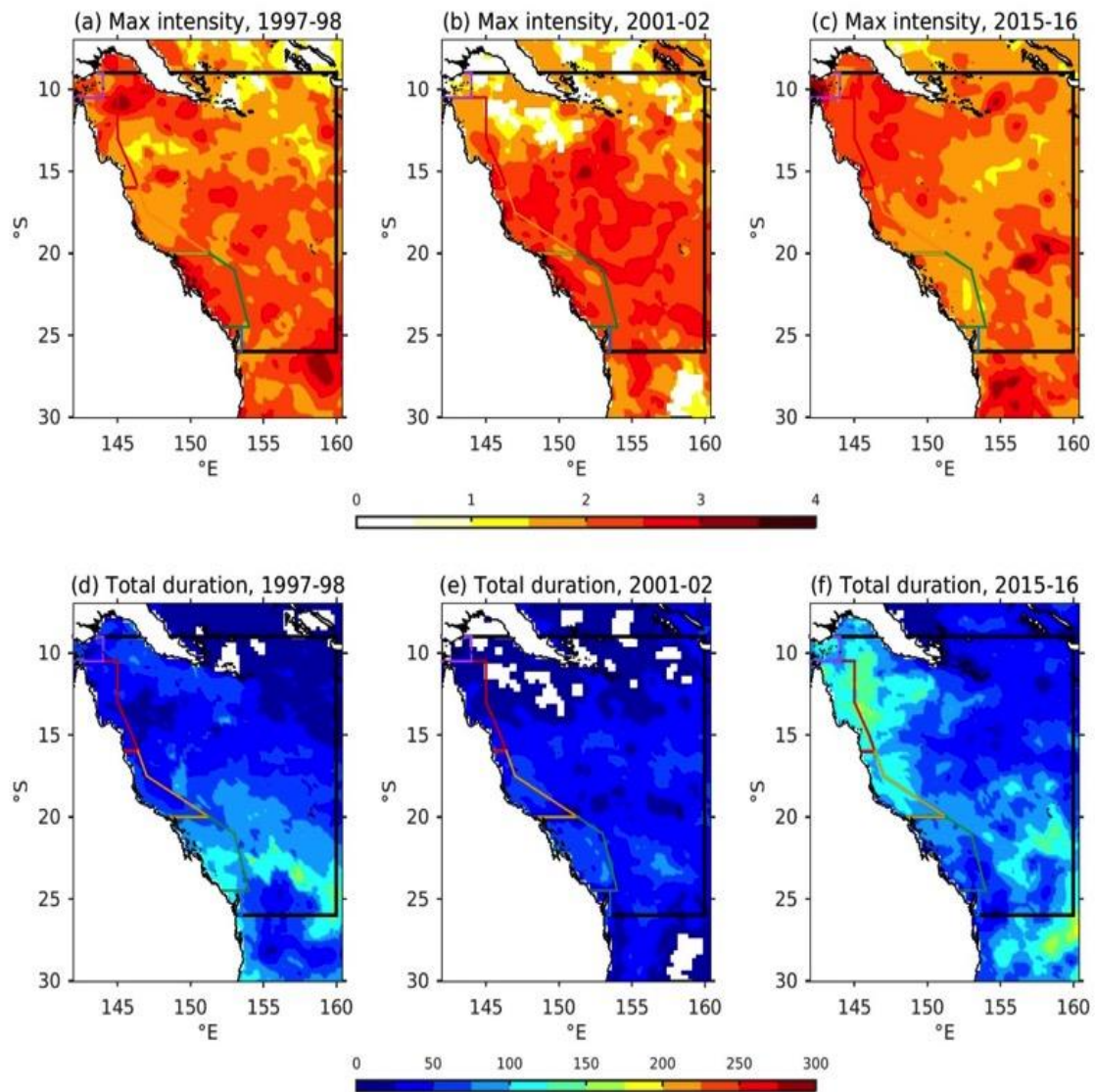


Figure 12: (a-c) The maximum intensity (°C) from all MHWs from 1 July – 30 Jun each year. (d-f) The total duration (days) of all MHW occurrences. The lines indicate the boundaries used to define the different domains: Torres Strait (purple), Northern GBR (red), Central GBR (orange), Southern GBR (green), Great Sandy Strait (Hervey Bay) and adjacent surroundings (blue), and the Coral Sea offshore of the coastal regions (black). Marine waters that are shaded white indicate no MHW detected during that time period.

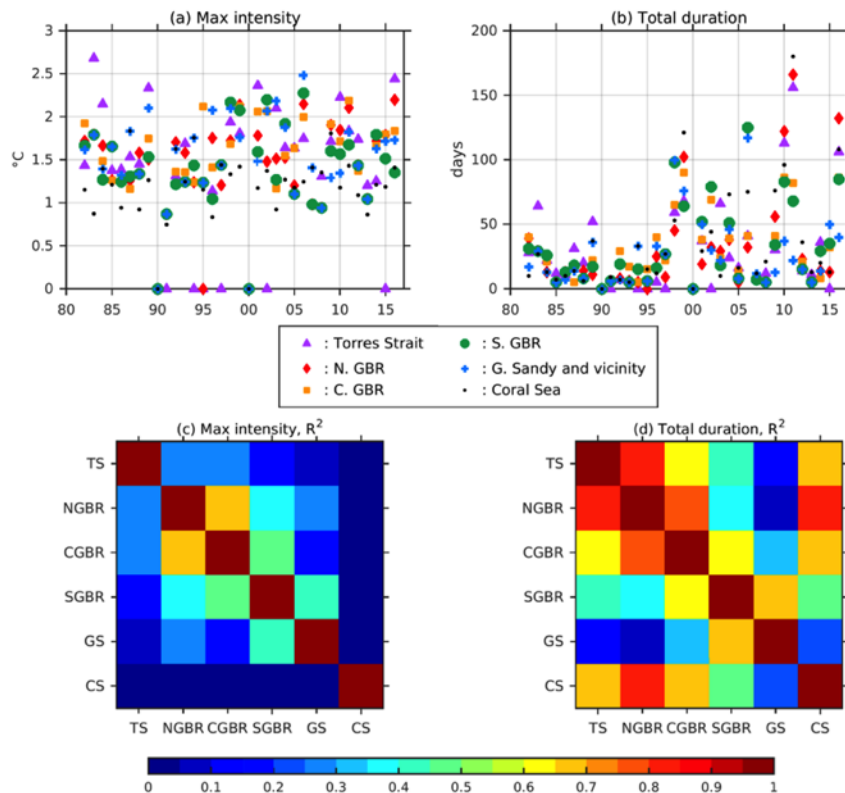


Figure 13: (a) For each domain, the most intense MHW recorded for the period 1 July – 30 June, centred on the latter year. The MHW intensity is zero when no MHW was detected for that year. (b) The total duration of all MHW for 1 July – 30 June. (c, d) The R^2 , coefficient of determination, comparing each region, based on linear regression of the time series for the most intense MHW and the total duration.

3.2 Values and attributes and their connectivity

To elicit expert input for identifying values and characterising their connectivity, the project convened a workshop to bring together experts with knowledge that spanned the full range of attributes that were identified in the scoping phase of the study (*NESP Project 3.3.3 Supplementary Synthesis Report: Part 2*). Participants were invited based on relevant expertise, to ensure a range of knowledge and experience on the management regimes within each jurisdiction – Coral Sea, Great Barrier Reef, Torres Strait, Great Sandy Strait – and the drivers of change (climatic, anthropogenic, terrestrial, cultural and heritage) that influence values and attributes. The expert workshop was attended by 34 stakeholders from diverse fields, including managers, policy makers, industry representatives, scientists and indigenous representatives (see Appendix A for participant list). The workshop used a participatory approach to map values and attributes (using maps generated through eAtlas), characterise connectivity (direction and magnitude) of values, and document current status and management regimes in the four marine areas, with the GBR being further divided into the four Marine Park management areas – Far Northern, Cairns-Cooktown, Townsville-Whitsundays, Mackay-Capricorn.

3.2.1 Identification of attributes

We identified 10 value components and 62 key attributes based on the synthesis report (see Johnson et al. 2018 Part 2), workshop participant input and key expert feedback. Through

this participatory process how these attributes are connected and/or inter-dependent among the four jurisdictions was characterised. There were 54 attributes identified for Natural Heritage values, and 3 attributes for each of the Indigenous Heritage, Social and Historic, and Economic values (Figure 14). The list of Natural Heritage attributes was necessarily long, as it included a prioritised list of the many species that exist across the region. Most of the values span the four marine jurisdictions, and are connected by ocean currents, animal movements, human activities and practices, and climate. These were selected based on various jurisdictional reports, such as the GBR World Heritage listing, GBRMP Outlook Report and Coral Sea Marine Reserve reports. While not intended to be exhaustive, this selection was chosen to be representative of the main values and attributes that are the foundations of these special marine areas.

The final list of Natural Heritage attributes was determined largely based on the expert opinion of scientists and managers. This included consideration of factors such as their social, ecological, economic or cultural importance, their distribution and abundance among the project jurisdictions, and the range of ecological niches these animals occupy.

The attributes within the Social and Historic values category were based in part on the Social and Economic Long-term Monitoring Program (SELTMP)¹ with the following definitions:

Tangible cultural resources that cross-jurisdictional boundaries include cultural resources such as traditional hunting grounds, initiation sites, midden sites, and burial grounds.

Intangible cultural resources that cross-jurisdictional boundaries include traditional stories, song, dance and other cultural practices.

Place attachment refers to places that people are particularly connected to. These places may be special across jurisdictional boundaries because they represent (i) attractive or meaningful features within the natural landscape (that cross boundaries), (ii) strong social bonds and networks that exist within such places, such as family and friends, and/or (iii) special events that may have occurred across jurisdictions, such as celebrations, funerals or special recreational outings.

Places of social significance that cross-jurisdictional boundaries are sites that people recognise as having important social, cultural or traditional heritage, such as recreational sites, fishing spots or places that people visit regularly.

¹ <http://seltmp.eatlas.org.au/seltmp>

VALUES	NATURAL HERITAGE							INDIGENOUS HERITAGE	SOCIAL & HISTORIC	ECONOMIC
COMPONENTS	Coral reefs	Mainland beaches & islands/cays	Estuarine and tidal habitats	Seagrass meadows	Inter-reefal habitats	Mobile adults	Species with mobile larvae	Indigenous culture	Social & historic culture	Industry sectors
Attributes	Hard coral	Casuarina & Pandanus	Mangroves	Seagrass – <i>Zostera muelleri</i>	<i>Halimeda</i> banks	Dugong	Ornate rock lobster	Location of Sea Country	Location of historic shipwrecks	Location of tourism destinations
	Crustose coralline algae	<i>Pisonia grandis</i>	Saltmarsh	Seagrass – tropical spp. (<i>Thalassia</i> etc.)	Inter-reef gardens	Flatback turtle	Black teatfish	Tangible cultural resources	Places of social significance	Location of commercial fishing activity
	<i>Acropora</i> larvae	<i>Argusia argentia</i>		Seagrass – pan-regional	Upwelling	Green turtle	Sandfish	Intangible cultural resources	Location of place attachment	Recreational use areas
	Macroalgae			Seagrass – sub-tropical species		Narrow-barred mackerel	Crown-of-thorns starfish			

↓

Loggerhead turtle, Hawksbill turtle, Yellowfin tuna, Spanish mackerel, Black marlin, pelagic foraging seabirds, inshore and offshore foraging seabirds, migratory shorebirds, Longfin & Shortfin eels, Tiger shark, Bull shark, White shark, Grey nurse shark, Humpback whale, Dogtooth tuna, Australian blacktip shark, Grey reef shark, Common blacktip shark, Scalloped hammerhead, Barramundi, Broad-barred mackerel, Coral trout (common), Coral trout (bluespot), Red throat emperor, Reef manta ray.

↓

Red-spot king prawn, Brown tiger prawn, Eastern king prawn, Mud crab, Saucer scallop

Figure 14: Full list of attributes identified for each of the Natural Heritage, Indigenous Heritage, Social and Historic, and Economic values.

3.2.2 Connectivity of values

A key objective of this project was to characterise the attributes and processes that influence values, and to describe their connectivity at a regional scale across the four marine domains. To achieve this, the connectivity of each of the 62 attributes that comprise the 10 values were mapped and characterised as per the criteria below (Table 1).

Table 1: Criteria used for characterising connectivity for natural, social, indigenous and economic values

Connectivity strength	Type of connection (natural values)	Type of connection (social, indigenous & economic values)	Confidence
Strong	Active dispersal (AD; larvae)	Visit for resource use	Low = based on assumptions only
Weak	Passive dispersal (PD; larvae)	Other visit	Medium = based on expert judgement
No connection	Daily travel (DT; adults)		
Bidirectional connection	Migration (M; adults)	Migration	High = based on observational and/or experimental data
	Breeding (B; adults)		

These connectivity types were defined as follows (adapted from Ament et al. 2014):

NATURAL VALUES

Larvae:

- *Active dispersal* (AD) – purposeful movement [long- and short-term] between areas that maintain genetic and/or demographic connectivity
- *Passive dispersal* (PD) – movement driven primarily by drifting between areas that maintain genetic and/or demographic connectivity

Adults:

- *Daily/short-term travel* (DT) – short-term movement of individuals within their home range that maintains demographic connectivity
- *Migration* (M) – predictable, periodic round-trip or seasonal movement between areas not used at other times of the year
- *Breeding* (B) – adult sex-specific movement between connected habitats for the purpose of completing their life-cycle

SOCIAL, INDIGENOUS & ECONOMIC VALUES

- *Visit for resource use* (VR) – fishers or tourism operators crossing jurisdictions for the purposes of using natural resources
- *Other Visit* (OV) – residents, researchers, government, tourists or others visiting across jurisdictions
- *Migration* (M) – individuals choosing to migrate to the other jurisdiction

The output maps for each of the 62 attributes used consistent symbols to represent these characteristics of connectivity, and some examples are provided below (Figures 15–18). The full suite of connectivity maps is available on the eAtlas online interactive tool:

<http://eatlas.org.au>. Experts consulted at the stakeholder workshops were particularly helpful in generating these maps. The maps provide a visual aid to quickly understand where the strongest connections exist across jurisdictional boundaries for each attribute, what type of connections exist, and therefore the most effective way for management to coordinate both spatially and temporally.

The example outputs below demonstrate where cross-jurisdictional management is highly recommended (e.g. between the GBR and Torres Strait for hard corals) and where it is not required (e.g. between the GBR and Coral Sea for Spanish mackerel). In this way, decision-makers can focus their efforts on building cooperative management for those attributes that: (1) have strong connections with adjacent marine areas, (2) are connected by processes that are amenable to management, and (3) cross-jurisdictional management is currently lacking or inconsistent. This was the foundation for the prioritisation process in Section 4.

