Tropical Water Quality Hub

National Environmental Science Programme

Final Report

Supplementary Synthesis Report: Connectivity and inter-dependencies of values in the northeast Australia seascape

Supplementary Report (Part 2)

Johanna E. Johnson, David J. Welch, Paul A. Marshall, Jon Day, Nadine Marshall, Craig R. Steinberg, Jessica A. Benthuysen, Chaojiao Sun, Jon Brodie, Helene Marsh, Mark Hamann and Colin Simpfendorfer

JAMES COOK UNIVERSITY AUSTRALIA

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Johanna E. Johnson[1,2], David J. Welch[1,3], Paul A. Marshall[4,5], Jon Day[6], Nadine Marshall[7], Craig R. Steinberg[8], Jessica A. Benthuysen[8], Chaojiao Sun[7], Jon Brodie[6], Helene Marsh[1], Mark Hamann[1] and Colin Simpfendorfer[9]

[1] School of Marine and Tropical Biology, James Cook University
[2] C_2O Consulting, Cairns, Australia
[3] C_2O 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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Cover photographs: (front) Green turtle, David Welch; (back) Intertidal Whitsundays, Johanna Johnson

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ACRONYMS

BoM .... [Australian] Bureau of Meteorology
CITES………..Convention on International Trade in Endangered Species Wild Fauna & 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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1.0 INTRODUCTION

The northeast Australia marine area has one of the world's most extensive continental shelves, and is recognised for its ecological complexity and biodiversity, as well as its social, economic and cultural values. The northeast Australia marine 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 marine area is a complex of interconnected ecosystems containing a range of habitats, species and processes that extend over large distances. The values of the ecosystem, and the pressures and impacts that threaten the 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.

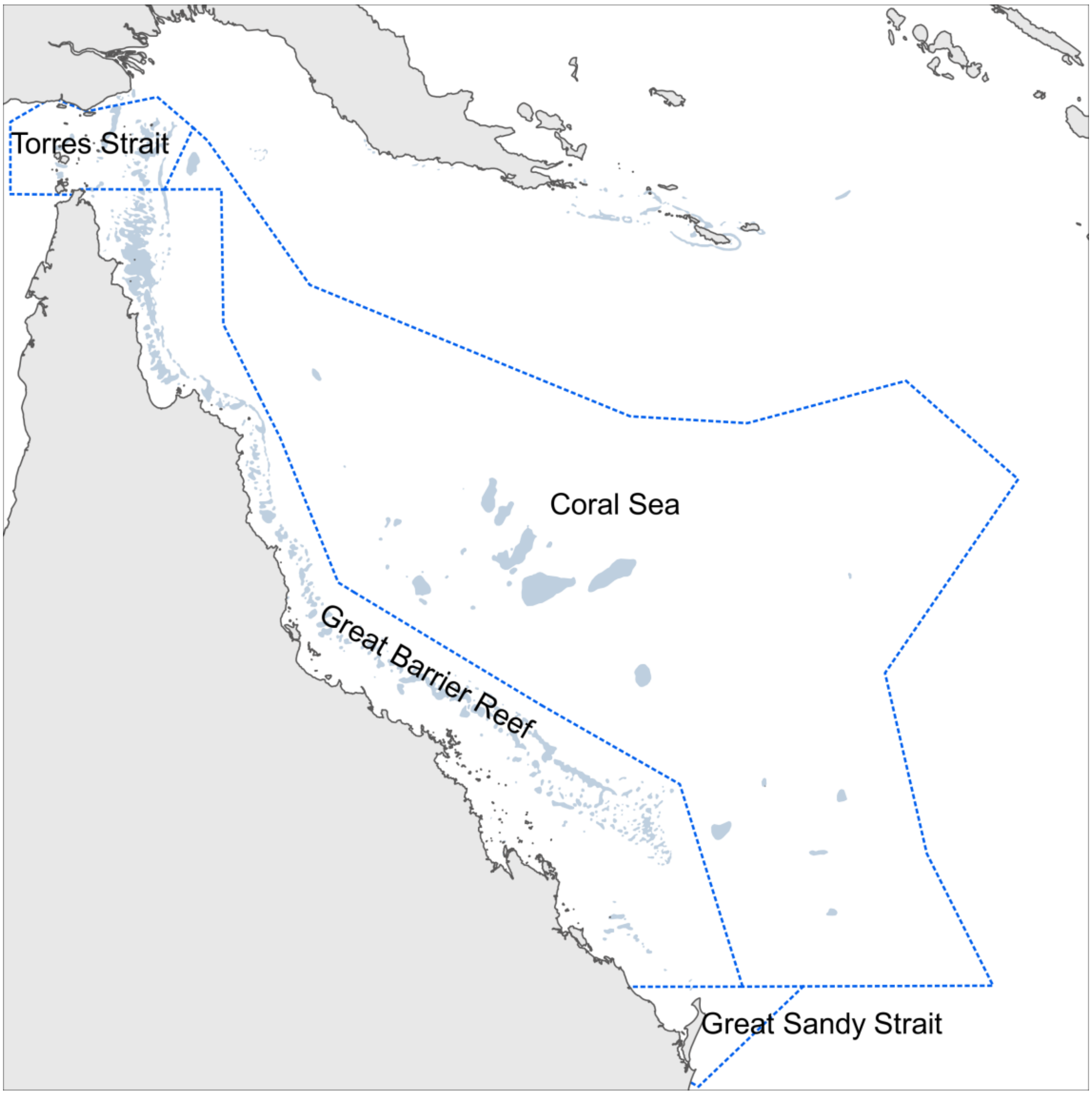

Figure 1: Map of project area known as the northeast Australia seascape, including the Great Barrier Reef, Torres Strait, Coral Sea, and Great Sandy Strait/ Hervey Bay.

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, commercial species and migratory species. The area has a multitude of habitats including coral reefs, inter-reefal areas, mangroves, seagrass meadows, estuaries, and islands and cays. The clear waters and coral reefs provide habitat for hundreds of species of plants and animals, 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.

The northern boundary of the GBR World Heritage Area (GBRWHA) extents to Cape York and excludes the Torres Strait, a relatively pristine environment with an estimated 680 coral reefs (Lawrey et al. 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 supports many species of fish, seabirds, marine turtles, sharks and unique cold-water corals, including many species not found within the GBR (Beaman et al. 2016, Webster et al. 2008). Coral Sea reefs may be 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 purported 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 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 (Lucas et al. 1996, 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. 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 with 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 et al. 2016, Ganachaud et al. 2011, 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.

1.1 Objectives

The outputs of this project will provide accessible and relevant information on ecosystem values and connectivity at scales that can support informed decision-making and management for the northeast Australia marine area, and will broadly support steps towards holistic "seascape" management.

This project has three main objectives:

1. Synthesise existing information relating to values and their connectivity for all jurisdictions in the broader northeast Australia marine region (GBR, Torres Strait, Coral Sea, Great Sandy). Including established values where 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 Australia marine region.

1.2 Current management linkages

In terms of management approaches, there are some clear similarities and differences across the four jurisdictions. Table 1 lists some of the legislative 'tools' which apply across all, or some, of the 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 GBR Region'* (Kenchington and Day 2011).

Queensland legislation clearly applies in Great Sandy but some State legislation also applies in the other jurisdictions (e.g. Queensland fisheries legislation in the GBR). For example, most of the 1,050 islands within the outer boundaries of the GBR are under Queensland jurisdiction and are not part of the GBR Marine Park, 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 the 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). Table 1 identifies the range of national and international legislation and formal arrangements for the four marine jurisdictions, and Table 2 lists examples of management tools addressing different management issues, noting that only a few of these apply across all four jurisdictions.

Some thematic issues (e.g. most aspects of shipping) are managed in a consistent way across the four jurisdictions. Other management issues like 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 what is done where, when addressing similar management issues elsewhere.

The values that would benefit most from cross-jurisdictional management arrangements are obviously those which occur in several jurisdictions (e.g. migratory species which spend all, or part of their life cycles within several jurisdictions), are under threat, and don’t currently have complementary management in all jurisdictions.

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 Qld and the Commonwealth in the GBR) – the close working partnership between the federal management agency (GBRMPA) and the state of Queensland has been a key component of the success of the GBR. This relationship has evolved over 40 years and includes aspects such as complementary legislation 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.

There are also less formal arrangements for management occurring across jurisdictions (e.g. the operations of the Australian Border Force which assists with surveillance in the Torres Strait, GBR and Coral Sea). And a range of advisory groups/forums designed to assist managers in one jurisdiction that 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 also examples where the differing jurisdictions haven't built upon existing management arrangements and instead created stakeholder confusion by being inconsistent across jurisdictional boundaries. For example, the colours used for various zone types differ in the Coral Sea compared to the same zones (but different colours) in the adjoining waters of the GBR Marine Park.

Table 1: Main legislation applying to the four jurisdictions (Black cells indicate where the legislation isn't applicable).