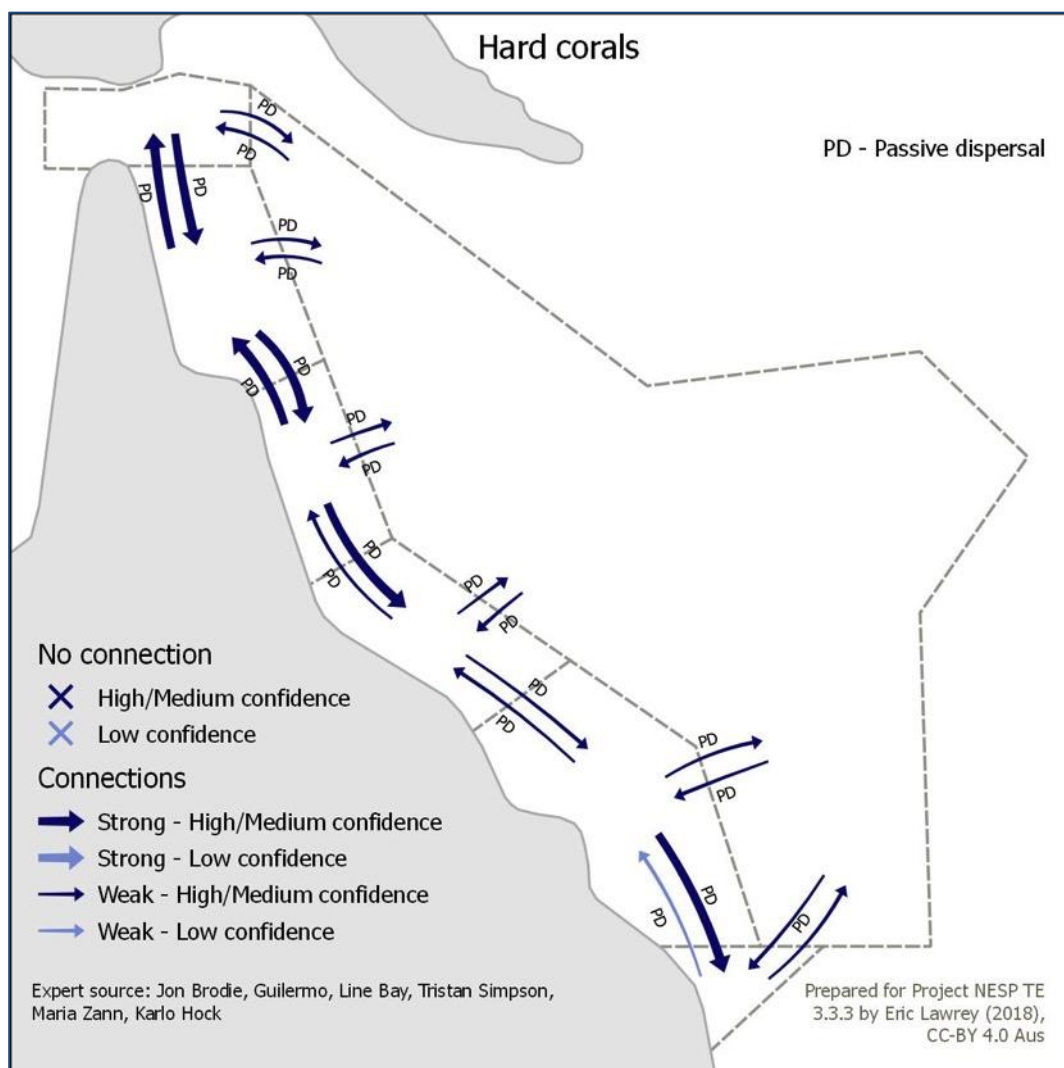


Figure 15: Connectivity map for hard corals showing that the main type of connectivity is through passive dispersal (PD) and is strongest from north to south. There are also weaker connections between the GBR and Coral Sea to the east, and south between the GBR and Great Sandy Straits. The level of confident in these data is predominantly high.

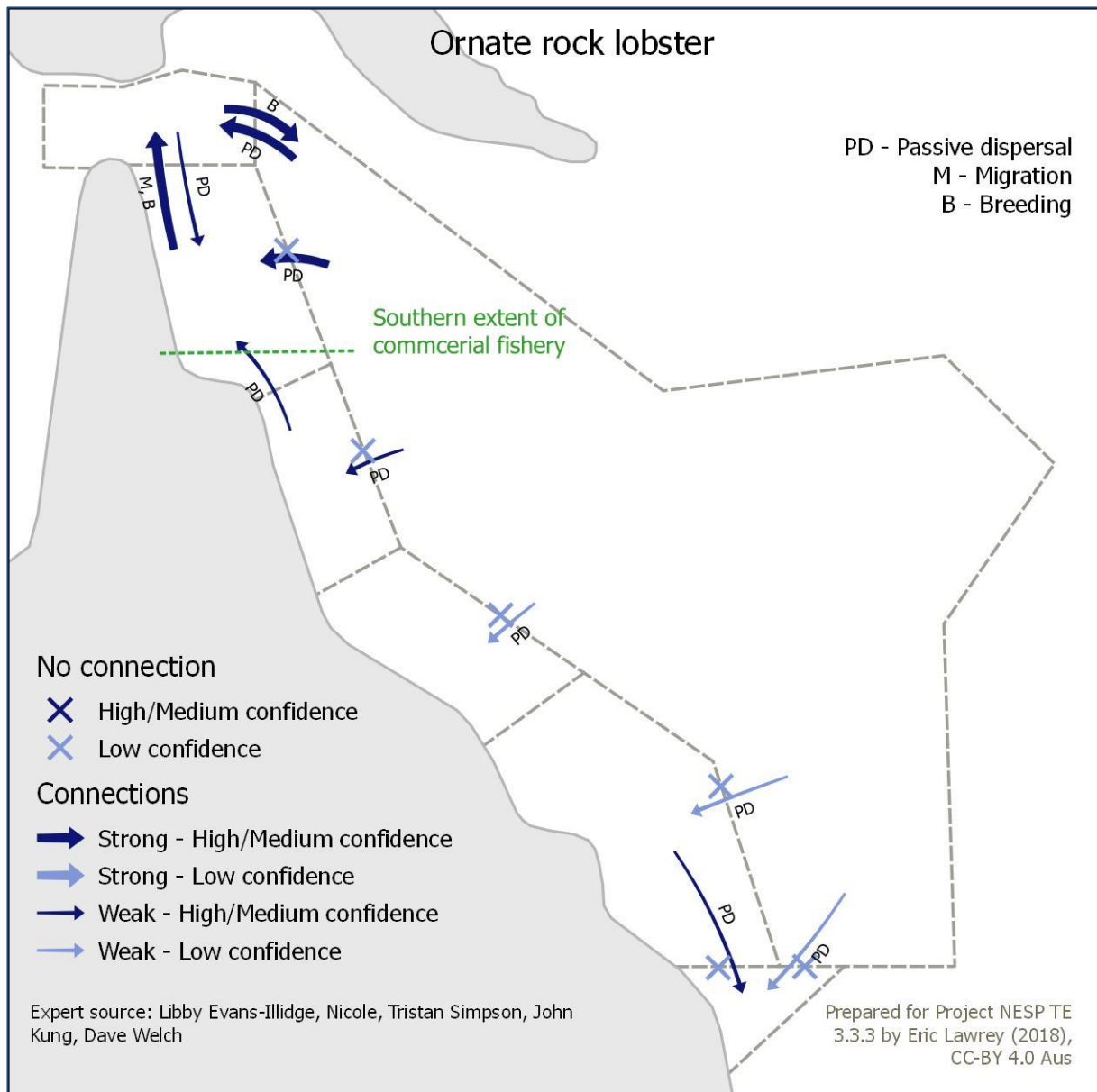


Figure 16: Connectivity map for ornate rock lobster showing three types of connectivity – passive dispersal of larvae, migration and breeding movements, with connections being strongest between the northern GBR and Torres Strait.

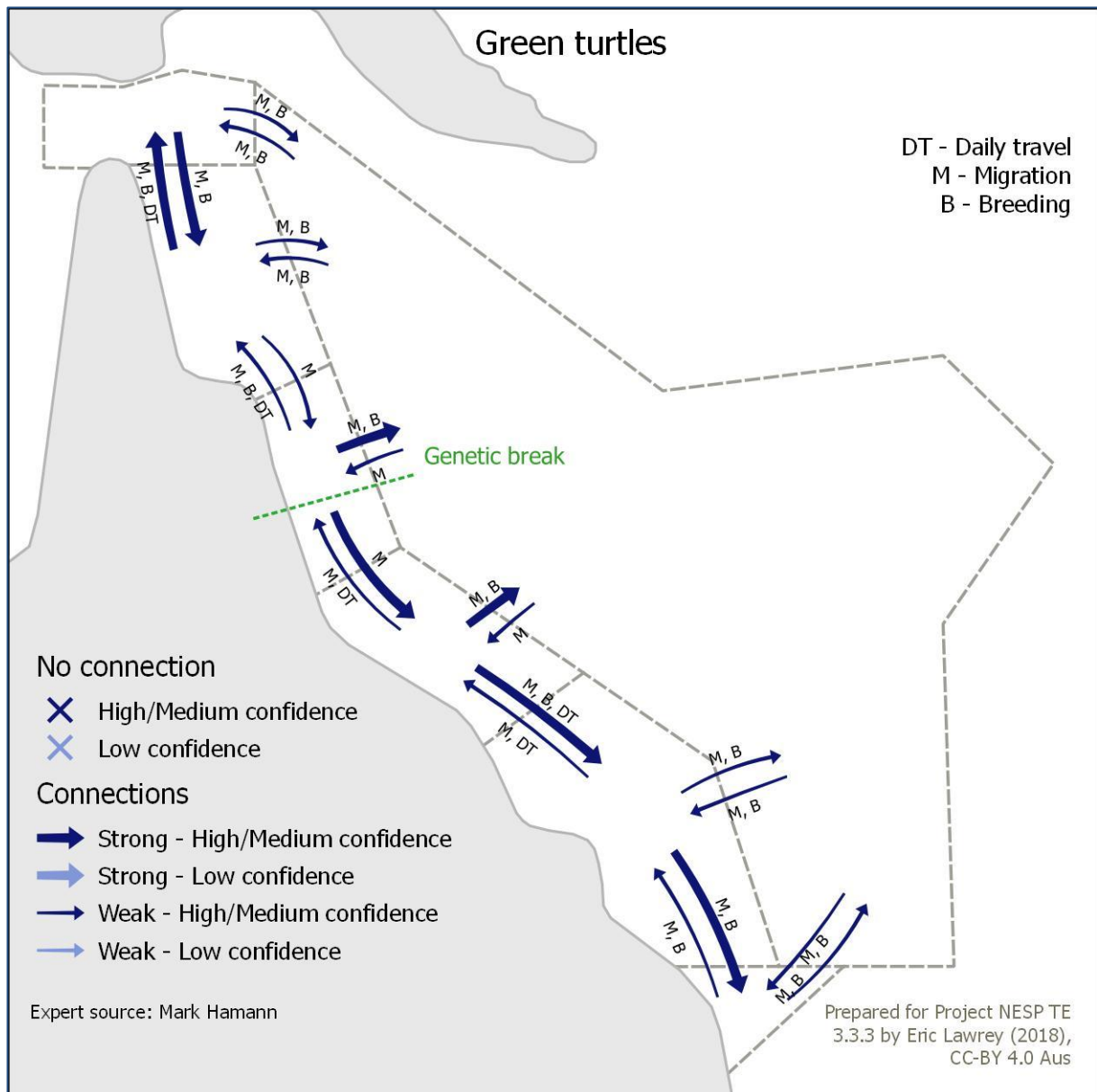


Figure 17: Connectivity map for green turtles. The genetic break reflects the approximate boundary where turtles residing north and south are more likely to be part of the northern and southern GBR breeding stocks respectively. A third genetic stock breeds on Coral Sea islands and disperses into the GBR.

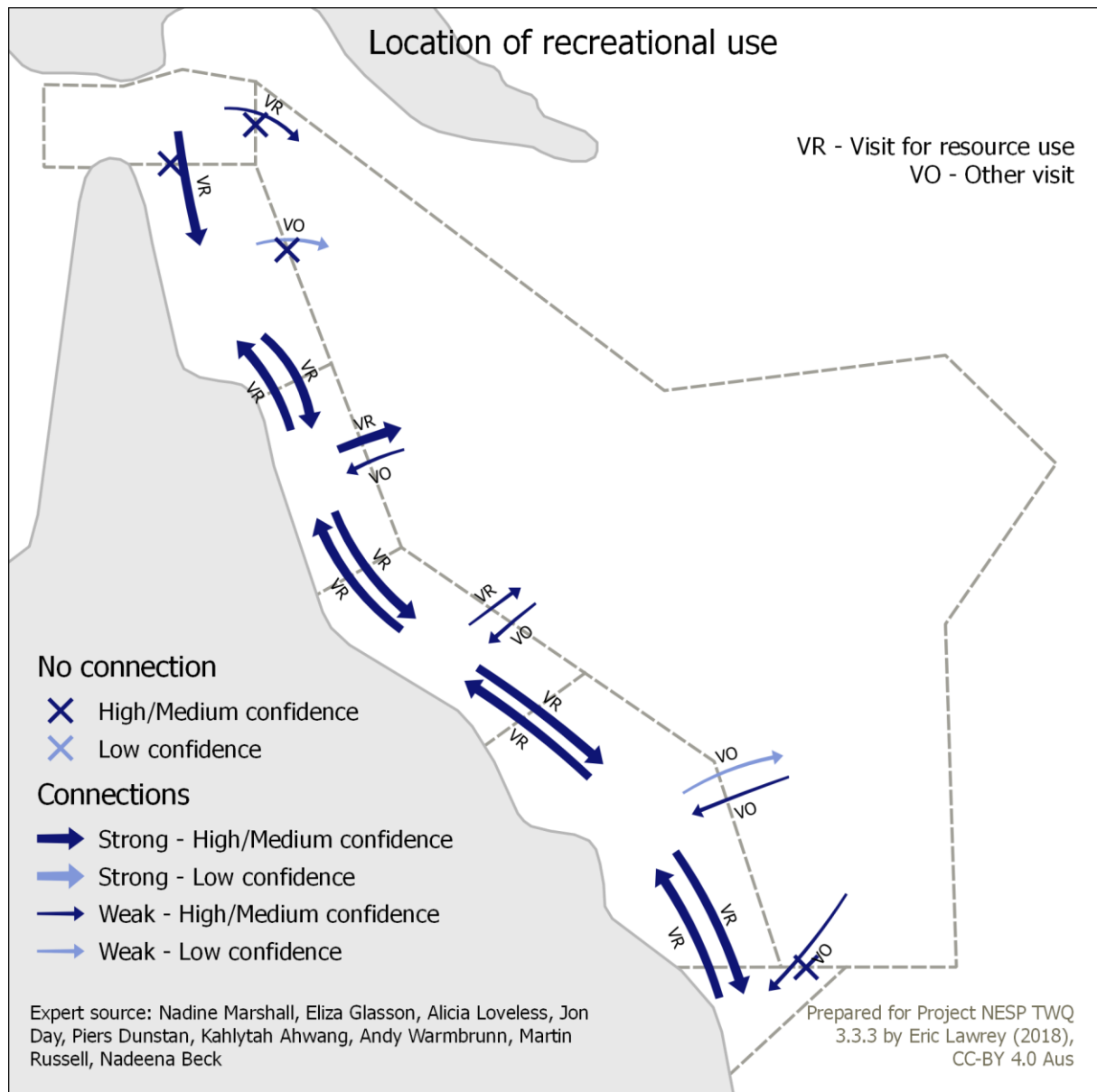


Figure 18: Connectivity maps for location of recreational use showing that the main type of connectivity is visitation for resource use.

3.3 Threats to values/attributes and connectivity

In this section, we present the results of a consultation process in which we compiled and synthesised expert knowledge to assess the level of threat posed by a range of drivers and pressures on the key values in each jurisdiction. Based on this synthesis, the scope for coordinated management was evaluated as a product of the potential for coordination and the likely impact of management in addressing each threat. This provides a potential for increased coordination across jurisdictions to magnify or leverage more local efforts to reduce threats to values within a jurisdiction. This latter analysis highlights the “value-adding” opportunities that could accrue from increased cooperation and coordination across jurisdictions.

3.3.1 Definition of threats to attributes and connectivity

Experts familiar with the management regime in each jurisdiction, together with experts in the full range of attributes, were asked to evaluate the significance of each major threat on the key values and attributes identified for this study.

Assessing threats to attributes

Each group used a Delphi approach to generate an estimate of the magnitude of effect of pressures or drivers of change using a scale of 0 to 2 (Table 2) on a subset of the key attributes that were selected by consensus among the participating managers to be representative of all values and most components (Table 3).

Table 2: Rating scale used to assess the magnitude or effect of each threat/pressure on each attribute.

Code	Rating	Definition
0	Low	Pressure not a significant threat or influence on attribute
1	Moderate	Pressure known to exercise significant influence on attribute or known to represent moderate risk
2	High	Pressure is a major risk to sustainability of attribute

The effect of a driver/pressure was rated as **low** if it was not a significant threat or a major influence on the attribute across its range within each jurisdiction. The effect of elevated sea surface temperatures on yellowfin tuna is an example of a low magnitude effect. A **moderate** rating was given where a pressure was known to have significant influence on the attribute or represent a moderate risk to the attribute across its range. Coastal development was considered a moderate magnitude effect (moderate risk) to tourism destinations. The rating of **high** was given to pressures that represented a major risk to the sustainability of the attribute across its range. An example of a high-level effect (high risk) is a pest outbreak on *Pisonia grandis* forests.

Table 3: Subset of attributes assessed in the pressure/ threats analysis.

VALUES	NATURAL HERITAGE						INDIGENOUS HERITAGE	SOCIAL & HISTORIC	ECONOMIC	
COMPONENTS	Coral reefs	Mainland beaches & islands/cays	Estuarine and tidal habitats	Seagrass meadows	Inter-reefal habitats	Mobile adults	Species with mobile larvae	Indigenous culture	Social & historic culture	Industry sectors
Attributes	Hard coral	<i>Pisonia grandis</i>	Mangroves	Seagrass (species grouped)		Dugong	Ornate rock lobster	Tangible cultural resources	Location of historic shipwrecks	Location of tourism destinations
			Saltmarsh			Flatback turtle	Black teatfish		Places of social significance	Location of commercial fishing activity
						Green turtle	Sandfish			
						Spanish mackerel				

Additional 'Mobile adults' attributes: Loggerhead turtle, Hawksbill turtle, Yellowfin tuna, pelagic foraging seabirds, inshore and offshore foraging seabirds, migratory shorebirds, Tiger shark, Grey nurse shark

Assessing scope for coordinated management to minimise threats

Once the potential impact of the key threats/pressures was assessed for each attribute in each jurisdiction, the expert working group evaluated the potential for cooperation across jurisdictions to help mitigate the risks. The scope for coordinated management of risks was assessed on two dimensions: the feasibility of cooperation across jurisdictions, and the likely effectiveness in reducing risk to the attribute. Explanations of the ratings (low, medium, high) and examples for each rating level are provided in Table 4.

The scope/need for cooperation across jurisdictions was considered **low** where cooperation between jurisdictions was not feasible for a particular threat, or where increased cooperation in management was unlikely to reduce risk. The risk from *disease or pest outbreak* for attributes such as sandfish or tiger sharks are examples of issues where there was low scope for improvement through cooperation across jurisdictions.

The scope for cooperation across jurisdictions was rated **medium** where cooperative management of the threat was feasible and could achieve some reductions in risk. A **medium** rating was given to situations where cooperation was easy but the reduction in risk was expected to be modest or less important to the sustainability of the attribute. The risk from *loss of food source* to turtles and dugong is an example of the former, while the risk of *traditional hunting* to Spanish mackerel is an example of the latter.

A **high** rating was identified where cooperation between jurisdictions was likely to be easy and would lead to significant reduction in risk, or when cooperation was challenging but could deliver important risk reduction if achieved. The risk from *coastal development* to seabirds was an example of an issue that could benefit substantially from improved cooperation in management across jurisdictions.

Table 4: Summary of rating levels and definitions used for assessing the scope for coordinated management across jurisdictions.

Code	Rating	Definition
L	Low	Cooperation between jurisdictions not feasible for this threat, or unlikely to reduce risk
M	Medium	Cooperation between jurisdictions feasible if difficult but will produce moderate reduction in risk; or cooperation easy but minimal prospect for reducing risk
H	High	Cooperation between jurisdictions easy and likely to produce at least some reduction in risk; or cooperation feasible but difficult, but large or important reduction in risk possible
-	Not applicable, or unknown	Threat not amenable to local management intervention; or threat only relevant to one jurisdiction; or the potential for threat mitigation is not known

3.3.2 Summary results

A key objective for this project was to identify issues that would benefit most from coordination among management jurisdictions. Through expert elicitation, we were able to identify the threats of most significance to neighbouring jurisdictions. We then rated threats based on the scope for management coordination, which is a function of the ease of coordination among jurisdictions in managing a threat, and the magnitude of benefit that would accrue from greater coordination. This provided a list of issues to inform discussions about future cross-jurisdictional planning and management.

Six issues ranked highly for future cross-jurisdictional planning and management because there was considerable scope for threat reduction through improved coordination, and because improved management would benefit multiple shared attributes. These threats are (see also Table 5):

- Flood events (notably pollutants delivered via river discharges)
- Chemical/oil spills (especially associated with shipping incidents)
- Dredging (associated with port developments & maintenance)
- Fishing (includes recreational & commercial)
- Pathogens/disease outbreaks (including terrestrial & marine)
- Loss of food source (notably seagrasses & baitfish).

Table 5: Summary of priority threats that would benefit from improved coordination of management and the attributes they influence.

	Attributes								
Threat	Hard corals	Seabirds	Turtles & dugong	Ornate rock lobster	Beche de mer	Spanish mackerel	Yellowfin tuna	Sharks	<i>Pisonia grandis</i>
Flood events									
Chemical/oil spills									
Dredging									
Fishing									
Pathogens/disease outbreak									
Loss of food source									
Pest outbreaks									
Regulation change									
Recreational use									
Agriculture									
Loss of natural habitat									
Traditional hunting									
Wildfires									
Loss of Traditional & Cultural Knowledge									
Ship grounding									
Drought									
Economic stress									
Mining & mineral processes									

Legend

Highest priority for inter-jurisdictional coordination	
Medium priority for inter-jurisdictional coordination	
Major benefit from improved management of threat	
Lesser benefit from improved management of threat	

Importantly, not all risks require coordination across all jurisdictions; in many cases significant improvements could result from improved coordination between only two jurisdictions. The full table of scores and results are provided in Appendix B.

3.3.3 Implications of connectivity

Human pressures can also affect the strength, location and constancy of connectivity across jurisdictions. Deterioration in water quality or episodic events such as floods can impact on processes or values that are important to connectivity for some species. For example, a

significant decline in coral cover due to flood plume exposure, should it occur on reefs that were important sources of coral larvae, could impact an adjacent jurisdiction.

Climate change is likely to be another major influence on connectivity for some values, such as thermally sensitive species whose distribution or spawning activities may be disrupted by increasing SST. Coral bleaching events could also affect reefs in one jurisdiction that are important sources of larvae to another jurisdiction. Changes in the timing or strength of currents caused by ocean warming could also have profound effects on the connectivity between jurisdictions. Climate change has been scored as a very high risk to the northern GBR green turtle population, and increases in air and sea temperatures could affect hatchling production and sex ratios with potential long-term effects on breeding ecology, population genetics and the supply of turtles from the northern GBR into Torres Strait.

Connectivity can also apply to threats. This requires managers to consider whether their management of threats could be important for the ability of managers in adjacent jurisdictions to achieve their objectives. Some of the threats for which connectivity could be particularly important include maritime incidents such as oil spills, marine debris such as ghost nets, and invasive/pest species such as crown-of-thorns starfish. Understanding the strength and direction of connectivity, and its variability in time and space, is an important consideration of for cross-jurisdictional management.

4.0 STRATEGIES FOR MANAGING FOR CONNECTIVITY

Values that are the focus of tropical marine system management are rarely confined entirely within a single management jurisdiction. Even in a jurisdiction as large as the GBR, the sustainability of key values depends on processes that extend into adjoining ecosystems. For some values, such as species of smaller demersal fishes or seagrasses that depend heavily on vegetative reproduction, the connectivity across jurisdictions might only be important on evolutionary timeframes. But even in these cases, connectivity can be important for maintaining genetic diversity that is a key factor in species resilience. For most priority values, however, connectivity is important on ecological timeframes (i.e. years to decades). Examples such as cetaceans, many reptiles (especially turtles), broadcast spawning corals and pelagic fishes clearly illustrate the need to manage connectivity across jurisdictions.

Managing connectivity requires managers to identify priority values and attributes, then assess and map the location, direction and strength of connections that are important to sustaining those attributes. With this knowledge, managers can identify jurisdictions with features or processes that are important to sustaining priority values, and collaborate with those jurisdictions to develop shared management plans for values that span boundaries (Figure 19). Given the range of possible mechanisms and the nature of connectivity for the 62 attributes assessed, it is important for managers to focus on the attributes that will benefit the most from cross-jurisdictional management. This was achieved by conducting a prioritisation step that identified targets for collaborative management discussions.

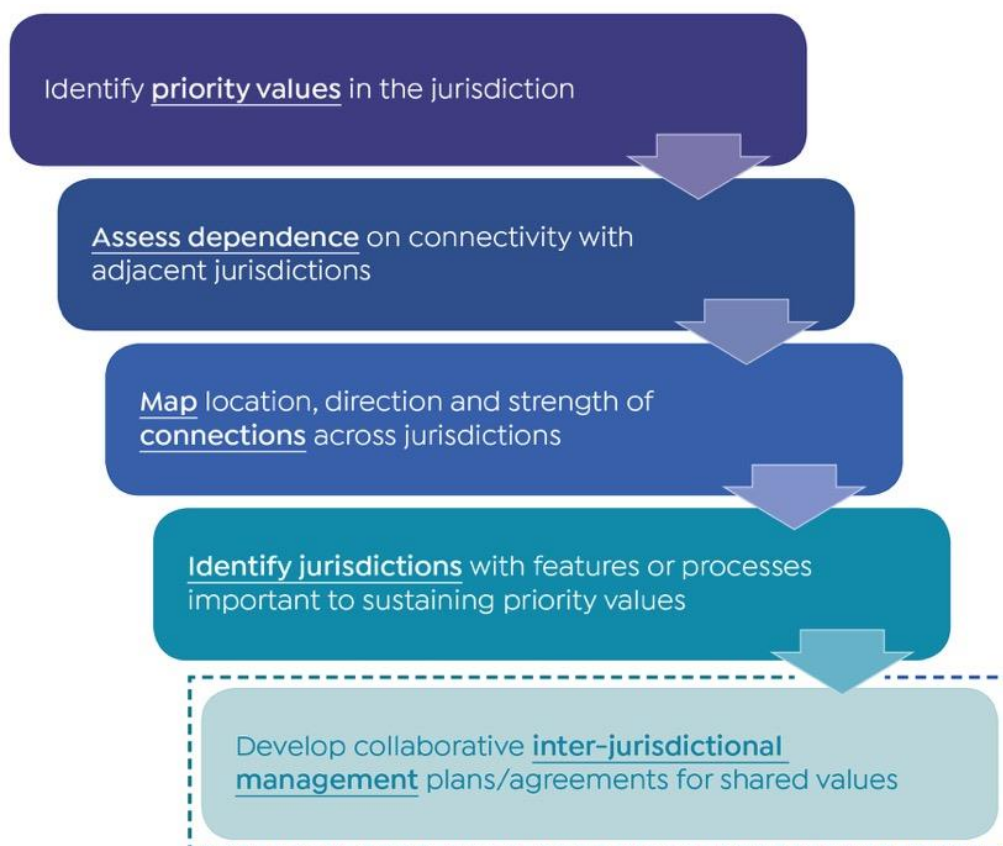


Figure 19: A decision-centric approach to managing for connectivity.

4.1 Management priorities

One of the key outputs from this project was to provide clear guidance to managers of the respective marine domains on the values and attributes that require cross-jurisdictional focus. In the context of the project, this meant identifying attributes that are strongly connected across jurisdictional boundaries coupled with an assessment of their current management status. This will enable managers to clearly identify which attributes they should focus on for collaboration across borders, and which relevant management jurisdictions they should be coordinating with to do this effectively.

To achieve this, we developed a simple framework using a semi-quantitative approach with two key components: (i) the strength of connectivity across jurisdictional boundaries, and (ii) the effectiveness of current collaborative management, comprising of four criteria. For each attribute, and each combination of the respective jurisdictional boundaries, connectivity was assigned a score of 0, 1 or 2 for 'no connectivity', 'weak connectivity' and 'strong connectivity', respectively (Table 6). Collaborative management effectiveness comprised of three sub-components: *Relevant management implemented*, *Management alignment across jurisdictions* and *Current status of the attribute*. Each of these sub-components was assigned a score of 1, 2 or 3 based on a set of scoring criteria, with the total score for 'Collaborative management effectiveness' based on the sum of these scores (Table 7). The final (relative) score was the basis for prioritisation and was the product of 'Connectivity strength' and 'Collaborative management effectiveness', with high scores reflecting a higher priority for cross-jurisdictional management.

Table 6: The components of the semi-quantitative framework used for prioritising attributes among jurisdictions for managers.

Components	Definition	Scoring criteria
Connectivity strength	The strength of connectivity of the <i>value</i> across the boundary of each jurisdiction pair. Derived from values maps	0 = none 1 = weak 2 = strong
Relevant management implemented	Whether there is management in place relevant to the <i>value</i> for each jurisdiction. Needs to be scored for each jurisdiction separately	1 = value a key and explicit focus of management 2 = value an explicit part of management but not a strong focus 3 = value not an explicit focus of management
Management alignment across jurisdiction	Degree of alignment in management targets and tools across jurisdictions relevant to the <i>value</i>	1 = both jurisdictions prioritise management of value and use similar tools and approaches 2 = both jurisdictions prioritise management of value but use different tools and approaches 3 = management of value is limited or not aligned
Current status	The current accepted and/or documented status of the <i>value</i>	1 = least concern 2 = currently in good condition but some concerns 3 = threatened/overexploited
Collaborative management effectiveness	A relative measure of how effective management of the <i>value</i> is based on: whether management is in	A composite (all scores added) of the above 3 components

	place, how well aligned it is among adjacent jurisdictions, and the current status of the value	
Relative score	Derived by multiplying the 'Connectivity strength' and 'Collaborative management effectiveness' scores	Lower scores are the highest priority for management

The majority of values and their attributes for which connectivity was assessed and maps generated (see Section 3) were included in the management prioritisation process. However, expert judgement was used to include only species deemed to have a relevance and significance across any jurisdictional boundary. For example, barramundi are an important coastal species found in three of the four jurisdictions, and as such were included as a key attribute. This species was excluded from the management prioritisation process because the Great Sandy Strait is close to the southern limit of their range, where they are less important, and in the north, where their relative abundance is also lower, due to the very small available coastline on the tip of Cape York that is part of Torres Strait. It could be deemed that this was a further prioritisation and was part of a deliberate strategy to ensure that the guidance provided to managers was relevant and practical.