KEY LEGISLATIVE TOOLS	Torres Strait	GBR	Great Sandy	Coral Sea
COMMONWEALTH LEGISLATION				
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)	Yes	Yes	Yes	Yes
Environment Protection (Sea Dumping) Act 1981	Yes	Yes	Yes	Yes
Historic Shipwrecks Act 1976	Yes	Yes	Yes	Yes
Navigation Act 2012	Yes	Yes	Yes	Yes
Native Title Act 1993	Yes	Yes	Yes	Yes
Protection of the Sea (Prevention of Pollution from Ships) Act 1983	Yes	Yes	Yes	Yes
Sea Installations Act 1987	Yes	Yes	Yes	Yes
Great Barrier Reef Marine Park Act 1975		Yes		
Great Barrier Reef Marine Park Regulations 1983		Yes		
Great Barrier Reef Marine Park (Aquaculture) Regulations 2000		Yes		
Torres Strait Fisheries Act 1984	Yes			
QUEENSLAND LEGISLATION				
Aboriginal Cultural Heritage Act 2003		Islands only	Yes	
Coastal Protection and Management Act 1995		Islands only	Yes	
Environmental Protection Act 1994			Yes	
Fisheries Act 1994		Yes	Yes	
Great Barrier Reef Protection Amendment Act 2009 (Qld)		Yes		
Integrated Planning Act 1997		Islands only	Yes	
Local Government Act 1993		No	Yes	
Land Act 1994		Islands only	Yes	
Mineral Resources Act 1989		No	Yes	
Marine Parks Act 1982 (and 2004?)		Qld waters only	Yes	
Marine Parks (GGBR Coast) Zoning Plan 2004		Qld waters only	Yes	
Marine Parks Regulation 2006		Qld waters only	Yes	
Maritime Safety Queensland Act 2002			Yes	

Mineral Resources Act 1989		No		
Native Title (Queensland) Act 1993		Yes (Islands)		
Nature Conservation Act 1992		Yes (islands)	Yes	
Queensland Heritage Act 1992		Yes (lighthouses)	Yes	
Recreation Areas Management Act 1988		Green Island only		
State Coastal Management Plan Queensland's Coastal Policy 2001		Yes (Islands)		
State Development and Public Works Organisation Act 1971		Yes (Islands)		
Sustainable Planning Act 2009		Yes (Islands)	Yes	
Torres Strait Islander Cultural Heritage Act 2003	Yes			
Transport Operations (Marine Pollution) Act 1995			Yes	
Transport Operations (Marine Safety) Act 1994		Yes	Yes	
Transport Infrastructure Act 1994			Yes	
Vegetation Management Act 1999		Islands only	Yes	
Water Act 2000			Yes	
Workplace Health and Safety Act 1995.		Yes	Yes	
INTERNATIONAL AGREEMENTS/CONVENTIONS				
Convention for the Protection of World Cultural and Natural Heritage, 1972		Yes	Yes (Fraser is)	
Convention on Biological Diversity, 1992	Yes	Yes	Yes	Yes
Convention on International Trade in Endangered Species of Wild Fauna and Flora, 1973 (CITES)	Yes	Yes	Yes	Yes
Convention on the Conservation of Migratory Species of Wild Animals, 1979 (BONN)	Yes	Yes	Yes	Yes
Convention on Wetlands of International Importance Especially as Waterfowl Habitats, 1971 (RAMSAR)		Shoalwater Bay only	Yes	
International Convention for the Prevention of Pollution from Ships, (MARPOL) 1973	Yes	Yes	Yes	Yes
Japan–Australia Migratory Bird Agreement, 1974 (JAMBA)	Yes	Yes	Yes	Yes
China–Australia Migratory Bird Agreement, 1986 (CAMBA)	Yes	Yes	Yes	Yes
Republic of Korea–Australia Migratory Bird Agreement, 2007 (ROKAMBA)	Yes	Yes	Yes	Yes

Torres Strait Treaty	Yes			
United Nations Convention on the Law of the Sea, 1982 (UNCLOS)	Yes	Yes	Yes	Yes
United Nations Framework Convention on Climate Change, 1992 (UNFCCC)	Yes	Yes	Yes	Yes

Table 2: Examples of management tools for thematic issues and jurisdictions they apply.

KEY THEMATIC MANAGEMENT TOOLS	Torres Strait	GBR	Great Sandy	Coral Sea
Examples of tools for Water Quality				
National Water Quality Management Strategy	Yes	Yes	Yes	Yes
Reef Rescue. Australian Government election commitment		Yes		
Reef Water Quality Protection Plan (Reef Plan) 2003, 2009, 2013, 2017		Yes		
Water Quality Guidelines for the GBR Marine Park 2009		Yes		
Annual Report Cards		Yes		
Strategy for the Conservation and Management of QLD's wetlands			Yes	
Environmental Protection (Water) Policy 2009			Yes	
Paddock to Reef Integrated Monitoring Program 2009 (in revision)		Yes		
Examples of tools for fisheries management				
(Qld) Fisheries Act and Regulations	Recreational fishing only	Yes (but not all fisheries)	Yes	
Torres Strait Fisheries Act 1984	Commercial fishing only			
National Compliance and Enforcement Policy			No	Yes
East Coast Otter Trawl Fishery Plan	No	Yes	Yes	
East Coast Coral Reef Line Fishery Plan	No	Yes	Yes	
East Coast Inshore Finfish Fishery Plan	No	Yes	Yes	
East Coast Dive-based Fishery Plan	No	Yes	Yes	
Coral Sea Fishery Plan	No	No	No	Yes
Great Sandy Regional Marine Aquaculture Plan 2011			Yes	
Eastern Tuna and Billfish Fishery Management Plan		Yes (but only some fisheries)	No	Yes

Examples of tools for shipping management				
Marine Orders				
GBR, Torres Strait and Coral Sea PSSA (Particularly Sensitive Sea Area)	Yes	Yes	No	Yes
Associated Protective Measures (APMs)	Yes	Yes		Yes
Examples of tools for climate change				
Climate Change and the Great Barrier Reef: A Vulnerability Assessment -		Yes		
Climate Change Action Plan 2007-2012		Yes		
Coral Bleaching Response Plan 2010-2011		Yes		
Torres Strait Climate Change Strategy 2014-18	Yes			
Examples of tools for tourism management				
Environmental Management Charge (EMC)				
Cairns Area and Whitsundays Plans of Management				
Onboard - Tourism Operators' Handbook for the GBR.				
High Standard Tourism Program				
Whitsunday and Mackay Islands Visitor Management Strategy				
Examples of tools for biodiversity conservation				
EPBC Act – provision for threatened spp, MNES, migratory spp	Yes	Yes	Yes	Yes
EHP threatened species plans & Wetlands program				
Seagrass mapping	Yes	Yes	Yes	No
Threat Abatement Plans (AG) for marine debris etc.				
World Heritage Listing	No	Yes	Yes	No
Marine turtle recovery plan and CMS-action plan for loggerhead turtles				

Miscellaneous management tools				
eReefs models		Yes		
TUMRAs (includes Port Curtis Coral Coast with Great Sandy)	No	Yes		No
Reef 2050 plan	No	Yes	No	No

Table 3: Identified management linkages between the four marine jurisdictions and how collaborative management can be improved.

Jurisdiction	Current linkages between jurisdictions	Formal or informal	Priority values for cross-jurisdictional management	How to facilitate cross-jurisdictional management	Opportunities and barriers
GBR	– Intergovernmental (AG-QLD) agreement for joint MP mgt – Fisheries and mangroves – eReefs models – Coral Sea zoning complements GBR Marine Park zones – Reef Plan includes river discharges south of MP – WH listing includes Great Sandy Strait and GBR – Joint estuaries mgt with Qld – TUMRAs includes Port Curtis Coral Coast with Great Sandy – Indig. compliance with TSRA – AMSA & MSQ for shipping	– Formal – Formal – Informal – Informal – Formal – Formal – Formal – Formal – Informal – Formal	– Tourism permitting system between GBR and Coral Sea – Historic shipwrecks – COTS mgt between GBR and TSRA – Protection of coral source reefs in Coral Sea – Migratory fish and seabirds – Research with universities – Water quality with TS, Coral Sea and PNG	– Improved coordination between jurisdictions, esp. TS-GBR and Coral Sea-GBR – Clear consistent objectives between jurisdictions – Consistent shipping mgt, zoning etc. – Linking WHAs to simplify reporting – More mgt funding – Better understanding of cross cultural values	– Co-mgt between TOs GBR-TS – Consistent compliance and enforcement, e.g. Indig and other groups (Border Force) – Poor communication around combining all areas into one mgt system to recognise single ecosystem – Adopt TS community-based approach to mgt – Regional fisheries mgt – Sharing of information and lessons
Torres Strait	– PZJA (AG & PNG) high level policy – Fisheries mgt (AFMA and Australian Border force) – Queensland legislation enforced for sewage plants, industrial discharges, shipping, landfill, pesticide use – Monitoring and research (NRM) *ad hoc* and based on relationships – Traditional governance variable – Shipping	– Formal – Formal – Informal – Informal – Formal (Native Title) & informal – Formal	– Improve coordination between TS-nGBR for fisheries research, monitoring and mgt – Formalise and coord mgt of water quality with northern GBR, including with PNG	– Include TOs in monitoring and mgt with formal consultation process for decisions – Identify consistent mgt for sea claims, Traditional governance, land & sea mgt – Clarify terminology – GBR is NOT the WHA alone and does include the TS (and CS) and mgt, monitoring and funding should be more evenly spread	– Sharing of information and lessons – Cross-jurisdiction annual mtg to discuss joint issues (include TOs), e.g. fisheries, bleaching, COTS, WQ – Expand 'Eye on the Reef' community-based reporting/monitoring and share data – Expand eReefs to include TS and broader ocean circulation model – Joint decision-making body for marine mgt of <u>all</u> jurisdictions (policy, legislation, monitoring,