4.1.1 Priority values and attributes: Results

The outcomes of the management prioritisation process are summarised for each of the eight jurisdictional boundaries in Figures 20–28. The full framework and scores behind the prioritisation are given in Appendix C, so that managers (and other stakeholders) can fully understand the basis for the results.

Not surprisingly, the highest priority attributes for cross-jurisdictional management were those that were strongly connected across adjacent boundaries and where current collaborative management effectiveness was low and/or inconsistent. However, connectivity alone was given greater weighting, and therefore had the greatest influence on how attributes were prioritised. Despite this, there were several cases where attributes had weak connectivity, but due to their very low collaborative management effectiveness were ranked as a moderate priority for collaborative management.

The 'Intangible cultural resources' attribute was ranked as moderate priority for managers in the Great Sandy Strait and the Mackay-Capricorn section of the GBR (Figure 27). Despite low connectivity between the two jurisdictions, it had the lowest possible score for collaborative management. This was evident for this attribute across all borders, making it an important priority for managers of all jurisdictions. Similarly, 'Shorebirds' and 'Seabirds' had low connectivity across the boundary of Torres Strait and the Far Northern section of the GBR, however they were rated as a moderate priority due to the significant potential for improved collaborative management in the region (Figure 20). In particular, there are benefits in one jurisdiction sharing their management policies and experiences with an adjacent jurisdiction so management can align and improve. Similarly, 'Grey reef shark' had low connectivity across the Torres Strait and Far Northern GBR boundary but has potential for improved collaborative management in the region (Figure 20).

While the results of the prioritisation identify which attributes should be the focus of discussion between adjacent jurisdictions, the threats and pressures assessment also informs that discussion by identifying which risks to address.

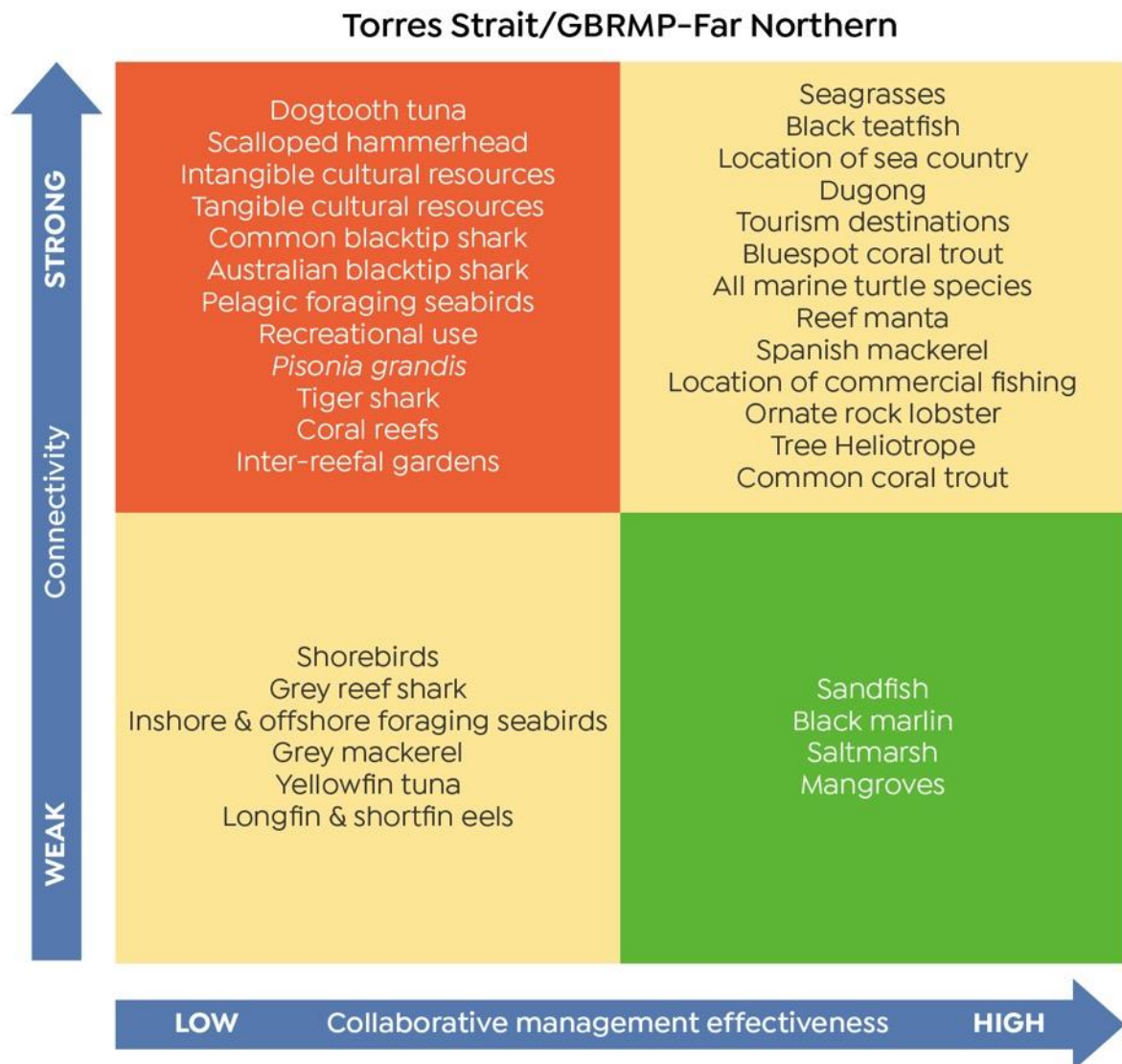


Figure 20: Results of the management prioritisation for attributes that are connected between the Torres Strait and Far Northern section of the GBRMP. Red = attributes that are highest priority due to strong connectivity and low collaborative management effectiveness; Yellow = attributes that are moderate priority due to either weak connectivity and low collaborative management effectiveness or strong connectivity and high management effectiveness; Green = attributes that are lowest priority due to weak connectivity and high management effectiveness.

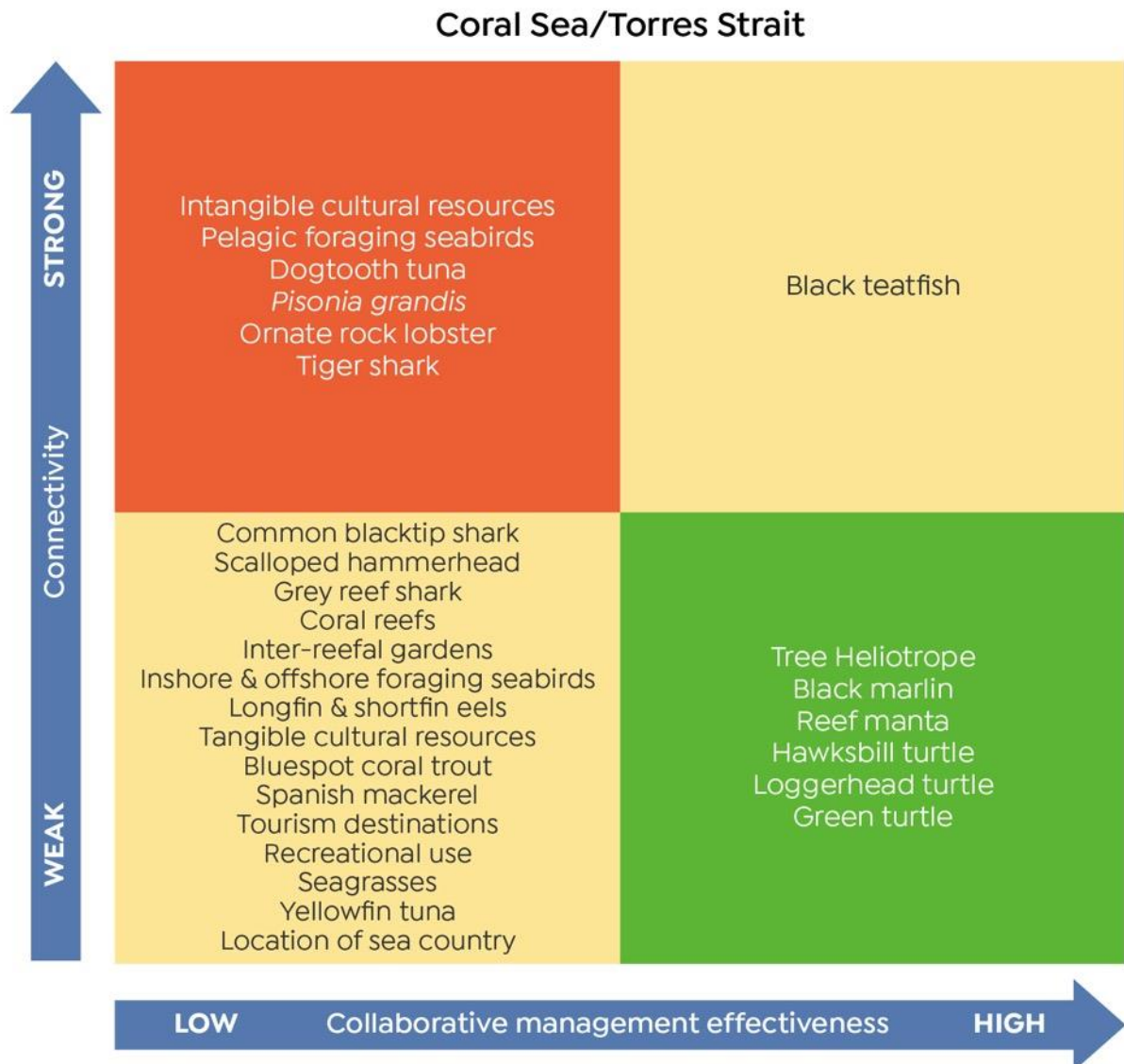


Figure 21: Results of the management prioritisation for attributes that are connected between the Torres Strait and Coral Sea. Red = attributes that are highest priority due to strong connectivity and low collaborative management effectiveness; Yellow = attributes that are moderate priority due to either weak connectivity and low collaborative management effectiveness or strong connectivity and high management effectiveness; Green = attributes that are lowest priority due to weak connectivity and high management effectiveness.

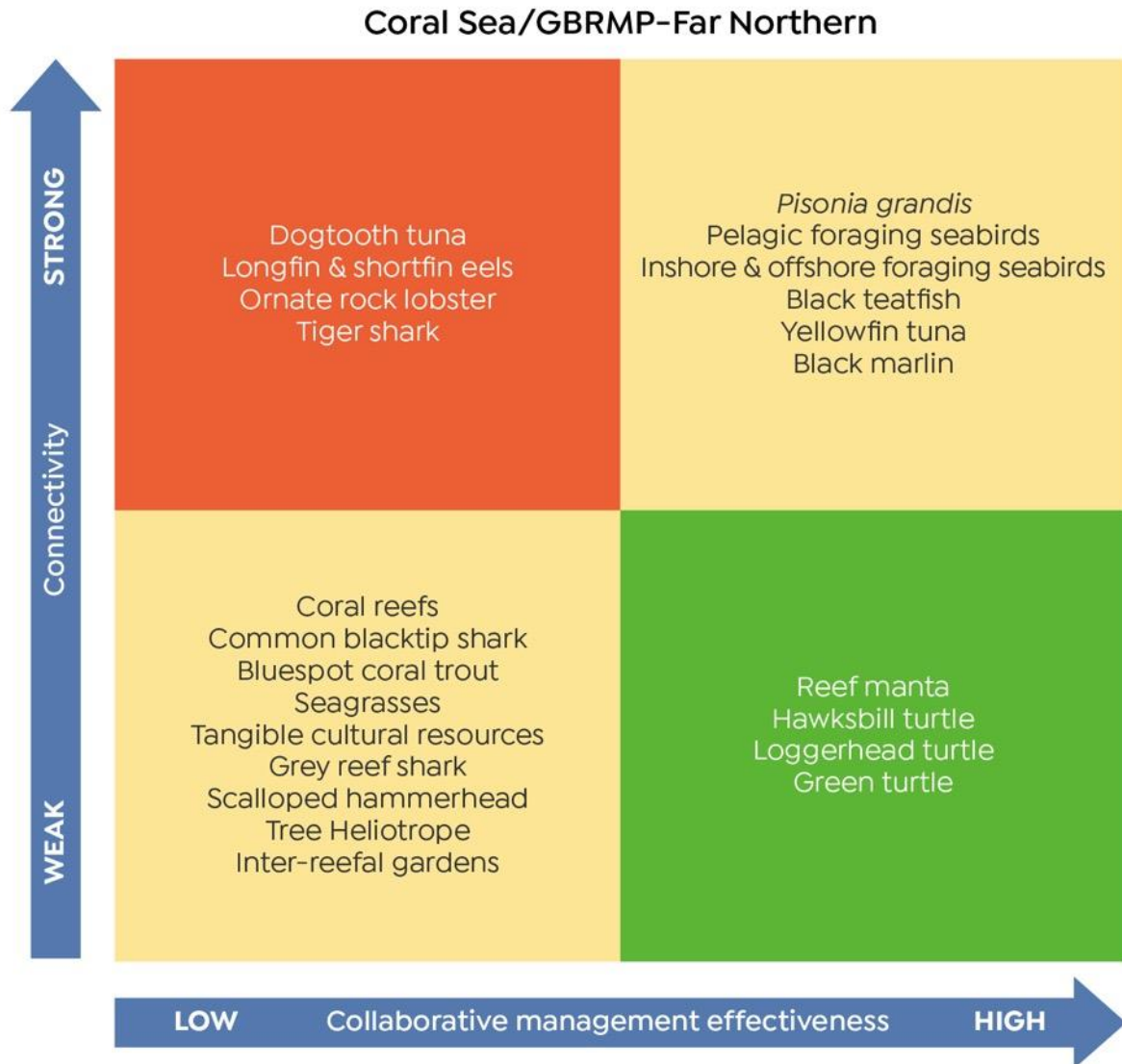


Figure 22: Results of the management prioritisation for attributes that are connected between the Coral Sea and Far Northern section of the GBRMP. Red = attributes that are highest priority due to strong connectivity and low collaborative management effectiveness; Yellow = attributes that are moderate priority due to either weak connectivity and low collaborative management effectiveness or strong connectivity and high management effectiveness; Green = attributes that are lowest priority due to weak connectivity and high management effectiveness.