					compliance etc.)
Great Sandy Strait	– Reef 2050 Plan – Paddock to Reef – Intergovernmental (AG-QLD) agreement for joint MP mgt – Approvals process for fisheries – QPWS (NPSR) field mgt agreement with GBRMPA – Peak bodies (NGOs, QSIA) – Research linkages – TO Agreements – EHP threatened species – Island and marine conservation network in QPW – EHP Wetlands program – Seagrass zoning and mapping – QPWS values based mgt framework	– Formal – Formal – Formal – Formal – Formal – Informal – Informal – Formal – Formal – Formal – Formal – Formal – Formal	– Moreton Bay connectivity and linkages – Consistency of Zoning bw GS-GBR and gaps – Water quality coord of catchment mgt of Burnett Mary Rivers that influences the southern GBR and Hervey Bay – Habitat mgt for shorebirds/ coastal birds under NCA, Marine Parks Act, EPBC – Migratory spp – whales, turtles, dugong – Fisheries productivity and stocks	– Clarify jurisdictional roles and capacity, and where co-mgt is needed – Consistent/coord fisheries mgt, e.g. scallop, shark mgt that's needed across borders – Better referral process for marine activities that influence multiple jurisdictions – LMAC for Great Sandy Strait is needed	– Opportunity to manage the risk assoc with unzoned Cth waters (gaps bw jurisdictions) – Cross-jurisdictional consistent mgt of AG waters (GBR-CS-TS) and into Great Sandy – Peak bodies/NGOs can cross borders and offer regional and global scale research and monitoring – Cross-jurisdictional working groups are an opportunity – AG to fund cross-jurisdictional research
Coral Sea	– EPBC Act – threatened & migratory species, MNES – Marine turtle recovery plan and CMS-action plan for loggerhead turtles – Draft Coral Sea Management Plan consulted on shared areas of concern – Intent to formalize links with New Caledonia – Threat Abatement Plans (AG) for marine debris etc. – Fisheries legislation – Commercial shipping legislation and regulations – MARPOL/CMS – Sustainable fisheries section in DoEE	– Formal – Formal – Informal – Informal (at present) – Formal – Formal – Formal – Formal – Formal	– Fisheries – Migratory spp – cetaceans, turtles, seabirds, sharks – Islands – Seabird conservation dependent on fisheries mgt – Key ecological features – BIAs in EPBC Act	– Intra-agency organization with different divisions/ groups in DoEE responsible for CS and GBR – Better communication with all other jurisdictions – Need to increase capacity to manage and communicate with other jurisdictions	– Sharing of information and lessons – Key ecological features and BIA can be tools for better cross-jurisdictional mgt

2.0 CHARACTERISTICS AND STATUS OF VALUES

Values can be *held*, *relational* or *assigned*, and each can be associated with an individual or can be shared amongst a group or community (Goddard et al. 2018). 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 often 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 (see Appendix 1). Below is a description of the values and attributes selected in the project and a synthesis of available information in their current status and trends in the northeast Australian seascape.

2.1 Natural Heritage Values

Habitats & Biodiversity

Coral reefs

Coral reefs are the key habitat providers within coral reef ecosystems. As biogenic structures built through the accretion of calcium carbonate by scleractinian corals, crustose coralline algae and other calcifying species, they are the result of complex associations between a diverse community of organisms. Although the reef-building species comprising this community are generally sessile, most have reproductive strategies that include a pelagic larval phase. As a result, connectivity between physically isolated reefs can be strong, often spanning large distances. Therefore, despite the predominantly sessile nature of reef-building organisms, there is a need to consider the potential for connectivity across jurisdictions when designing or implementing management measures for these values.

Mainland beaches & Islands

The northeast Australia marine area has a significant length of coastline that includes estuaries, coastal beaches and wetlands (tidal and ephemeral freshwater) and islands and cays (see Figure 1). Notable among these are the continental islands of Curtis, Facing, Hinchinbrook, Fraser Islands and the Torres Strait islands. Mainland beaches and islands support nesting and migratory species, fisheries and marine tourism. Islands are critically important seabird and marine turtle nesting sites (e.g. Raine Island, Curtis Island, Bramble Cay) (GBRMPA 2013). Globally important populations of loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*) and flatback (*Natator depressus*) turtles nest on the islands of the region and forage in nearby waters (Hamann et al. 2007).

Mainland beaches and islands provide a stepping-stone between coastal, inshore and offshore waters, as well as latitudinally from the Torres Strait in the north to Hervey Bay in the south. The connections of genetic and geochemical materials driven by ocean currents, wind and waves, demonstrates the inter-dependencies between the four marine jurisdictions as well as internationally. While cross-jurisdictional management can improve the prospects for species that move between and utilise the beaches and islands of Australia, there remain strong biophysical connections with PNG, Vanuatu, New Caledonia and Solomon Islands that will continue to influence values in the northeast Australia marine area.

Estuaries & tidal habitats

Estuaries and tidal habitats in northeast Australia include numerous freshwater wetlands, floodplains and lagoon systems that provide coastal protection, nutrient cycling and important habitat for fish and invertebrates, and species such as turtles, dugong, and dolphins. The size of estuaries and tidal habitats varies seasonally due to natural variations in climate, flow, geography, geology and soils as well as variations relating to diverse anthropogenic activities (Flint et al. 2013, Ryan et al. 2003, Wolanski 2014, Brodie and Waterhouse 2016). Many of the palustrine, lacustrine, riverine and modified freshwater habitats are ephemeral (seasonally dry) but are also prone to extensive flooding (Pearson 2016). There are many nationally important wetlands in the northeast Australia marine area including three Ramsar sites (GBRMPA 2016, Waterhouse et al. 2016).

In the northeast Australia marine area, there is a wide range of basins that drain through estuaries directly into the marine environment, including large basins into the GBR and Great Sandy Strait/ Hervey Bay to the south, and short basins in the Torres Strait. Estuaries and tidal habitats are not present in the Coral Sea (Figure 2). The Torres Strait is unusual as there are few large estuaries on the islands, however, the marine environment is influenced by three major estuaries in PNG – the Fly, Jardine and Mai rivers (Figure 3).

In river high flow events, estuaries extend far offshore into an estuarine plume zone that enters marine waters and can influence marine habitats and species (Devlin et al. 2012). Some estuaries in northeast Australia are very large, e.g. Great Sandy Strait, while others are small, e.g. Mai River in Torres Strait. Land-use pressures and coastal development, particularly in highly urban or industrial areas affect estuaries, such as around major cities (e.g. Townsville, Cairns, Bundaberg) and industrial hubs (e.g. Gladstone, Mackay). The downstream effects of agricultural pollutants, such as nutrients, sediments and pesticides, can also impact estuaries.

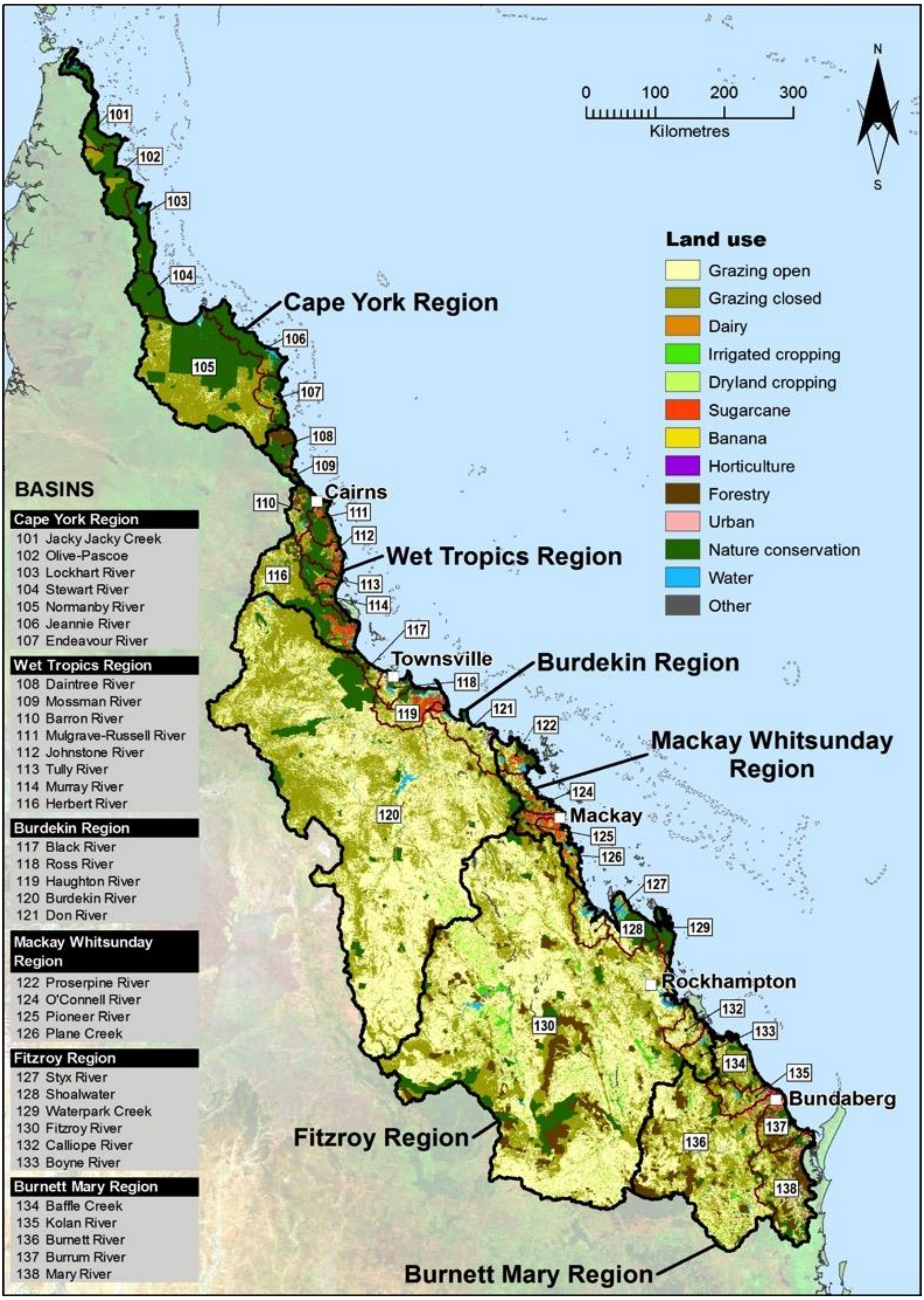

Figure 2: Basins with estuaries between Cape York and Fraser Island draining into the Great Barrier Reef and Great Sandy Strait/ Hervey Bay.