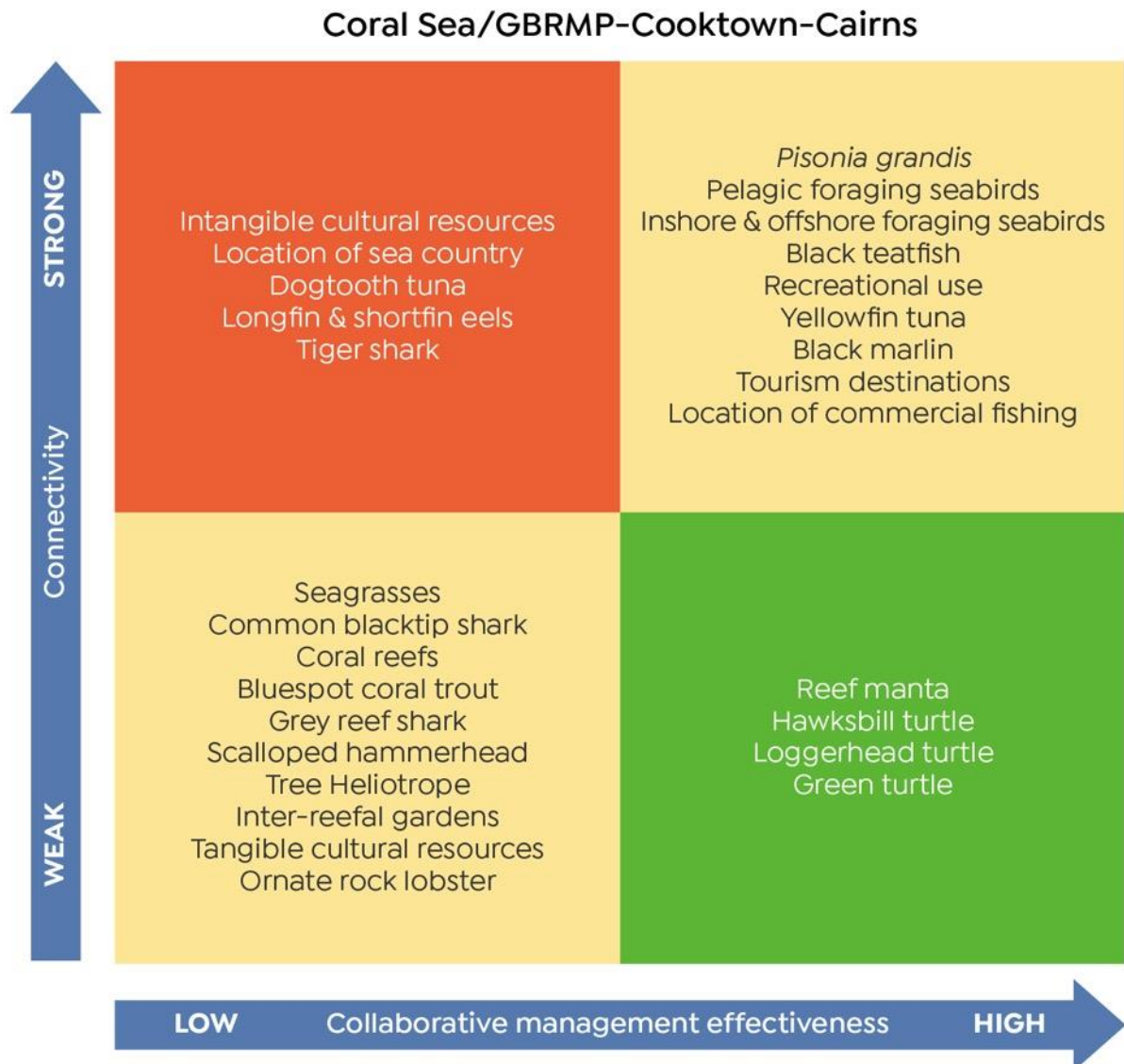


Figure 23: Results of the management prioritisation for attributes that are connected between the Coral Sea and Cooktown-Cairns section of the GBRMP. Red = attributes that are highest priority due to strong connectivity and low collaborative management effectiveness; Yellow = attributes that are moderate priority due to either weak connectivity and low collaborative management effectiveness or strong connectivity and high management effectiveness; Green = attributes that are lowest priority due to weak connectivity and high management effectiveness.

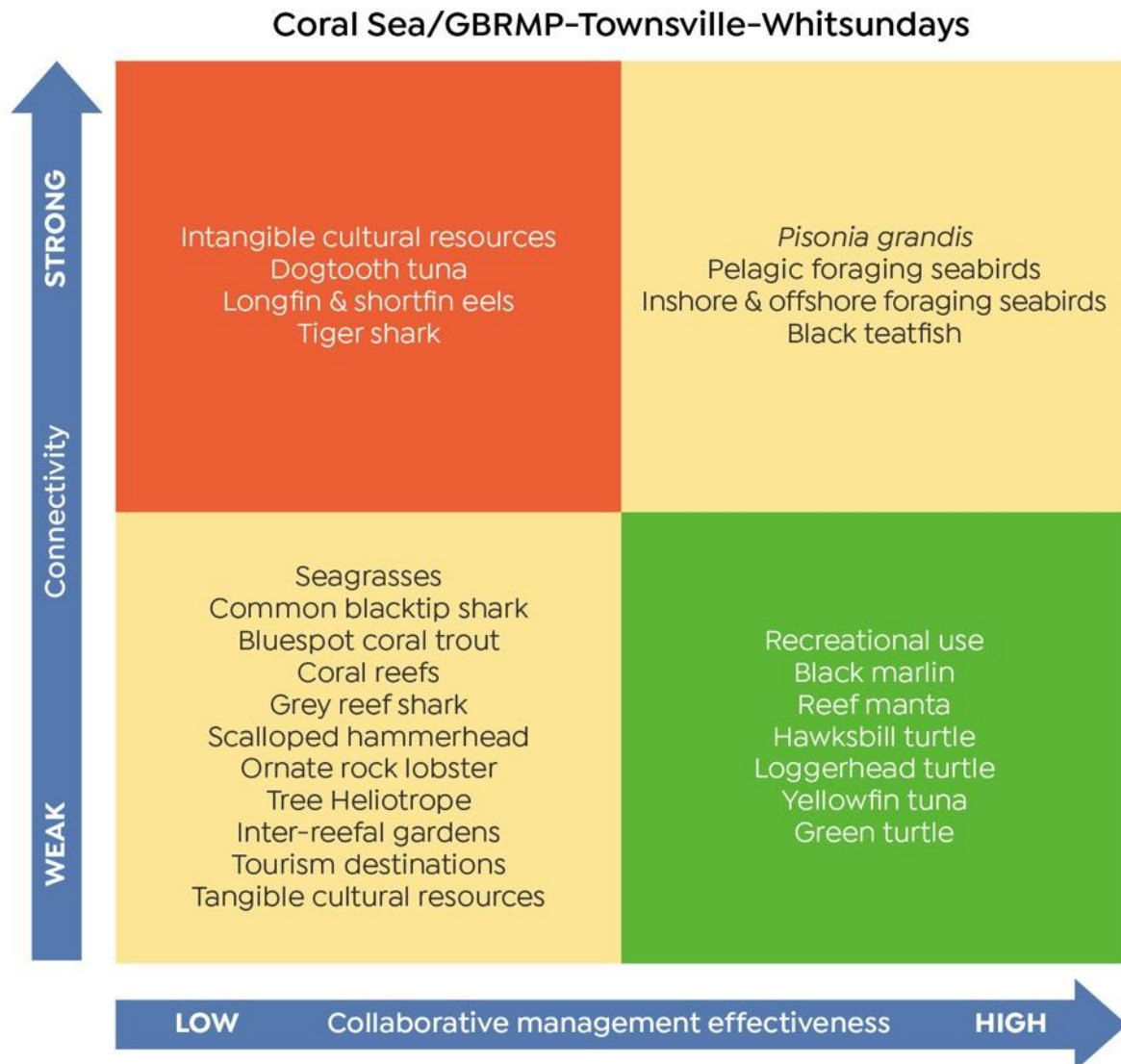


Figure 24: Results of the management prioritisation for attributes that are connected between the Coral Sea and Townsville-Whitsunday section of the GBRMP. Red = attributes that are highest priority due to strong connectivity and low collaborative management effectiveness; Yellow = attributes that are moderate priority due to either weak connectivity and low collaborative management effectiveness or strong connectivity and high management effectiveness; Green = attributes that are lowest priority due to weak connectivity and high management effectiveness.

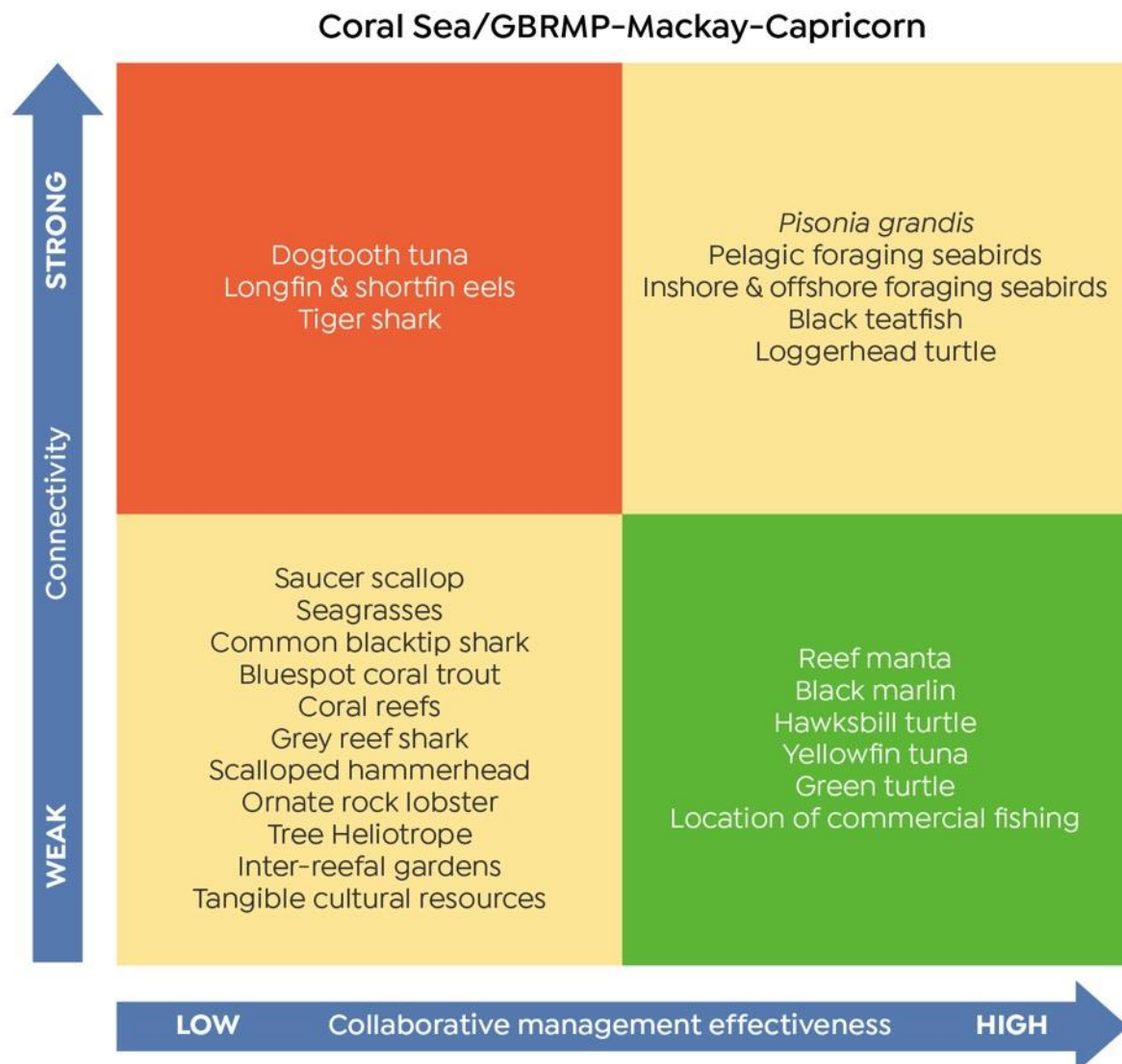


Figure 25: Results of the management prioritisation for attributes that are connected between the Coral Sea and Mackay-Capricorn section of the GBRMP. Red = attributes that are highest priority due to strong connectivity and low collaborative management effectiveness; Yellow = attributes that are moderate priority due to either weak connectivity and low collaborative management effectiveness or strong connectivity and high management effectiveness; Green = attributes that are lowest priority due to weak connectivity and high management effectiveness.

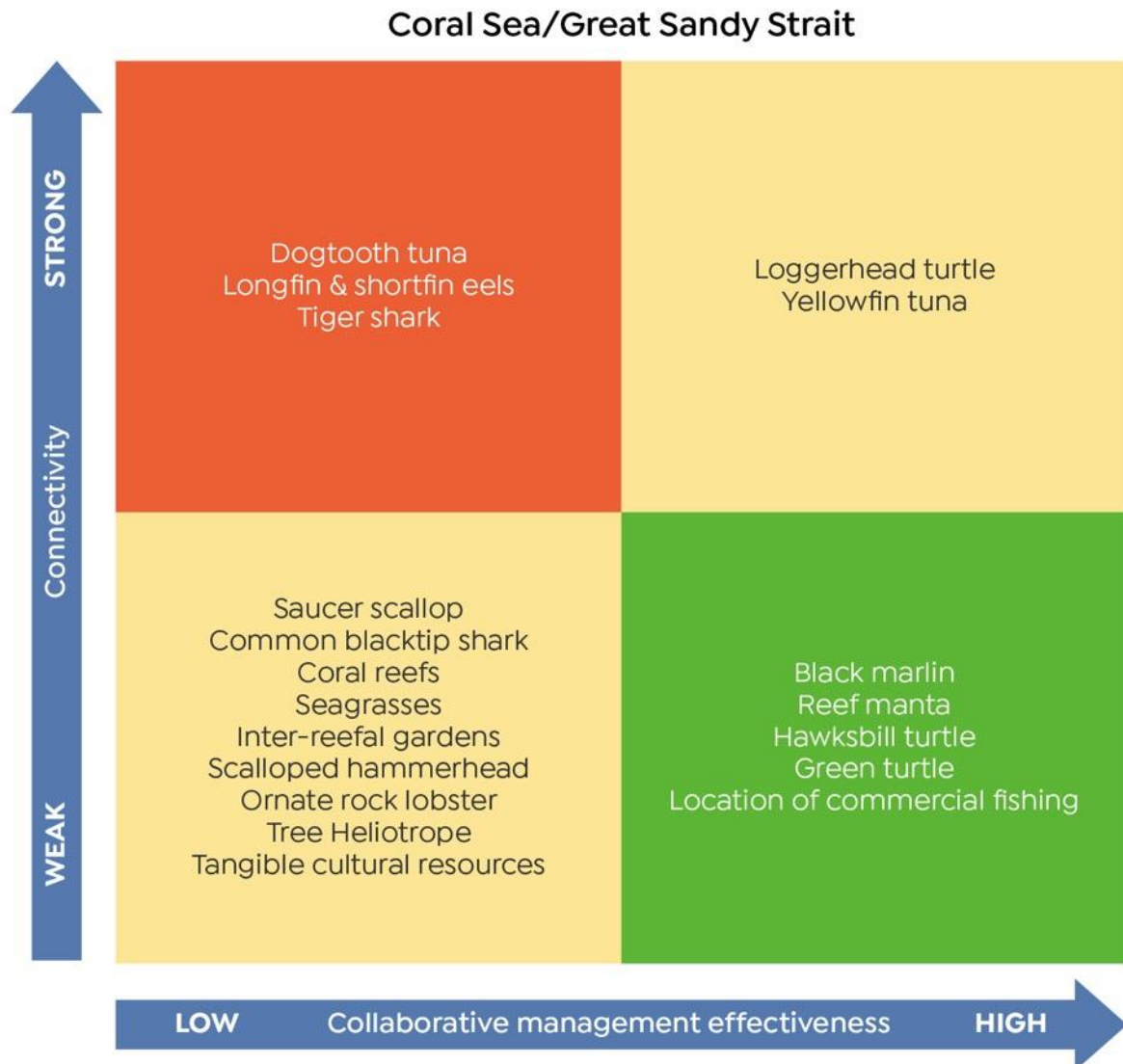


Figure 26: Results of the management prioritisation for attributes that are connected between the Coral Sea and Great Sandy Strait. Red = attributes that are highest priority due to strong connectivity and low collaborative management effectiveness; Yellow = attributes that are moderate priority due to either weak connectivity and low collaborative management effectiveness or strong connectivity and high management effectiveness; Green = attributes that are lowest priority due to weak connectivity and high management effectiveness.

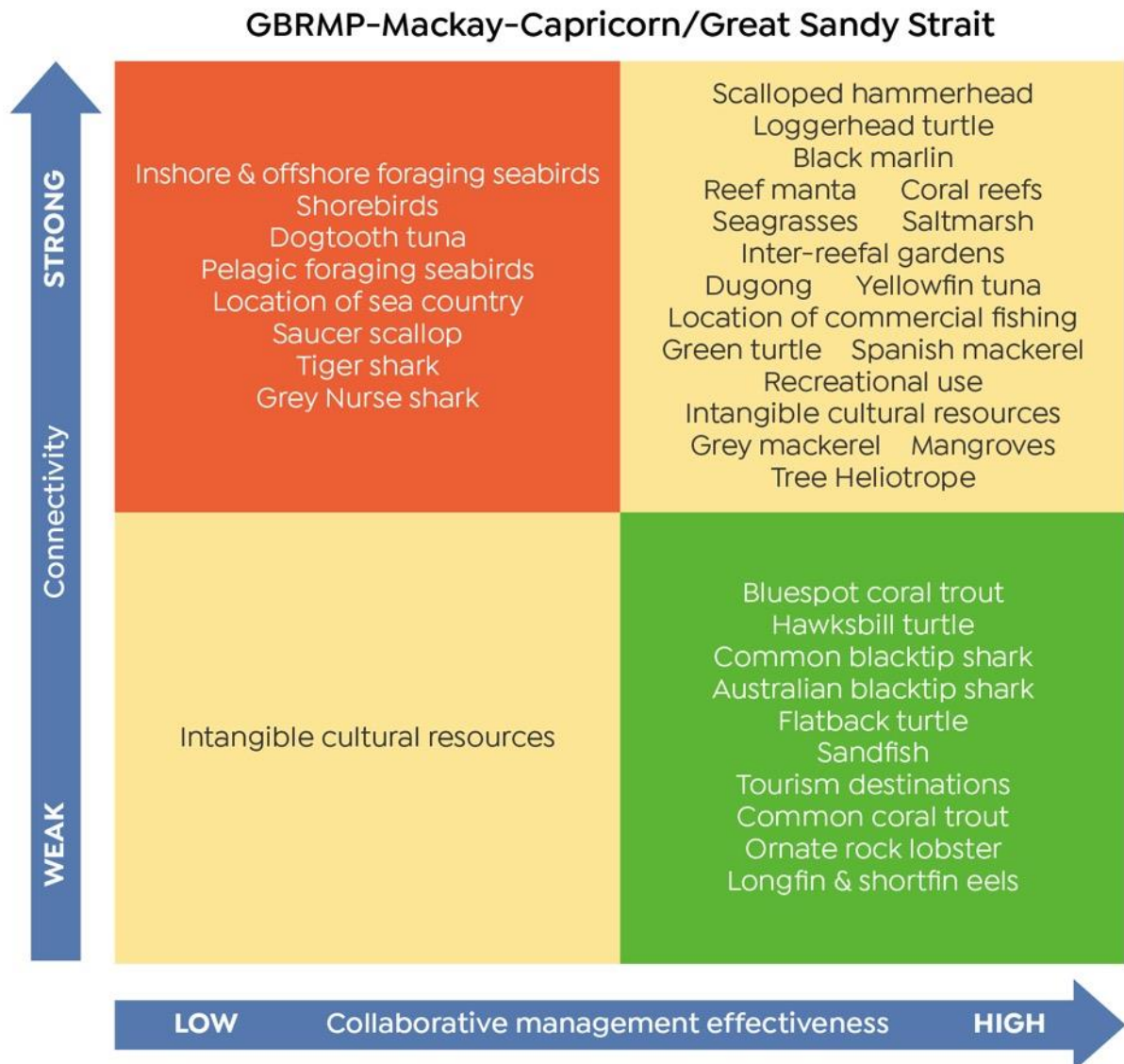


Figure 27: Results of the management prioritisation for attributes that are connected between the Mackay-Capricorn section of the GBRMP and Great Sandy Strait. Red = attributes that are highest priority due to strong connectivity and low collaborative management effectiveness; Yellow = attributes that are moderate priority due to either weak connectivity and low collaborative management effectiveness or strong connectivity and high management effectiveness; Green = attributes that are lowest priority due to weak connectivity and high management effectiveness.

4.1.2 Jurisdictions

While the Coral Sea is the largest jurisdiction, it also shares borders with all other marine areas, as does the GBR. Therefore, management of these two marine areas will naturally need to consider values and attributes that cross borders, and encourage cross-jurisdictional approaches. Despite this, the prioritisation results have been presented for each border and management of each of the four marine areas will require some level of cross-jurisdictional cooperation to improve the management of, and the focus on, high priority values and attributes.

For example, there is substantial research on inshore/offshore foraging seabirds and shorebirds in the Mackay-Capricorn section of the GBR, with critically important nesting islands and cays identified and protected in this section. The results of the prioritisation show that these two attributes – inshore/offshore foraging seabirds and shorebirds – cross into the Great Sandy Strait (Figure 26), and therefore effective management will require greater cooperation and complementary strategies between these two jurisdictions.

4.2 Shared human values and how they influence decision-making

One aim of this project was to deliver an understanding of adjacent marine values or attributes in the northeast Australia seascape. How attributes are regarded within each jurisdiction can have implications in adjacent jurisdictions. For example, if two adjacent jurisdictions have similar regard for an attribute, then cross-jurisdictional management is needed and more likely to be effective, as they ‘share’ the same held values. Conversely, the simplistic challenge for cross-jurisdictional management is when one jurisdiction regards an attribute for its intrinsic or cultural values, such as the biodiversity value of dugongs, and an adjacent jurisdiction values its resource potential, such as for traditional hunting. Identifying areas of potential conflict and focusing on the shared importance of attributes becomes key for developing cross-jurisdictional management strategies.

To develop insights into values that were likely to be in conflict across jurisdictions, we asked workshop participants to break out into jurisdictional subgroups and identify the regard or “held values” around each marine attribute within their jurisdiction. Workshop participants were given a list of possible ‘held values’, including; biodiversity & conservation, traditional hunting, commercial fishing, recreational fishing, subsistence fishing, tourism, recreation, cultural, and aesthetic. Participants were not restricted to this list. The purpose of the exercise was to understand which held values were shared across jurisdictions, and which were in potential conflict; the results are compiled in Table 7.

Results show that there were several marine attributes, such as seagrass, shipwrecks and sea-country, which were equally regarded across all jurisdictions, and were unlikely to invite conflict across adjacent jurisdictions. Results also show that marine attributes could be valued for a range of reasons (“multiple held values”), and that these were often in conflict with each other within a single jurisdiction. For example, coral was valued for biodiversity & conservation, as well as coral collecting, tourism and recreation, the latter of which are sometimes regarded to be in conflict with biodiversity and conservation.

Table 7: Results from each of the regional sub-groups that were asked to list the held values for each marine attribute. The last column lists those marine attributes that are potentially in conflict or represent shared values.

Attribute	GBR held values	Torres Strait held values	Great Sandy held values	Coral Sea held values	Shared value or possible conflict?
<i>Halimeda</i> & seagrass	Biodiversity & conservation, commercial fishing	Biodiversity & conservation	Biodiversity & conservation, commercial fishing, recreational fishing	Commercial fishing, biodiversity	Shared value
Hard coral	Biodiversity, coral collecting, aesthetic, cultural, tourism, recreation	Biodiversity, variably valued as people from country need to speak for their country	Biodiversity, tourism, recreation	Biodiversity, tourism, recreation	Conflict <u>within</u> jurisdictions between biodiversity values and all other values
Seabirds & shorebirds	Biodiversity & conservation, tourism, recreation	Biodiversity & conservation	Biodiversity & conservation	Biodiversity & conservation, tourism	Conflict <u>within</u> and <u>between</u> jurisdictions between biodiversity values and all other values
Commercial fishing (non-finish)	Commercial, Biodiversity, recreational	Biodiversity, cultural, traditional hunting, subsistence fishing, commercial fishing, recreational	Commercial fishing	Commercial fishing	Conflict <u>within</u> and <u>between</u> jurisdictions between biodiversity values and all other values
Targeted finfish	Commercial, recreational, traditional, biodiversity	Biodiversity, cultural, traditional hunting, subsistence fishing, commercial fishing, recreational	Commercial fishing	Commercial fishing	Conflict <u>within</u> and <u>between</u> jurisdictions between biodiversity values and all other values
Other finfish	Biodiversity, recreational fishing, tourism	Biodiversity, cultural, tourism	Biodiversity, recreational fishing, tourism	Biodiversity, recreational fishing, tourism	Conflict <u>within</u> and <u>between</u> jurisdictions between biodiversity values and all other values
Sharks	Tourism, biodiversity, recreational, cultural	Traditional hunting, subsistence fishing, recreational, biodiversity, cultural	Biodiversity, recreational fishing, tourism	Biodiversity, recreational fishing, tourism	Conflict <u>within</u> and <u>between</u> jurisdictions between biodiversity values and all other values
Dugong and turtle	Biodiversity, traditional use, totemic, cultural,	Traditional hunting, subsistence fishing, recreational, biodiversity, cultural	Biodiversity, tourism	Biodiversity, tourism	Torres Strait more focused on traditional use than other regions, which are more focused on conservation
Whales and dolphins	Biodiversity, tourism, traditional hunting	Biodiversity, tourism, traditional hunting	Biodiversity, tourism	Biodiversity, tourism	Conflict <u>within</u> jurisdictions between biodiversity values and tourism, traditional, cultural

					and recreational values
Historic shipwrecks	Historical, cultural, recreational, fish aggregation device	Historical, cultural, recreational	Historical, cultural, recreational	Historical, cultural, recreational,	Shared value
Sea country	Traditional hunting, cultural	Traditional hunting, cultural	Traditional hunting, cultural	Traditional hunting, cultural	Shared value
Islands and cays	Recreational, tourism, biodiversity, aesthetic, traditional	Recreational, tourism, biodiversity, aesthetic, traditional	Recreational, tourism, biodiversity, aesthetic, traditional	Recreational, tourism, biodiversity, aesthetic, traditional	Conflict <u>within</u> and <u>between</u> jurisdictions between biodiversity values and all other values
Mangroves	Biodiversity & conservation	Biodiversity & conservation, traditional, cultural	No data	Recreational, tourism, biodiversity, aesthetic, traditional	Conflict <u>within</u> jurisdictions between biodiversity values and tourism and recreational values

Results also show that marine attributes could be valued for a range of reasons that were conflicting across jurisdictions, however, in all cases, these were in addition to within jurisdiction conflict around held values. For example, commercial finfish species were identified as having high biodiversity value within each jurisdiction, as well as having high commercial, recreational, tourism, cultural, and subsistence values. Conflict in developing management strategies is likely to be observed both within jurisdictions and across jurisdictions. Multiple held values make it difficult to manage attributes within any one jurisdiction, as well as across jurisdictions.

In summary, the results obtained from this exercise suggest that conflicts are possible because of conflicting multiple values held for a single attribute within a jurisdiction, rather than because of differing held values across jurisdictions.

5.0 MARINE TURTLE CASE STUDY

Six of the world's seven species of marine turtle reside within the northeast Australian seascape, and there are globally significant breeding sites for four of the six species. Leatherback and Olive ridley turtles are present in the region, but do not breed. Each of the six species is listed as threatened under the Australian *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. Marine turtles in Australasia congregate around genetically distinct breeding sites, and individuals disperse or migrate out to mixed-stock foraging areas. For example, there are three genetically distinct stocks of green turtles in eastern Australia arising from breeding sites in the northern GBR and Torres Strait (e.g. Raine Island in the GBR and Maizub Kaur in Torres Strait), southern GBR (e.g. Heron Island) and the Coral Sea (e.g. the Herald Cays). While turtles for each stock aggregate in their respective areas for nesting, individuals from these stocks are dispersed throughout the south-western Pacific Ocean and the Gulf of Carpentaria (Limpus et al. 1992, Limpus 2009a,b,c,d, Read et al. 2014, Commonwealth of Australia 2017).

In addition to the connectivity between the four regions, it is likely that marine turtles residing in south-eastern Australia (NSW, Victoria and Tasmania) breed in northeast Australia or migrate through the regions towards international rookeries in New Caledonia, Solomon Islands or PNG, or to rookeries in the Arafura Sea (FitzSimmons and Limpus 2014, Read et al. 2014, Commonwealth of Australia 2017). Recovery of tagged turtles and satellite tracking results indicate that some green, flatback and hawksbill turtles residing in the Gulf of Carpentaria migrate to breeding sites in the Torres Strait or the GBR (Limpus 2009b,c,d).

The green turtle stock breeding in the Coral Sea is shared with New Caledonia – in particular, females breeding on the Australian Coral Sea islands are genetically similar to green turtles breeding on the Chesterfield reefs of New Caledonia (Read et al. 2015). Similarly, loggerhead turtles breeding in the GBR and southeast Queensland (including in the Great Sandy Straits) are part of a genetic stock that includes loggerhead turtles breeding on the islands of New Caledonia (Fitzsimmons and Limpus 2014).

The migratory nature of marine turtles is well recognised. In northern and eastern Australia there is evidence from molecular studies, satellite tracking and recoveries of tagged turtles that indicates: (1) green turtles breeding in the GBR migrate to foraging sites in Indonesia, PNG and New Caledonia (and vice versa) (Dethmers et al. 2011), (2) hawksbill turtles foraging within the GBR migrate to breed in the Solomon Islands (Miller et al. 1998), and (3) loggerhead turtles breeding in the southern GBR, Great Sandy Strait and the Woongarra Coast migrate to foraging areas in New Caledonia (and vice versa) and PNG (Limpus et al. 1992, Limpus 2009a). Satellite tracking of leatherback turtles from northern PNG indicates that the Coral Sea is an important migratory corridor and foraging site (Benson et al. 2011).