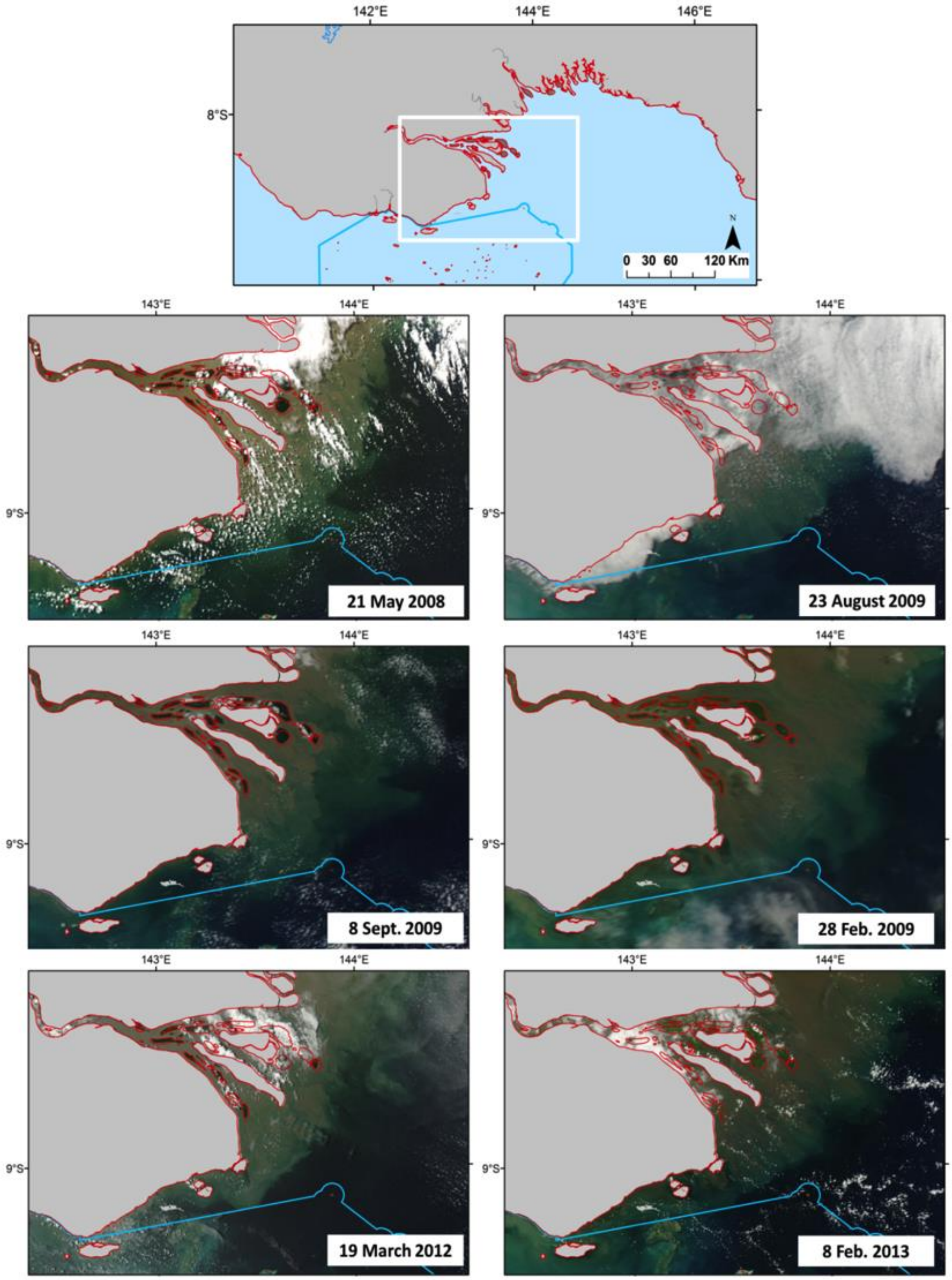

Figure 3: Satellite imagery of the Fly River estuary during high flow periods, showing the extent of the flood plume and its influence on Torres Strait marine environments.

While some estuaries remain in good condition, many others have suffered degradation as a result of historic and continuing land use practices (Waterhouse et al. 2016). Human structures, such as dams and weirs, modify the natural hydrology of rivers and creeks, altering the length of estuaries and the tidal range, resulting in loss of habitat and changes to the natural hydrodynamic characteristics (Connell et al. 1981).

Despite the recognised economic, social, cultural and ecosystem values associated with coastal wetlands, wetland loss and degradation in Australia has been estimated at more than 50% over the last 200 years (Finlayson 2000). Wetland losses may be even higher in Queensland at between 70 and 90% (GBRMPA 2009). Threats to wetland habitats and species include coastal development (particularly clearing or modifying vegetation), the ongoing influence of past management practices, damage by feral animals, grazing, illegal dumping, weeds, pollution, and changes to upstream flows and water quality (Flint et al. 2014, Johnson et al. 2015).

Seagrass meadows

Seagrass meadows are a major marine habitat in the northeast Australia seascape and are a component of marine ecosystems, contributing to total primary carbon production as well as providing regionally important dugong and turtle habitat and supporting productive fisheries. There are estimated to be 3,063 km^2 of shallow seagrass meadows (<15 m depth), and 31,778 km^2 of deep seagrass meadows including modelled deep-water meadows (Coles et al. 2015) in northeast Australia (Figure 4). Results of inshore seagrass monitoring show declines in 2011/12 in coastal meadows in the southern GBR, which appear to be the consequence of local scale disturbances (e.g. sediment or sand bank movement). In contrast, seagrass meadows in Torres Strait and Hervey Bay remain in good condition and spatially extensive.

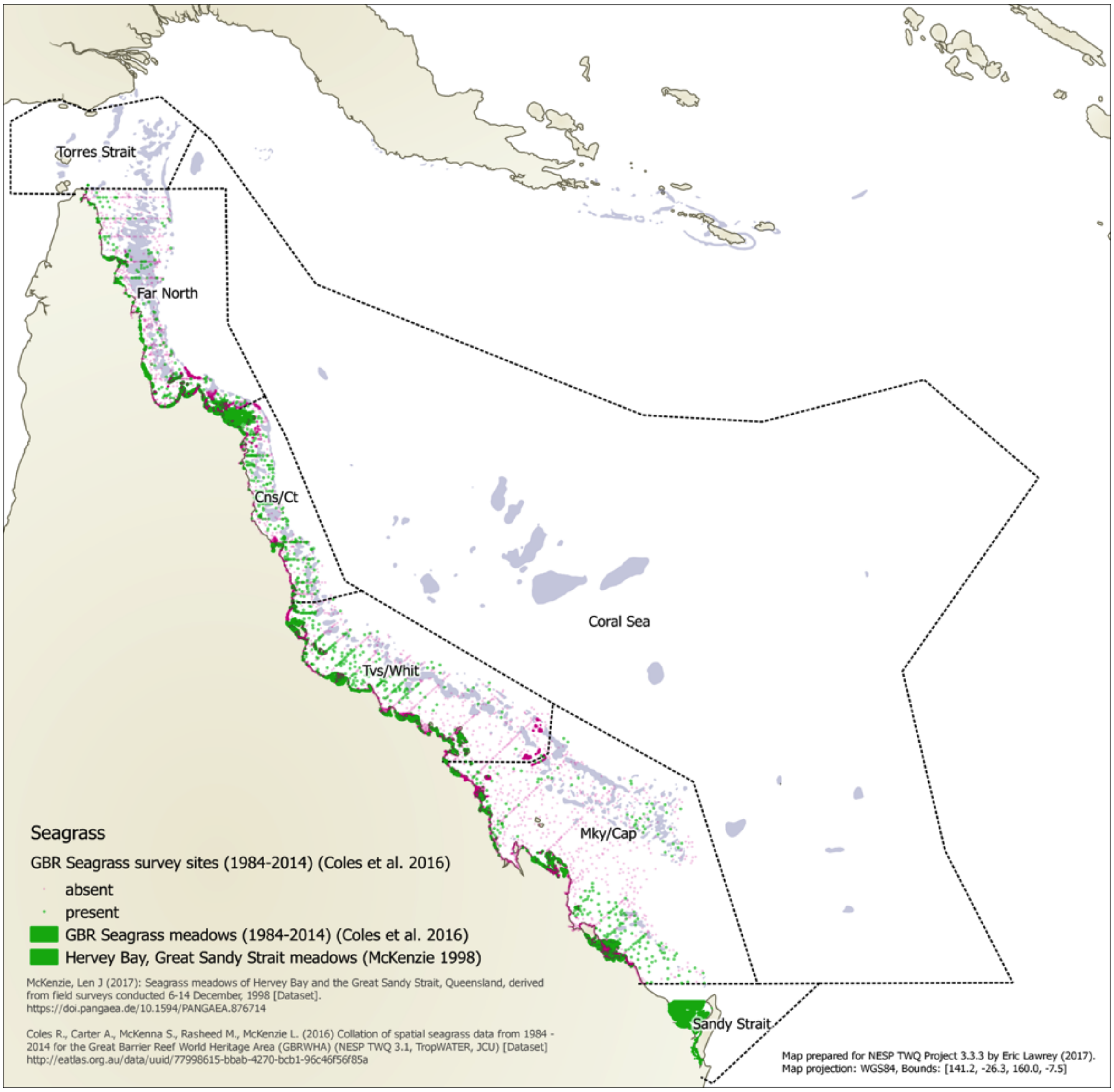

Figure 4: Spatial distribution of seagrass meadows in the northeast Australia seascape; represented in green in the GBR and Great Sandy Strait, and yellow in Torres Strait. Source: eAtlas data (2017).

The Torres Strait has some of the most extensive seagrass meadows in northern Australia that support populations of threatened species and fisheries resources, and the area has been described as the most extensive, ecologically complex shelf in the world. Eleven species of seagrass have been recorded in Torres Strait providing a high diversity of species.

Seagrass meadows in Hervey Bay are one of the largest single areas of seagrass resources on the eastern Australian seaboard. Six species of seagrass have been reported from Hervey Bay (*Halophila spinulosa, Halophila ovalis, Halophila decipiens, Zostera capricorni, Halodule uninervis* and *Ruppia maritima*) (Seagrass-Watch data[1]). The Great Sandy Strait contains 5,554 hectares of shallow seagrass meadows that form part of the significant Ramsar wetlands, are within the Great Sandy Marine Park, and provide critical nursery habitat for

[1] http://www.seagrasswatch.org, Accessed 5 July 2017.

prawn and finfish fisheries. Seven species of seagrass have been reported in the Great Sandy Strait (*Zostera capricorni, Halodule uninervis, Halophila ovalis, Halophila decipiens, Halophila spinulosa, Cymodocea serrulata* and *Syringodium isoetifolium*) (Seagrass-Watch data[1]).

Inter-reefal habitats

Inter-reefal (or non-reef) areas comprise a complex mix of physical environments across the entire northeast Australia seascape but are less studied than reef areas. There are some similarities in inter-reefal habitats across the four marine domains, for example, the Torres Strait is similar to northern habitats of the GBR[2] and deep-water habitats of the GBR are similar to adjacent habitats of the Coral Sea, but the majority of the Coral Sea and Great Sandy Strait are unique and comprised of different inter-reefal areas to the GBR or Torres Strait.

Great Barrier Reef

The Representative Areas Program (RAP) mapped 40 non-reef bioregions across the GBR (see Appendix 2). These non-reef habitats collectively comprise approximately 92% of the GBR (Table 4) and are therefore a significant value of the ecosystem.

Table 4: Overview of biodiversity of habitats in the Great Barrier Reef (GBRMPA 2013).

Habitats/communities	Percentage of GBRMP
Seagrass, shoals and sandy or muddy seabed (up to 200 m deep)	~61%
Mangroves	~0.6%
Fringing reefs, mid-shelf reefs and outer reefs	7%
Continental shelf/slope	~15%
Deep-water habitats	16%
Islands	~1%

The GBR lagoon floor habitat is 61% of the GBR area, and has an average depth of between 20 and 40 m. There is a wide range of inter-reefal habitats within the GBR *"…due to varying riverine inputs, tides, currents and upwellings, seasonal winds, waves and cyclonic winds, with different combinations of these forces governing the topography, grain size and composition of sediments, the chemical properties of the overlying waters and therefore the nature of seabed assemblages and their dynamics"* (Pitcher et al. 2007). Pitcher et al. (2007) have shown differing cross-shelf patterns that change more quickly across the shelf than latitudinally. *"For example, about a third of the coast from about Mackay south is sandy not muddy, as is the fat northern coast from Shelbourne Bay north… Conversely much of the mid-shelf from about Mackay south is muddy not sandy, as is the far northern inner/mid shelf from about Shelbourne Bay north; the outer shelf from about Innisfail to Cooktown has significant areas of high carbonate mud fraction. The Capricornia section is almost entirely sand… …*

[2] Some 550 coral reefs in the Torres Strait are part of the same reef ecosystem as the GBR.

While the coastal areas are almost always shallow, much of the outer shelf north of about Cooktown is about as shallow as the inner and mid-shelf, as is the Swains even though it is the most offshore area in the region. In the southern GBR, the mid-shelf is the deepest…".

Some other important aspects of inter-reefal areas in the GBR include:

- ***Halimeda* algal banks** - substantial *Halimeda* banks exist inside the Ribbon Reefs passages of the northern GBR but also in the central northern GBR. Dominated by a live veneer of the calcareous green algae *Halimeda* which dies to forms banks, typically up to 20 metres thick, on the seafloor usually in waters 40 metres or more deep. Their distribution is determined by "*a complex interaction of outer-shelf geometry, regional and local currents, coupled with the morphology and depth of continental slope submarine canyons determining the delivery of cool, nutrient-rich water upwelling through inter-reef passages*". Recent work by McNeil et al. (2016) reveals the morphology is far more complex than previously thought. They describe three morphological sub-types distributed in a cross-shelf pattern of reduced complexity from east to west. The northern GBR bioherms cover an area of 6095 km^2, three times larger than the original estimate, exceeding the area and volume of calcium carbonate in the adjacent modern shelf-edge barrier reefs. Also recently mapped was a 1740 km^2 bioherm complex north of Raine Island not previously recorded, extending the northern limit > 1° of latitude (McNeil et al. 2016).
- In the **macro-tidal areas** of Broad Sound and Shoalwater Bay, tidal currents are the dominant force influencing the mobility and grain size properties and contrasting with the rest of the GBR. Along the GBR there are also latitudinal differences in flushing rates and the amplitude of seasonal variation in SST and salinity
- **Shoals** are submerged features on the seafloor in areas away from obvious emergent coral reefs. They may be unconsolidated sediments of sand, rubble, rock or reef substrate, or structurally more complex and diverse communities of filter feeders and corals. Harris et al. (2013) have shown that *"only about 39% of available seabed on submerged banks is capped by NSS coral reefs (16 110 km^2); the other 61% of bank area (25 600 km^2) is submerged at a mean depth of around 27 m and represents potential deep reef habitat that is spatially distributed along the GBR continental shelf in the same latitudinal distribution as NSS reefs. Out of 25 600 km^2 of submerged bank area, predictive habitat modelling indicates that more than half (around 14 000 km2) is suitable habitat for coral communities".*
- **Drowned (or submerged) reefs** were identified by Harris et al. (2013), i.e. coral reefs that grew during lower sea-levels, which now lie in depths greater than those typically associated with modern coral reefs. In the GBR, "*an extensive line of drowned reefs are found along the shelf-edge in depths of about 40 to 70 m. These drowned reefs lie in deeper waters compared to the shallow reefs that people see when they visit the Great Barrier Reef. … narrow in width, just a few 100s of m wide, and run parallel with the shelf break where the edge of the shelf meets the continental slope".*

The **continental slope** (~15% of the GBR) is a complex area, composed of relic reefs, landslides, canyons and plateaux, which extends down to more than 2000 metres.
"Seaward of the outer barrier reefs in about 100 m of water, the seafloor begins the steep drop that marks the start of the continental slope, which does not flatten out until reaching the abyssal plain at depths of over 1000 m. On the northern GBR the continental slope has an underwater terrain that is just as rugged as any of the mountain ranges to the west of Cairns. Cutting deeply into the slope are dozens of submarine canyons which carry sediment shed

from the continental shelf into the deep abyss. The canyons are the conduits for the enormous debris slides and slump deposits found at the base of the continental slope which spread for tens of kilometres across the flat, abyssal plain (Beaman 2008).

In 2007, Beaman mapped "*a series of underwater landslides along the GBR margin. Some of these landslides … occurred right at the continental shelf edge, in about 90 m water depth about where sea level was positioned near the last ice age. The Viper Slide (named because of its proximity to Viper Reef), represents a collapse of the shelf edge 7 km long with debris up to 5 km spreading down the upper slope…. Smaller shelf edge and upper slope slides were found clustered around the central GBR area, likely related to the over-steepening (steeper gradients) of the upper slope due to the shelf-edge delta developed by the paleo-Burdekin River".*

Two huge landslide scarps, up to 20 km long, were found that stretch the full height of the continental slope. The Gloria Knolls slide, offshore Cairns, lies in depths 300-1000 m. About 20 km downslope are eight knolls, 10s to several 100 m high, that are the remains of the debris from this slide. Also in the central GBR, the Bowl Slide (named due to its proximity to Bowl Reef), is another huge slide stretching from 200 to 900 m. Other distinct features on the continental slope identified by Beaman include Gloria Knolls and the Noggin Block.

Deep-water habitats (including abyssal plains) are more abundant in the Coral Sea and are covered in the section below.

Torres Strait

The Torres Strait covers an area of 48,000 km^2 between Cape York and Papua New Guinea, of which 2.6% is land, 6.2% is reefs, and 91.2% is inter-reefal habitats, most of which is relatively shallow (20–60 m). The region is protected from swell by the northern GBR and has strong tidal currents and complex bathymetry with a narrow continental shelf. Strong physical drivers – large tidal ranges, strong currents and turbidity – have influenced the formation and character of the ~1,200 east-west coral reefs and shallow shoals with intervening passages, generally <12 m deep. Coral reefs dominate on the eastern shelf and are contiguous with the northern GBR, while seagrass habitats dominate in the more turbid and sediment-laden conditions in the west that are influenced by a number of small coastal rivers flowing into the Gulf of Papua (Haywood et al. 2007).

Torres Strait has large tides up to 3 m and current speeds up to 5 knots in the central and western parts where velocities are accelerated. In places, the strong tidal currents have created submarine sand-waves and sandbanks. Research on the benthic habitats has been fairly limited (Haywood et al. 2007).

Coral Sea

The Coral Sea consists of a number of basins interspersed with plateaus and rises covering the large geographic extent between the Australian continental shelf (i.e. the GBR) and the Solomon Islands/Vanuatu arc to the east. The primary geomorphic inter-reefal features are broadly characterised as offshore plateaus, terraces, deep-water basins/troughs, seamounts and abyssal plains; this complex seafloor topography stretches across a broad latitudinal (8^o-23^{o}S) and depth range that can be sub-divided into four broad environments:

- inner shelf environment (0-25 m depth)
- outer shelf environment (25-250 m depth)
- continental slope environment (250-700 m depth)
- abyssal environment (>700 m depth)

There are three marginal **plateaus** offshore of the GBR that formed during the break-up of the continental crust and subsequent seafloor spreading. The Queensland Plateau is the largest (~ 165,000 km^2) of these marginal plateaus. It has been described as a 'biogeographic island' with 50% of the plateau in water depths of <1,000 m surrounded on all sides by deeper waters. Living reefs cover 10-15% of the plateau surface; these are emergent reefs and may have relict fauna dating back to the Pleistocene. On the plateau surface are several distinct terraces at depths of approx. 500-600 m. On the basis of water depth, the Queensland Plateau can be divided into a north-west half that falls in this provincial bioregion and a south-east half that falls in the Northeast Province. The north-west half of the plateau is 1000 to 2000 m deep and the south-east half is less than 1000 m deep. The northern edge of the plateau falls steeply to the abyssal plain of the Coral Sea Basin at around 4000 m deep. The western side of the plateau drops down to the Queensland Trough at around 2900 m deep. Prominent terraces occur at 450 to 500 m depth, and carbonate platforms that provide foundations for present reefs are at 50 m depth. There are numerous drowned reefs on the platform, and some large isolated pinnacles on the western edge of the plateau.