More remarkable, and less studied, are the large-scale dispersal routes of hatchling and neonate green and loggerhead turtles from breeding sites in eastern Australia. Loggerhead turtles disperse across the southern Pacific Ocean to the South American coast (Boyle et al. 2009) before returning back to the Australian region some 10 to 15 years later (Limpus 2009a). Similarly, green turtles disperse south along the EAC until they reach cooler waters,

before swimming east and north with prevailing currents and eventually returning to the Australian coast some 5 to 10 years later (Limpus 2009b, Wolanski 2016).

The high connectivity of the different life history stages of marine turtles exposes them to many threats and pressures throughout their range, which are generally well described, although data on the extent to which they impact genetic stocks is not always well understood. The recent Recovery Plan for Marine Turtles in Australia (Commonwealth of Australia 2017²) lists all existing known pressures and assigns a level of risk for each of the six turtle species in Australia. Importantly, the extent to which each pressure impacts stocks differs between species and regions. The threats ranked 'very high' and 'high' risk for marine turtle stocks in northeast Australia in the recovery plan include:

- Climate change and climate variability – all turtle stocks breeding in the region, especially green turtles from the northern GBR and flatback turtles from the GBR.
- Ingestion of or entanglement in marine debris – green (especially from the GBR), hawksbill and loggerhead turtles.
- Chronic effects of chemical and terrestrial pollution – green turtles in the southern GBR.
- International take or international fisheries pressure – loggerhead and hawksbill turtles.
- Terrestrial predation – hawksbill turtles in the northern GBR and Torres Strait.
- Light pollution – loggerhead and flatback turtles in the southern GBR and Great Sandy Strait.

Each of these pressures occurs in more than one region and addressing these cross-border pressures requires collaborative management. In Australia, both State and Federal Governments are involved in coordination. There is an Australia-wide Recovery Plan, co-developed with Queensland and NSW, which aims to coordinate actions to improve the conservation status of marine turtles. In the Torres Strait, communities and government have developed community-based management plans to manage the use of marine turtles (and dugongs) in a culturally appropriate and effective way. Since 2006, they have supported or maintained monitoring of nesting turtles and contributed towards monitoring in the northern GBR. The Queensland Government coordinates monitoring of marine turtles in the GBR and Great Sandy Strait, and several of the monitoring sites have close to 50 years of data. There is a marine wildlife-stranding database in Queensland, which is managed by the Queensland Department of Environment and Heritage Protection and GBRMPA.

In addition, Australia is a signatory to the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES), the Convention on the Conservation of Migratory Species of Wild Animals (CMS), and the Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA Marine Turtle MOU). These international conservation instruments are focused on aiding and facilitating international support for the conservation of migratory species, such as marine turtles. The Australian Government is also a signatory to a CMS Single Species Action Plan³ (Convention on Migratory Species 2014) to guide conservation actions in South Pacific Ocean nations where loggerhead turtles reside and/or breed. A key

² <http://www.environment.gov.au/marine/publications/recovery-plan-marine-turtles-australia-2017>

³ <http://www.cms.int/en/document/single-species-action-plan-loggerhead-turtle-south-pacific-ocean>

component of the action plan is to coordinate actions across multiple countries, especially in relation to minimising the frequency of bycatch in artisanal and industrial fisheries. This case study demonstrates how a highly mobile attribute, such as marine turtles, that is connected through different mechanisms across borders, can be managed in a coordinated manner. However, it also confirms that such cross-jurisdictional management requires ongoing cooperation and engagement with multiple agencies and can take many years to decades to implement.



Green turtle in seagrass meadows at Green island, offshore Cairns in the GBR (Image: Catherine Collier).

6.0 KNOWLEDGE GAPS AND FUTURE WORK

The primary knowledge gaps relate to information on key values and attributes, and the connections and inter-dependences between these values and attributes across jurisdictions. The availability of data is variable for the different values this project focused on, with a dearth of documented information for some values in some locations, such as Indigenous (cultural) resources, oceanic/pelagic systems, and mobile larvae. In particular, some marine jurisdictions have better data than others, for example, the GBR is relatively data-rich, while the Great Sandy Strait including Hervey Bay are not, despite their relative size and their internationally-recognised significance.

The key gaps that influence the confidence in results to characterize and map connectivity between the marine domains in the northeast Australian seascape relate primarily to the interactions, inter-dependencies and linkages between values (ecological, social and cultural). Examples include how sand nourishment of beaches interacts along the mainland and with coastal islands; the extent and direction of regeneration between seagrass meadows; and the cultural connections through story, song and dance and their movement across large areas. In particular, being able to map Sea Country and document the connections between areas is needed. Such knowledge gaps affect the depth in which values and their connectivity can be understood and therefore inform cross-jurisdictional management and planning.

In addition, it is unclear how the values, 62 attributes and their connectivity will change in the future given climate change projections (e.g. ocean warming, changes in the boundary currents), increasing population pressures and coastal development. An improved understanding of trends in northeast Australia's atmospheric and oceanic conditions can inform how they may impact different values in the future, including regional warming trends, trends in marine heatwaves, trends in rainfall patterns and river discharge and ecosystem disturbances including the frequency and spatial distributions of thermal stress events and cyclones. As information improves and allows clearer predictions of future drivers and pressures, it would be worth incorporating this into our understanding of connectivity of values and how this might change. Similarly, large-scale coastal developments and other activities in the northeast Australian seascape should consider how they might impact the connectivity and inter-dependencies of values and attributes, and the implications across jurisdictions. A more structured approach to assessing the cumulative impacts of future climate change and coastal development on connectivity and inter-dependencies between values would support more effective cross-jurisdictional decision-making.

While documenting and understanding connectivity of values is important for informing management, being able to fully integrate the information into policy and planning needs to be supported by research that quantifies the economic benefits of different forms of connectivity across jurisdictional boundaries and how these might be altered by future change.

Important specific information gaps to arise around connectivity among the four marine jurisdictions in the northeast Australian seascape are:

- Research into circulation variability, particularly:

- Poleward movement of the EAC bifurcation point,
 - Eddy climate – increasing eddy kinetic energy embedded in the main inflows of the SEC – awareness of prevailing current reversals,
 - Thermocline response to ENSO – whether the east coast is decoupled,
 - Upwelling and rate of warming at depth – will these regions persist on century time scales?
- Stock structure of Torres Strait Spanish mackerel. They are considered to be a separate stock to the Gulf of Carpentaria and the Queensland east coast, however the extent that the Torres Strait stock connects with the GBRMP is unknown, though likely. Their movement patterns, including movement throughout Papua New Guinea to the north and West Papua to the west, is unknown but critical for managers of Torres Strait in ensuring their sustainability.
- Stock structure of tropical (ornate) rock lobster for the east coast fishery including the Torres Strait. This is a shared resource and current work done on the stock structure of northeast Australia is incomplete and knowledge gaps remain.
- Although it is illegal for PNG trawlers to target spawning migrations of tropical (ornate) rock lobster as they make their way through the Gulf of Papua, there is no enforcement or monitoring to ensure this does not occur. Such targeting could have dramatic consequences for the Torres Strait–Queensland tropical rock lobster fishery.
- The biology of the bluespot coral trout is reasonably well documented, and they are known to occur in all four of the project jurisdictions, however their stock structure is poorly known. In particular, research is needed to better understand their connectivity between the Coral Sea Marine Reserve and jurisdictions to the west.
- Exploration of threats where the potential for management interventions isn't clear (e.g. disease outbreaks). Practical feasibility of some threat interventions require further assessment by managers, particularly those that cross boundaries.

Future work needs to focus on addressing these critical knowledge gaps, as well as how the information can be best communicated to inform cooperative management. Part of this will entail a management component to explicitly include values and attributes that are an identified cross-jurisdictional priority into relevant management planning and decisions.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This project has synthesised a range of information about attributes in the northeast Australian seascape that support the important values the region is recognised for. These values are a focus of management objectives in all four marine domains, and the connectivity maps and typing provide a resource that can inform adjacent jurisdictions about what attributes and values cross borders, and the strength and nature of those connections. Understanding the strength and type of connectivity of values/attributes, and the current condition or the integrity (“naturalness”) of connectivity processes is important for setting and prioritizing targets for cross-jurisdictional management. Values or connectivity processes that are degraded may warrant higher priority to avoid further deterioration and to protect against further erosion of resilience to the point where recovery is difficult. Recognising when a value or process is degraded is also important for setting targets. Degraded values or processes may require managers to strive for a net improvement in condition, rather than just minimising further impact.

The assessment of threats to attributes and the prioritisation of collaborative management identified key targets for cross-jurisdictional management. The values that would benefit most from cross-jurisdictional management arrangements are those with the following characteristics:

- Occur in several jurisdictions (e.g. migratory species which spend all, or part of their life cycles within several jurisdictions),
- Are under threat,
- Have strong connections across borders, and
- Currently lack complementary management in all jurisdictions.

Jurisdictions that share threats are invariably connected through ecological transfer of propagules, migration of adults or evolutionary linkages. Where risks are high, increased effort to coordinate management of threats across jurisdictions represents an important strategy for protecting the aspects of connectivity contributing to the sustainability of attributes. At the same time, more coordinated management can help to minimise the potential for threats to move from one jurisdiction to another.

Further, the prioritisation results can focus management efforts to target limited resources where they will have the greatest benefit for conserving values and achieving objectives. The prioritisation results identify which attributes have the strongest connectivity across borders and least coordinated or effective management, and are therefore targets for improved cross-jurisdictional management. The threats assessment provides insight into what pressures need to be addressed for values that cross borders and are the focus of collaborative management. Importantly, the prioritisation output can be updated as new information becomes available, or if management changes. For example, if new research demonstrates that the connectivity of an attribute between two adjacent jurisdictions is stronger than initially thought, the score for that attribute would change and it would most likely increase in priority for cross-jurisdictional management. Likewise, if management of an attribute is currently under a regional management plan that includes all jurisdictions (e.g. Recovery Plan for Marine Turtles in Australia or National Dugong and Turtle Protection Plan) and that joint arrangement changes, the score for that attribute would change and it would most likely increase in priority.

Based on the findings of this project, the key recommendations for collaborative management of the northeast Australian seascape involving all four relevant jurisdictions are:

1. **Raise awareness and inform** all levels of government and relevant authorities across all jurisdictions of the importance of coordinating management of marine values/attributes that cross jurisdictions.
2. **Establish formal and trusting working relationships** amongst management authorities in adjacent jurisdictions. For example, set up a Coordination Working Group to discuss values, connectivity and results of the prioritisation, and arrange regular meetings for collaborative management and complementary policy and planning.
3. **Develop collaborative agreements** for cross-jurisdictional management of connected priority values/attributes.
4. **Identify mechanisms to improve the alignment of existing management** (including zoning and other forms of spatial management, policy and management plans) with adjacent marine areas through participation in more regular coordination meetings.
5. **Prioritise research** to fill key knowledge gaps that will inform the focus of future cross-jurisdictional management and appropriate management actions.
6. **Periodically update connectivity information and the prioritisation assessment** using expert elicitation and the automated prioritisation tool. The methods developed in the project should be re-applied to update the maps and prioritisation outputs every 2-3 years to build on the results, improve confidence in the data and help support improved alignment between jurisdictions.

The results of this study provide targets for management, in terms of what species, habitats, resources or human activities should be the focus of cooperation between jurisdictions, and where these values and attributes have the strongest connectivity across borders. Many of the recommendations of this project focus on greater cross-jurisdictional collaboration and governance; for example, the development of a Northeast Coordination Working Group and collaborative agreements. However, we have deliberately not dictated what governance mechanisms or paradigm shifts should be implemented in order to achieve improved cross-jurisdictional management. While critically important, such discussions and decisions need to be a priority for managers, for example at an initial Coordination Working Group meeting.

An examination of the main channels of knowledge exchange for linking policy and planning found that researchers were the main conduit on an *ad hoc* basis, and there were no formal mechanisms for cross-jurisdictional collaboration between managers (Wise et al. 2011). This is not a desirable situation, and more formal coordination mechanisms that facilitate adaptive management are needed. Patterns of knowledge exchange to inform policy and planning were found to present significant communication barriers to adaptive management (Wise et al. 2011). This has been demonstrated by a study that systematically assessed national, joint (national and Queensland), and Queensland policies and plans governing migratory species in the Great Barrier Reef World Heritage Area, Torres Strait, the Coral Sea, and the Great Sandy Strait (Pullin and Stewart 2006). The results of this study reinforce this critical need for cross-jurisdictional communication and cooperation to facilitate adaptive management, but only managers and government can identify a suitable mechanism to achieve this.

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APPENDIX A: EXPERT WORKSHOP PARTICIPANTS

Name	Organisation	Representation
Kahlytah Ahwang	CSIRO	Indigenous values (Torres Strait)
Line Bay	Australian Institute of Marine Science	Coral reefs & genetic connectivity
Jessica Benthuisen	Australian Institute of Marine Science	Physical drivers of connectivity
Mick Bishop	AMSA	Maritime response (oil spills)
Jon Brodie	JCU Centre of Excellence	COTS, wetlands & estuaries
Catherine Collier	JCU TropWater	Seagrass
Brad Congdon	James Cook University	Seabirds (biology & Coral Sea management)
Jon Day	JCU Centre of Excellence	GBR management and planning
Guillermo Diaz-Pullido	Central Queensland University	Halimeda & macroalgae
Piers Dunstan	CSIRO	Values in marine ecosystems (Marine Biodiversity Hub)
Libby Evans-Illidge	Australian Institute of Marine Science	Connectivity & Torres Strait
Karin Gerhardt	James Cook University	Indigenous & social values
Eliza Glasson	GBRMPA	Heritage & social values
Paul Groves	GBRMPA	Wetlands & estuaries
Mark Hamann	James Cook University	Marine turtles (biology & management)
Jim Higgs	WWF	Fisheries & conservation
Karlo Hock	University of Queensland	Larval dispersal & connectivity
Peter Illidge	GBRMPA	Historic heritage
Melissa Jess	Reef & Rainforest Research Centre	TWQ Hub coordinator
Johanna Johnson	James Cook University	Principle Investigator & Facilitator
John Kung	QDAFF	Queensland fisheries

Alicia Loveless	Queensland Parks and Wildlife	Queensland marine parks planning & policy
Eric Lawrey	Australian Institute of Marine Science	eAtlas mapping and tools
Paul Marshall	University of Queensland	GBR biodiversity & habitats
Nadine Marshall	CSIRO	Heritage & social values
Len McKenzie	JCU TropWater	Seagrass
John Olds	Queensland Parks and Wildlife	Marine Park management (pest species, islands & vegetation)
Tristan Simpson	Torres Strait Regional Authority	Torres Strait region
Colin Simpfendorfer	James Cook University	Sharks & rays
Peter Spear	Australian Institute of Marine Science	Pelagic fish & habitats
Craig Steinberg	Australian Institute of Marine Science	Physical drivers of connectivity
Sven Uthicke	Australian Institute of Marine Science	Invertebrates (adults & larval dispersal)
David Welch	James Cook University	Fisheries species & larval dispersal
Maria Zann	Queensland Environment & Heritage Protection	Great Sandy Straits biodiversity and planning

APPENDIX B: THREATS AND PRESSURES ASSESSMENT

Summary of the results of the assessment of threats and pressures for each attribute rated on a scale of 0-2 where 0= pressure not a significant influence on the attribute, 1= pressure known to exercise significant influence on attribute or known to represent moderate risk, and 2= pressure is a major risk to the sustainability of the attribute.