Marion Plateau covers approx. 77,000 km^2. Eastern Plateau has a surface of approx. 31,000 km^2 and is gently convex in shape, with an average water depth on the plateau of >1,500 m.

Deep sea or **submarine canyons** occur in the north where the Queensland Plateau drops into the Coral Sea Abyssal Basin, and also in the Cape Province bioregion. Bligh Canyon is a relatively straight depression with a valley floor up to 10 km wide and valley sides with gradients of between 3^o and 20^o (Harris et al. 2005).

Canyons are areas of topographically-induced upwelling and are important influences on faunal abundance and composition along the continental shelf and slope. Canyons channel upwelling water over the slope and shelf, while seasonal down-welling (winter cooling) may reverse the flow through these structures (Prince 2001).

Basins/marginal depressions are formed through seafloor spreading, e.g. Pandora Trough is an *"elongate basin 250 km long and 50 km wide on the western margin of the Eastern Plateau…"* (Harris et al. 2005). Others include Bligh Trough (~200 km long), Queensland Trough, the Townsville Trough and the Coral Sea Basin (with water depths > 4,000 m)

Seamounts exist running north-south in the Coral Sea, at approximately 155^oE longitude, is the Tasmantid Seamount Chain, a prominent chain of submarine volcanoes extending into the Tasman Basin (Harris et al. 2005). Some of these seamounts support reefs (e.g. Wreck, Kenn and Cato Reefs) while the southern seamounts are deeper and remain solely as submarine seamounts (e.g. Fraser and Recorder seamounts).

Abyssal plains are vast areas bordered by submerged plateaus and separated by broad troughs and valleys. Relatively flat plains and plateau tops have numerous finer-scale abyssal hills, or ridges and knolls.

Appendix 3 summarises the geomorphic features in the Coral Sea, Torres Strait and Great Sandy Strait.

Great Sandy Strait

The Great Sandy Strait is one of Australia's few passage landscapes where a river's outflow is blocked by an offshore island (Fraser Island). The area includes a range of marine and coastal environments, including rocky shores, fringing reefs, mangroves, seagrass meadows and sandy beaches. The intertidal sand banks, mud flats and calm waters are ideal for shallow seagrass beds, mangrove forests, salt marshes and saltpans, and important feeding grounds for shorebirds, dugong, turtles, dolphins, fish, molluscs and crustaceans.

The Great Sandy Strait is one of the three most important summer stopovers in Australia for migratory waders (birds) from the northern hemisphere, and as a result, the site is listed under the Ramsar Convention.

Hervey Bay's waters are protected by Fraser Island. The island has extensive surf beaches, separated by rocky headlands. The protection provided by Fraser Island has led to the formation of shallow bays and sheltered channels, which blend into seagrass meadows, mudflats and mangroves**.** The diversity of marine and intertidal habitats within the Marine Park includes seagrass, mangroves, salt marshes, surf and sheltered beaches, rocky headlands, estuaries, coral reefs, rocky reefs and sand and mud banks. Extensive seagrass meadows, estimated at 2500 km^2, grow on sand and mud from intertidal areas to a depth of 32 m, and are significant feeding grounds for marine turtles and dugong.

Sand is the dominant sediment type associated with the geomorphic features found in this bioregion including shelf, slope and shallow water terraces. Sediment texture is relatively homogenous, dominated by sand with localised gravel deposits and negligible mud.

Breaksea Spit, north of Fraser Island, is an extensive sand spit exposed to the energy of the open ocean. It is the shallowest point, with a depth of 1 m whereas the deepest point in the same bioregion is 240 m. The formation of the spit continues due to the transportation of sand along Australia's east coast by long shore transport (drift). As the sand travels north, it creates shoals and underwater dune fields. North of the Great Sandy Strait, this sand disappears over the continental shelf into the deep ocean. The canyons off Breaksea Spit that feed into the deep sea valley are examples of modern active canyons; the only other example of an active canyon in Australia is in Bass Strait.

Connectivity within and between the northeast Australia seascape

A recent synthesis of the broadscale ecological processes, and the direction, strength and timescale of connectivity between marine ecosystems (Ceccarelli et al. 2013) across the four jurisdictions demonstrates that there is spatial variation (Figure 5). Further, consideration of the connectivity beyond the Coral Sea concludes that:

"The Coral Sea's character changes latitudinally in response to oceanographic-topographic interactions. The reefs and Islands have unique assemblages that show varying degrees of connectivity within the Coral Sea, links to the western Pacific, individual sectors of the GBR and the wider Indo-pacific beyond." (Ceccarelli et al. 2013)

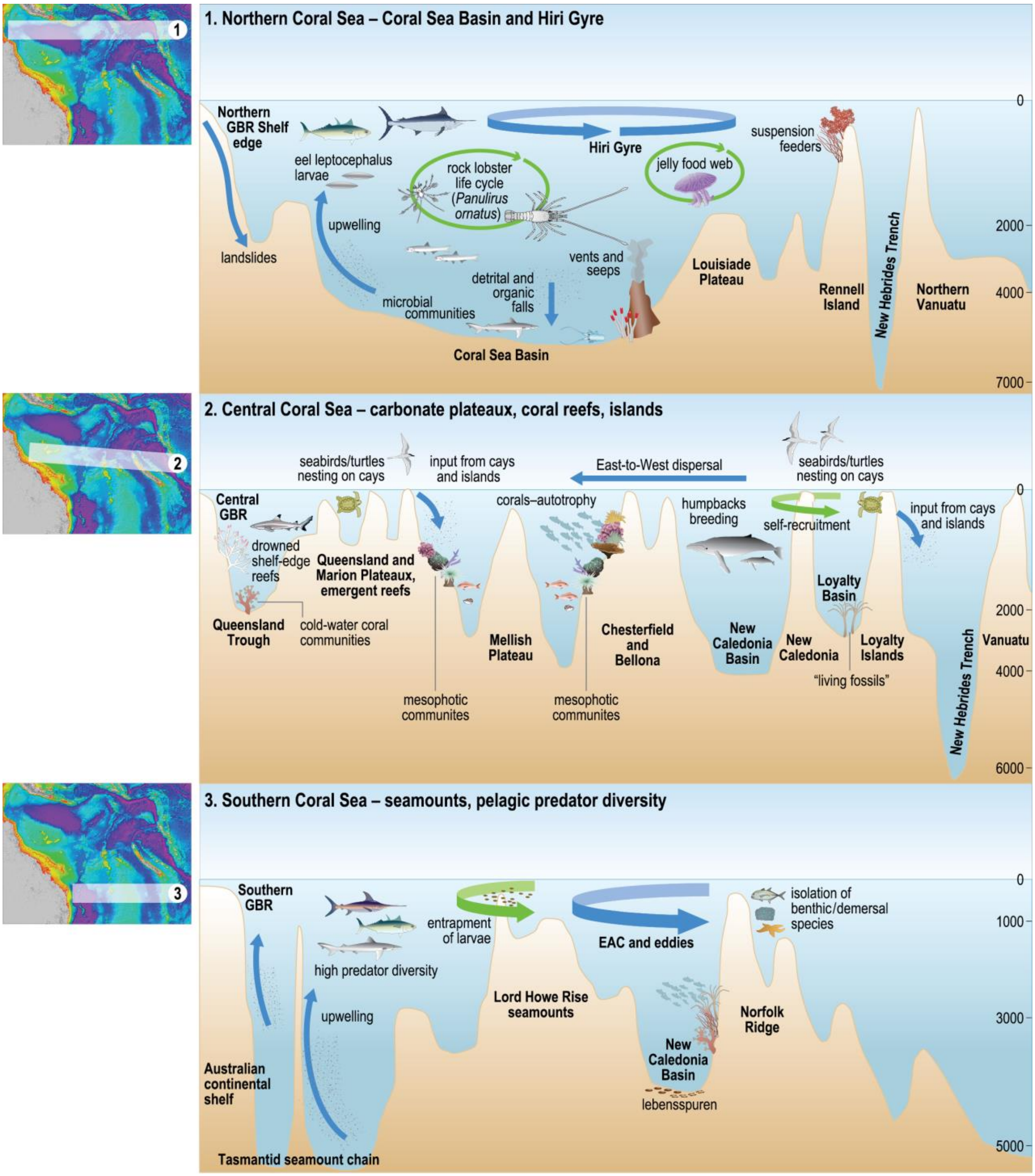

Figure 5: Key features and defining features of the northern, central and southern Coral Sea. Cross-section profiles adapted from bathymetry data provided by R. Beaman (Source: Ceccarelli et al. 2013)

Oceanic & pelagic systems

The open water environment represents a key habitat for a number of specialist pelagic species, and also supports the larvae of many species of fish, invertebrates and corals. Pelagic ecosystems are strongly influenced by upwelling processes on which most oceanic primary productivity depends. Upwelling brings nutrient-rich waters to the surface and is influenced by the vertical structure of the water masses and the depth and strength of the thermocline, all of which regulate the availability of nutrients. The production of phytoplankton at the base of the food web supports higher trophic species and is primarily constrained by the availability of nutrients, such as nitrogen, and/or micro-nutrients, such as iron. Because phytoplankton rapidly exhaust the limited nutrients of surface waters, substantial primary production occurs only where deep, nutrient-rich waters are brought to the surface by upwelling and eddies, or when the thermocline becomes shallower and/or weaker allowing the diffusion of nutrients from the deep nutrient-rich water masses towards the surface (Le Borgne et al. 2011). In turn, production of organisms at higher trophic levels in the food web (zooplankton, micronekton, mid-level and top predators) are constrained by variations in phytoplankton production, and directly by environmental factors such as temperature.

The tropical pelagic assemblages that oceanic systems can support are diverse with great variation in body size, from tiny viruses to whales. Plankton includes viruses, bacteria, cyanobacteria (e.g. Trichodesmium), dinoflagellates, diatoms, copepods, larvaceans, arrow worms, larval forms of invertebrates and fishes, and tiny jellyfishes (Kingsford and Welch 2007). Although seasons often have limited influence in tropical environments, the latitudinal range of the northeast Australian seascape is extensive (9 to 25° S) and seasonal change in the composition of plankton is considerable.

Critical links between benthic and pelagic assemblages occur through the larval forms of reef-associated organisms such as corals, fish, crabs, crown-of-thorns-starfish, sea urchins and sea cucumbers. At times of the year when animals are spawning, larvae can constitute a major component of total plankton. The biophysical processes occurring in oceanic systems greatly affect the pelagic assemblages, including the survival and distribution of larvae across large distances, and is a key driver of connectivity across marine jurisdictions.

Species

Highly mobile species

Dugongs

Hervey Bay, the Great Barrier Reef and Torres Strait are all globally significant dugong habitats (Marsh et al. 2011; Figure 6). Torres Strait supports the world's largest dugong population. The latest standardised estimate of dugong relative abundance in central and western Torres Strait was more than 100,000 animals, a likely underestimate (Hagihara et al. 2016). The Hervey Bay area is the most important dugong habitat on the east coast of Australia south of Cape York (Marsh et al. 2011). The 2016 standardised abundance estimate for Hervey Bay was about 2,000 dugongs (Sobtzick et al. 2017). Although the Coral Sea likely supported refugia for dugongs during past glacial maxima (Blair et al. 2014), there is no evidence that this area supports significant dugong habitat today. Nonetheless, there are occasional unconfirmed sightings of dugongs in the Coral Sea reported on the Eye on the Reef database (Lazur 2017), and a dugong was filmed at Raine Island on the outer edge of the GBR in 2015 using an underwater automated video (Richard Fitzpatrick pers comm 2017).

Temporal changes in the spatial distribution of dugongs are believed to be largely driven by temporary immigration in response to changes in the extent and biomass of the seagrasses on which dugong depend for food (Marsh et al. 2011). These changes are associated with sub-regional climatic drivers (Meager and Limpus 2014, Fuentes et al. 2016), particularly the sustained periods of elevated freshwater discharge and low air temperatures associated with La Niña episodes. In response to these changes in food supply, dugongs move between seagrass habitats along the Queensland coast and possibly offshore where there are deep water and reef top seagrass beds (Coles et al. 2009, McKenzie et al. 2016). Dugong movements between Hervey Bay and the GBR as far north as Clairview (north of Shoalwater Bay) have been confirmed by satellite tracking (Sheppard et al. 2006) and to Shoalwater Bay by pedigree analysis (Cope et al. 2015), even though genetic analyses suggest weak population structure between the dugong populations in Hervey Bay and Shoalwater Bay (Seddon et al. 2014). Pedigree analysis by Cope et al. (2015) indicates that dugongs move between Moreton Bay (near Brisbane) and Hervey Bay more often than suggested by genetic analysis or the limited telemetry conducted to date (Sheppard et al. 2006, Zeh et al. 2016). It is thus likely that dugongs also move between Hervey Bay and the southern GBR more often than documented. Aerial survey results also suggest that dugongs moved between the southern GBR and Hervey Bay as a result of seagrass dieback in the north prior to any habitat recovery (Sobtzick et al. 2012, 2017). However, the intermittent snapshot aerial surveys cannot confirm the nature and extent of such movements.

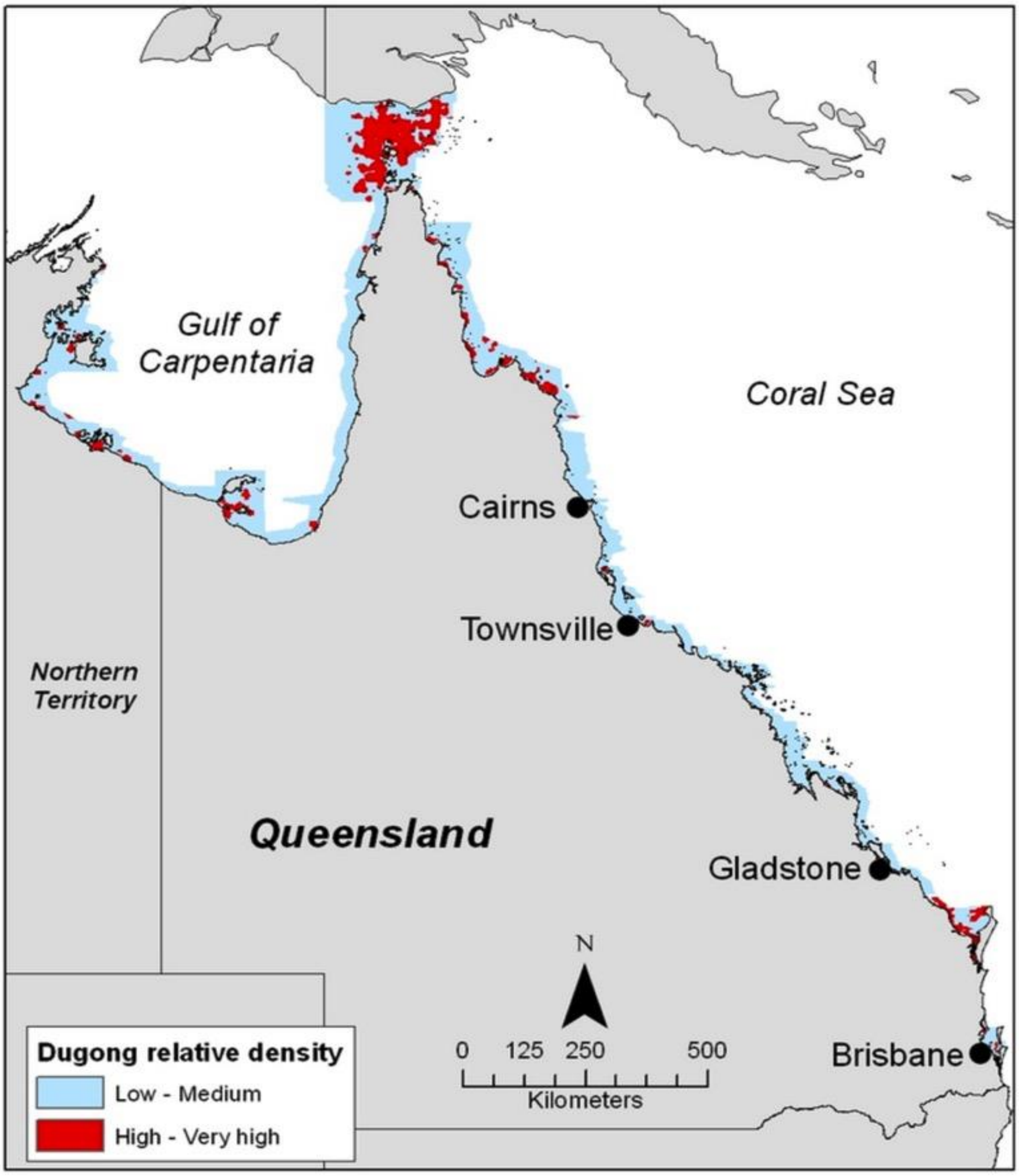

Figure 6: Dugong relative density in Queensland and Torres Strait waters (Source: Alana Grech).

Recent genetic analysis of samples from dugongs indicates that the deepest genetic break along the east coast of Queensland occurs around Midge Point (McGowan et al. unpublished) and little genetic differentiating has been detected between northern GBR and Torres Strait dugongs (Blair et al. 2014). However, movements between the two areas have not been confirmed by tracking individual animals even though the temporal fluctuations in the Torres Strait dugong population (Marsh et al. 2015) suggest that such movements are likely, and well within the documented extent of dugong movements (Sheppard et al. 2006).

Toll et al. (2017) confirmed that seagrass seeds can survive passage through the alimentary canal of a dugong. Thus, it is likely that dugong movements between Torres Strait and the northern GBR, and Hervey Bay and the southern GBR also disperse seagrass seeds across these areas.

Cetaceans

Distribution data suggest that more than 30 species of whales and dolphins visit or reside in the Great Barrier Reef region (Marsh 2008). Some species are rarely seen and are known only from stranded carcasses. Many of the oceanic whales and dolphins likely move between the GBR, the Coral Sea and eastern Torres Strait but there is no direct evidence to confirm such movements.

Coastal dolphins, such as the snubfin dolphin, the Australian humpback dolphin and the bottlenose dolphin, also likely move between the coastal waters of Torres Strait and the northern GBR, and between the coastal waters of the southern GBR and Hervey Bay (Great Sandy Strait) but there is no documented evidence of such movements.

The best-known movements are those of humpback whales between the GBR and Hervey Bay. These whales form part of the Group E breeding stock, the members of which generally feed in Antarctica (Area V) and migrate along the eastern Australian coast to the GBR to mate and give birth. This population was severely depleted by commercial whaling operations in the 20th century but has increased rapidly since hunting ceased. In 2011, the population estimate was around 14,600 animals (Smith et al. 2012) with a long-term rate of increase of 10.9% annually (Noad et al. 2008, 2011, 2016). Satellite tracking of a small sample of 12 whales suggests that they migrate north to the GBR along the eastern edge of Fraser Island (Smith et al. 2012). Hervey Bay is an important stopping point for humpback whales on their return journey from the GBR to Antarctica.

Along the east coast of Australia, the humpback whale migration occurs between April and November. Breeding and calving in the GBR occurs from June to September (Smith et al. 2012). Warm, comparatively shallow (< 100 m depth) waters are preferred by humpbacks for breeding and calving areas. Spatial distribution models of humpback whales in the GBR have identified the likely breeding ground ~100 km east of Proserpine south to Mackay (particularly the inner and outer Proserpine and the outer reefs off Mackay). Individual humpback whales have also been documented moving between Hervey Bay and New Caledonia, so it is very likely that animals also move between the GBR and the Coral Sea.