[illegible]

[illegible]

APPENDIX C: MANAGEMENT PRIORITISATION RESULTS

Attribute	Connectivity	Relevant management in J1 (Torres Strait)	Relevant management in J2 (GBRMP Far Northern)	Management consistent in J1 & J2	Current status of the value	Management focus	Relative score
Intangible cultural resources	2	3	1	3	3	10	20
Scalloped hammerhead	2	3	1	3	3	10	20
Tangible cultural resources	2	3	2	2	3	10	20
Dogtooth tuna	2	3	3	3	1	10	20
Pelagic foraging seabirds	2	3	1	3	2	9	18
recreational use	2	3	2	2	2	9	18
Blacktip shark (<i>C. limbatus</i>)	2	3	1	3	2	9	18
Blacktip shark (<i>C. tilstoni</i>)	2	3	1	3	2	9	18
Coral reefs	2	1	1	3	3	8	16
<i>Pisonia grandis</i>	2	1	1	3	3	8	16
Inter-reefal gardens	2	3	1	3	1	8	16
Tiger shark	2	2	2	2	2	8	16
Tourism Destination	2	2	1	2	2	7	14
Seagrasses	2	1	1	3	2	7	14
Black Teatfish	2	1	1	2	3	7	14
location of sea country	2	1	2	2	2	7	14
Reef manta	2	2	2	1	1	6	12
Coral trout (<i>P. laevis</i>)	2	2	2	1	1	6	12
Hawksbill turtle	2	1	1	1	3	6	12
Loggerhead turtles	2	1	1	1	3	6	12
Spanish Mackerel	2	1	1	2	2	6	12
Shorebirds	1	3	2	3	3	11	11

Green turtles	2	1	1	1	2	5	10
Flatback turtle	2	1	1	1	2	5	10
Location of commercial fishing	2	2	1	1	1	5	10
Grey reef shark	1	3	2	3	2	10	10
Inshore & Offshore foraging seabirds	1	3	1	3	2	9	9
Coral trout (<i>P. leopardus</i>)	2	1	1	1	1	4	8
Ornate rock lobster	2	1	1	1	1	4	8
<i>Argusia argentia</i>	2	1	1	1	1	4	8
Grey mackerel	1	3	1	3	1	8	8
Yellowfin tuna	1	3	1	2	2	8	8
Longfin Eels + Shortfin Eels	1	3	1	3	1	8	8
Black marlin	1	1	1	2	2	6	6
Dugongs	1	1	1	2	2	6	6
Sand fish	1	1	1	2	2	6	6
Mangroves	1	2	1	1	1	5	5
Saltmarsh	1	2	1	1	1	5	5

Attribute	Connectivity	Relevant management in J1 (Coral Sea)	Relevant management in J2 (Torres Strait)	Management consistent in J1 & J2	Current status of the value	Collaborative management effectiveness	Relative score
Intangible cultural resources	2	3	3	3	3	12	24
Pelagic foraging seabirds	2	2	3	3	2	10	20
Dogtooth tuna	2	3	3	3	1	10	20
<i>Pisonia grandis</i>	2	1	1	3	3	8	16
Ornate rock lobster	2	3	1	3	1	8	16
Tiger shark	2	2	2	2	2	8	16
Black Teatfish	2	1	1	2	3	7	14
Blacktip shark (<i>C. limbatus</i>)	1	3	3	3	2	11	11
Scalloped hammerhead	1	2	3	2	3	10	10

Grey reef shark	1	2	3	3	2	10	10
Coral reefs	1	2	2	3	3	10	10
Inter-reefal gardens	1	3	3	3	1	10	10
Inshore & Offshore foraging seabirds	1	2	3	3	2	10	10
Longfin Eels + Shortfin Eels	1	3	3	3	1	10	10
Tangible cultural resources	1	3	3	2	2	10	10
Coral trout (<i>P. laevis</i>)	1	3	2	3	1	9	9
Spanish Mackerel	1	3	1	3	2	9	9
Tourism Destination	1	2	3	3	1	9	9
recreational use	1	3	3	2	1	9	9
Seagrasses	1	3	1	3	1	8	8
Yellowfin tuna	1	1	3	2	2	8	8
location of sea country	1	3	1	3	1	8	8
<i>Argusia argentia</i>	1	3	1	2	1	7	7
Black marlin	1	1	1	2	2	6	6
Reef manta	1	2	2	1	1	6	6
Hawksbill turtle	1	1	1	1	3	6	6
Loggerhead turtles	1	1	1	1	3	6	6
Green turtles	1	1	1	1	2	5	5

Attribute	Connectivity	Relevant management in J1 (Coral Sea)	Relevant management in J2 (GBRMP Far Northern)	Management consistent in J1 & J2	Current status of the value	Collaborative management effectiveness	Relative score
Dogtooth tuna	2	3	3	3	1	10	20
Longfin Eels + Shortfin Eels	2	3	1	3	1	8	16
Ornate rock lobster	2	3	1	3	1	8	16
Tiger shark	2	2	2	2	2	8	16
<i>Pisonia grandis</i>	2	1	1	2	3	7	14
Pelagic foraging seabirds	2	2	1	2	2	7	14
Inshore & Offshore foraging seabirds	2	2	1	2	2	7	14

Black Teatfish	2	1	1	2	3	7	14
Yellowfin tuna	2	1	1	2	2	6	12
Black marlin	2	1	1	2	2	6	12
Coral reefs	1	2	2	3	3	10	10
Blacktip shark (<i>C. limbatus</i>)	1	3	1	3	2	9	9
Coral trout (<i>P. laevis</i>)	1	3	2	3	1	9	9
Seagrasses	1	3	1	3	2	9	9
Tangible cultural resources	1	3	2	2	2	9	9
Grey reef shark	1	2	2	2	2	8	8
Scalloped hammerhead	1	2	1	2	3	8	8
<i>Argusia argentia</i>	1	3	1	3	1	8	8
Inter-reefal gardens	1	3	1	3	1	8	8
Reef manta	1	2	2	1	1	6	6
Hawksbill turtle	1	1	1	1	3	6	6
Loggerhead turtles	1	1	1	1	3	6	6
Green turtles	1	1	1	1	2	5	5

Attribute	Connectivity	Relevant management in J1 (Coral Sea)	Relevant management in J2 (GBRMP Cooktown/Cairns)	Management consistent in J1 & J2	Current status of the value	Collaborative management effectiveness	Relative score
Intangible cultural resources	2	3	3	3	3	12	24
Location of sea country	2	3	2	3	2	10	20
Dogtooth tuna	2	3	3	3	1	10	20
Longfin Eels + Shortfin Eels	2	3	1	3	1	8	16
Tiger shark	2	2	2	2	2	8	16
<i>Pisonia grandis</i>	2	1	1	2	3	7	14
Pelagic foraging seabirds	2	2	1	2	2	7	14
Inshore & Offshore foraging seabirds	2	2	1	2	2	7	14
Black Teatfish	2	1	1	2	3	7	14

recreational use	2	3	1	2	1	7	14
Yellowfin tuna	2	1	1	2	2	6	12
Black marlin	2	1	1	2	2	6	12
Tourism Destination	2	2	1	2	1	6	12
Location of commercial fishing	2	1	1	1	2	5	10
Seagrasses	1	3	1	3	3	10	10
Blacktip shark (<i>C. limbatus</i>)	1	3	1	3	2	9	9
Coral reefs	1	2	1	3	3	9	9
Coral trout (<i>P. laevis</i>)	1	3	2	3	1	9	9
Grey reef shark	1	2	2	2	2	8	8
Scalloped hammerhead	1	2	1	2	3	8	8
<i>Argusia argentia</i>	1	3	1	3	1	8	8
Inter-reefal gardens	1	3	1	3	1	8	8
Tangible cultural resources	1	3	1	2	2	8	8
Ornate rock lobster	1	3	1	3	1	8	8
Reef manta	1	2	2	1	1	6	6
Hawksbill turtle	1	1	1	1	3	6	6
Loggerhead turtles	1	1	1	1	3	6	6
Green turtles	1	1	1	1	2	5	5

Attribute	Connectivity	Relevant management in J1 (Coral Sea)	Relevant management in J2 (GBRMP Tsv/Whit)	Management consistent in J1 & J2	Current status of the value	Collaborative management effectiveness	Relative score
Intangible cultural resources	2	3	3	3	3	12	24
Dogtooth tuna	2	3	3	3	1	10	20
Longfin Eels + Shortfin Eels	2	3	1	3	1	8	16
Tiger shark	2	2	2	2	2	8	16
<i>Pisonia grandis</i>	2	1	1	2	3	7	14
Pelagic foraging seabirds	2	2	1	2	2	7	14
Inshore & Offshore foraging seabirds	2	2	1	2	2	7	14

Black Teatfish	2	1	1	2	3	7	14
Seagrasses	1	3	1	3	3	10	10
Blacktip shark (<i>C. limbatus</i>)	1	3	1	3	2	9	9
Coral trout (<i>P. laevis</i>)	1	3	2	3	1	9	9
Coral reefs	1	2	1	3	3	9	9
Grey reef shark	1	2	2	2	2	8	8
Scalloped hammerhead	1	2	1	2	3	8	8
Ornate rock lobster	1	3	1	3	1	8	8
<i>Argusia argentia</i>	1	3	1	3	1	8	8
Inter-reefal gardens	1	3	1	3	1	8	8
Tourism Destination	1	3	2	2	1	8	8
Tangible cultural resources	1	3	1	2	2	8	8
recreational use	1	3	1	2	1	7	7
Black marlin	1	1	1	2	2	6	6
Reef manta	1	2	2	1	1	6	6
Hawksbill turtle	1	1	1	1	3	6	6
Loggerhead turtles	1	1	1	1	3	6	6
Yellowfin tuna	1	1	1	2	2	6	6
Green turtles	1	1	1	1	2	5	5

Attribute	Connectivity	Relevant management in J1 (Coral Sea)	Relevant management in J2 (GBRMP Mackay/Cap)	Management consistent in J1 & J2	Current status of the value	Collaborative management effectiveness	Relative score
Dogtooth tuna	2	3	3	3	1	10	20
Longfin Eels + Shortfin Eels	2	3	1	3	1	8	16
Tiger shark	2	2	2	2	2	8	16
<i>Pisonia grandis</i>	2	1	1	2	3	7	14
Pelagic foraging seabirds	2	2	1	2	2	7	14
Inshore & Offshore foraging seabirds	2	2	1	2	2	7	14
Black Teatfish	2	1	1	2	3	7	14

Loggerhead turtles	2	1	1	1	3	6	12
Saucer scallop	1	3	1	3	3	10	10
Seagrasses	1	3	1	3	3	10	10
Blacktip shark (<i>C. limbatus</i>)	1	3	1	3	2	9	9
Coral trout (<i>P. laevis</i>)	1	3	2	3	1	9	9
Coral reefs	1	2	1	3	3	9	9
Grey reef shark	1	2	2	2	2	8	8
Scalloped hammerhead	1	2	1	2	3	8	8
Ornate rock lobster	1	3	1	3	1	8	8
<i>Argusia argentia</i>	1	3	1	3	1	8	8
Inter-reefal gardens	1	3	1	3	1	8	8
Tangible cultural resources	1	3	1	2	2	8	8
Reef manta	1	2	2	1	1	6	6
Black marlin	1	1	1	2	2	6	6
Hawksbill turtle	1	1	1	1	3	6	6
Yellowfin tuna	1	1	1	2	2	6	6
Green turtles	1	1	1	1	2	5	5
Location of commercial fishing	1	1	1	1	1	4	4

Attribute	Connectivity	Relevant management in J1 (Coral Sea)	Relevant management in J2 (Great Sandy Strait)	Management consistent in J1 & J2	Current status of the value	Collaborative management effectiveness	Relative score
Dogtooth tuna	2	3	3	3	1	10	20
Longfin Eels + Shortfin Eels	2	3	1	3	1	8	16
Tiger shark	2	2	2	2	2	8	16
Loggerhead turtles	2	1	1	1	3	6	12
Yellowfin tuna	2	1	1	2	2	6	12
Saucer scallop	1	3	1	3	3	10	10
Blacktip shark (<i>C. limbatus</i>)	1	3	1	3	2	9	9
Coral reefs	1	2	1	3	3	9	9

Seagrasses	1	3	1	3	2	9	9
Inter-reefal gardens	1	3	1	3	2	9	9
Scalloped hammerhead	1	2	1	2	3	8	8
Ornate rock lobster	1	3	1	3	1	8	8
<i>Argusia argentia</i>	1	3	1	3	1	8	8
Tangible cultural resources	1	3	1	2	2	8	8
Black marlin	1	1	1	2	2	6	6
Reef manta	1	2	2	1	1	6	6
Hawksbill turtle	1	1	1	1	3	6	6
Green turtles	1	1	1	1	2	5	5
Location of commercial fishing	1	1	1	1	1	4	4

Attribute	Connectivity	Relevant management in J1 (GBRMP Mackay/Cap)	Relevant management in J2 (Great Sandy Strait)	Management consistent in J1 & J2	Current status of the value	Collaborative management effectiveness	Relative score
Inshore & Offshore foraging seabirds	2	2	3	3	2	10	20
Shorebirds	2	2	2	3	3	10	20
Dogtooth tuna	2	3	3	3	1	10	20
Pelagic foraging seabirds	2	1	3	3	2	9	18
location of sea country	2	2	2	2	3	9	18
Saucer scallop	2	1	1	3	3	8	16
Tiger shark	2	2	2	2	2	8	16
Grey Nurse Shark	2	2	1	2	3	8	16
Intangible cultural resources	1	3	3	3	3	12	12
Scalloped hammerhead	2	1	1	1	3	6	12
Loggerhead turtles	2	1	1	1	3	6	12
Black marlin	2	1	1	2	2	6	12
Reef manta	2	2	2	1	1	6	12
Coral reefs	2	1	1	1	3	6	12
Seagrasses	2	1	1	1	3	6	12

Saltmarsh	2	1	1	1	3	6	12
Inter-reefal gardens	2	1	1	2	2	6	12
Dugongs	2	1	1	1	3	6	12
Yellowfin tuna	2	1	1	2	2	6	12
Location of commercial fishing	2	1	1	1	3	6	12
Green turtles	2	1	1	1	2	5	10
Spanish Mackerel	2	1	1	1	2	5	10
recreational use	2	1	1	1	2	5	10
Tangible cultural resources	2	1	1	1	2	5	10
Grey mackerel	2	1	1	1	1	4	8
Mangroves	2	1	1	1	1	4	8
<i>Argusia argentia</i>	2	1	1	1	1	4	8
Coral trout (<i>P. laevis</i>)	1	2	3	1	1	7	7
Hawksbill turtle	1	1	1	1	3	6	6
Blacktip shark (<i>C. limbatus</i>)	1	1	1	1	2	5	5
Blacktip shark (<i>C. tilstoni</i>)	1	1	1	1	2	5	5
Flatback turtle	1	1	1	1	2	5	5
Sand fish	1	1	1	1	2	5	5
Tourism Destination	1	1	1	2	1	5	5
Coral trout (<i>P. leopardus</i>)	1	1	1	1	1	4	4
Ornate rock lobster	1	1	1	1	1	4	4
Longfin Eels + Shortfin Eels	1	1	1	1	1	4	4



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