Satellite tagging studies in the GBR indicate that dwarf minke whales also migrate between feeding grounds in the Southern Ocean, and winter breeding grounds in the GBR (Birtles et al. 2015). Sighting records show dwarf minke whales are present in the GBR from April to September. Tourism vessels in the Cairns/Cooktown Management Area of the GBR Marine Park report most sightings as this is where the swim-with-whales tourism industry operates. A migration path along the east Australian coast was identified via a satellite tracking study over 2013-2015 (Birtles et al. 2015). The southward migration was consistent over the three-year study with tagged animals travelling from the Ribbon Reefs along the continental shelf edge until reaching the area around the Swain Reefs in the southern GBR (Birtles et al. 2015). Here the migration path becomes diffuse through the complex reef system before once again becoming consistent as the continental shelf narrows at the north-east point of Fraser Island south of the GBR. Although minke whales have not been tracked moving from the GBR to the Coral Sea it is likely that they do so.

Marine turtles

Six species of marine turtles have been recorded in each of the four marine domains and four species breed in at least two of the domains. There are populations of three species who share breeding sites which span at least two domains – the northern GBR population of green turtle breeds in both the northern GBR and Torres Strait, the southern GBR population of green turtle breeds in both the southern GBR and the Great Sandy Strait. Loggerhead turtles breed in both the southern GBR and the Great Sandy Strait and Hawksbill turtles breed in both the northern GBR and Torres Strait.

All marine turtle species are migratory and combinations of mark-recapture data and tracking data indicate that individual migrations for six species have been recorded occurring across the northeast Australian seascape. In addition, research on population genetics indicates that foraging aggregations of a single species are comprised of turtles from more than one population (loggerhead and green turtles – Limpus 1992, Limpus and Limpus 2001, Dethmers et al. 2011, Boyle et al.2008; Read et al. 2014; hawksbill turtles – Miller et al. 1998; Limpus 2009; Leatherback turtles – Benson et al.2011; flatback turtles – Wildermann et al. 2017 and olive ridley turtle – Limpus 2009).

Of the four species breeding in the region, three have a post-hatchling oceanic dispersal stage that is influenced in part by oceanic circulation patterns (see Boyle et al. 2009, Wolanski 2016). The fourth species, the flatback turtle, has a post-hatchling phase restricted to Australia's continental shelf and its dispersal and distribution is less influenced by oceanic circulation in the Coral Sea (Hamann et al. 2011, Wildermann et al. 2017).

Green turtles (*Chelonia mydas*) – Five genetically distinct populations: (i & ii) northern and southern GBR, (iii) Coral Sea (including New Caledonia), (iv) northern New Caledonia, and (v) Vanuatu. Individuals from each stock live in, and migrate through, each of the four marine domains.

Hawksbill turtles (*Eretmochelys imbricata*) – Regional genetic structure is incomplete. However, it is known that the northern GBR and Torres Strait comprise a single population, which is likely to be different to the populations breeding in New Caledonia, Solomon Islands, PNG and other areas in the south-western Pacific. Individuals from each stock live in, and migrate through the Torres Strait, GBR and the Coral Sea. The rocky reef systems in the

Great Sandy Strait support low numbers of hawksbill turtles. No migrations between nesting sites and foraging sites in the Great Sandy Strait have been recorded but to reach the closest breeding sites they would have to migrate through the GBR or Coral Sea (Figure 7).

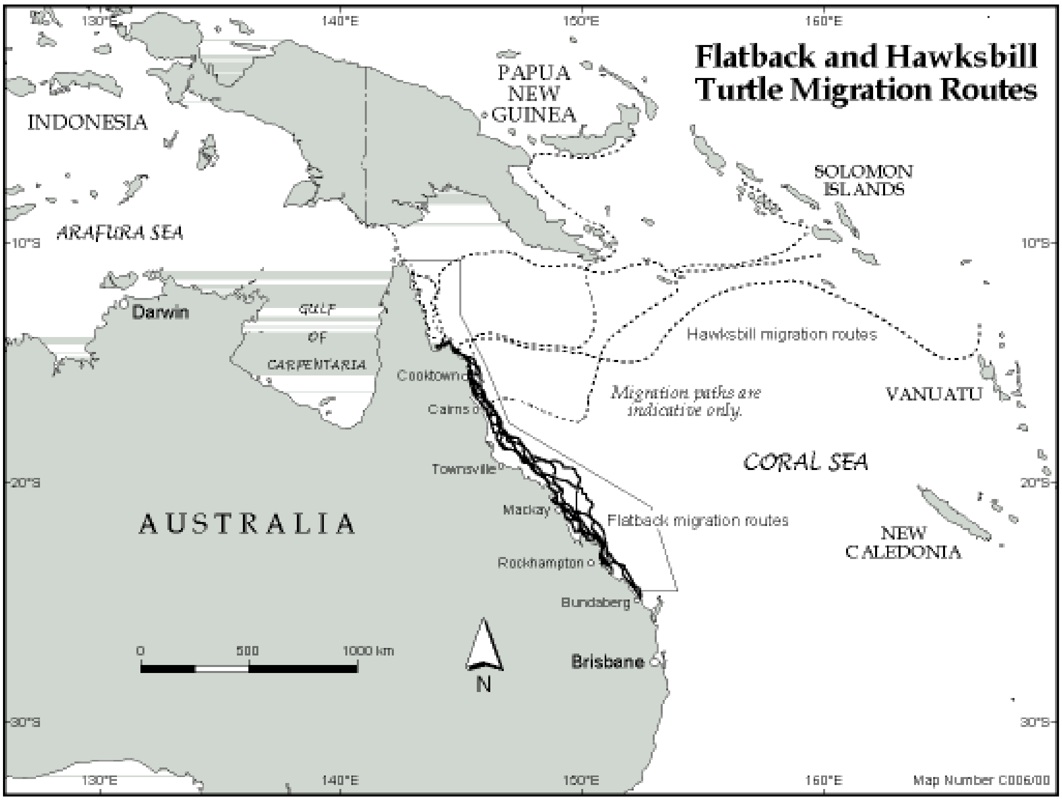

Figure 7: Indicative migration path of flatback and hawksbill turtles through the northeast Australian seascape (Source: www.gbrmpa.gov.au).

Loggerhead turtles (*Caretta caretta*) – There is a single population of loggerhead turtles that breeds in New Caledonia, the GBR and Great Sandy Strait. Migrations have been recorded between breeding sites in the southern GBR and Woongarra Coast (Bundaberg region) and foraging sites in Great Sandy Strait, GBR, Coral Sea (New Caledonia) and Torres Strait. Individual turtles breeding in New Caledonia have been recorded in the GBR. Individuals from this population live in, and migrate through, each of the four marine domains.

Flatback turtles (*Natator depressus*) – There are two genetically distinct populations of flatback turtles, one breeding in Torres Strait and the other breeding in the GBR. Individuals from the Torres Strait population likely live in, and migrate through, the Torres Strait and the GBR. Individuals from the GBR population likely live in, and migrate through, the GBR, Torres Strait and Great Sandy Strait (Figure 7).

Leatherback turtles (*Dermochelys coriacea*) – Forage and migrate in each of the four marine domains, however are less common in the Torres Strait, GBR and Great Sandy Strait. Although scattered nesting has occurred in the Northern Territory, the closest nesting sites are along the northern coastline of Indonesia and PNG.

Olive ridley turtles (*Lepidochelys olivacea*) – Present, but not commonly observed, in any of the four marine domains. The closest nesting sites are along the western Cape York coast and Northern Territory. No migrations have been recorded for olive ridley turtles in any of the four domains and no genetic analysis has been conducted to establish migration or connectivity between turtles foraging in the four domains and regional nesting aggregations.

Fish, invertebrates, sharks and rays

There are many species of elasmobranchs (sharks and rays), invertebrates and finfish that span at least one of the four study jurisdictions. Even when using our definition for the term 'value' it is challenging to determine which species to include. A recent study that examined the vulnerability of key fishery species for north-eastern Australia to climate change went through a prioritisation process to identify key species (Welch et al. 2014). To identify the key species for inclusion here we used this species list as a starting point and incorporated other factors including: (i) ecological niche/function, (ii) distributions known to overlap the study regions, and (iii) expert opinion.

Sharks & Rays

Australia is home to about one third of global biodiversity of sharks and rays. The Great Barrier Reef coast is home to at least 133 species, including coastal, pelagic and deep-water species (Chin et al. 2010). A small number of species are targeted by fishers for flesh and fins (e.g. Australian blacktip sharks) while many are taken as incidental catches in non-target fisheries. Globally 25% of shark and rays species have elevated risks of extinction (Dulvy et al. 2014), but shark catches in Australian fisheries are better managed than in most parts of the world (Simpfendorfer and Dulvy, 2017) and so populations of most species are not under threat. However, the movement and migration of shark and ray species means that they often cross jurisdictional boundaries (domestically and internationally), complicating management of shark stocks (Heupel et al. 2015; Chin et al. 2017). The following species represent a cross-section of the species that occur within the study area (see Table 5).

Black tip sharks (*Carcharhinus limbatus* and *C. tilstoni*)

Black tip sharks in Australian waters are comprised of two co-occurring species that are morphologically indistinct, making identification virtually impossible in the field. The two species are the common blacktip shark, *Carcharhinus limbatus*, and the Australian blacktip shark, *C. tilstoni,* which have dominated commercial shark fisheries catches in northern Australia for the past 40 years (Stevens and Wiley, 1986; Harry *et al.* 2011). Recent research has developed a genetic assay test to distinguish between the two species, however this is complicated by recent evidence of widespread hybridisation occurring between the two species in northern Australian waters (Morgan *et al.* 2011; 2012).

Although *C. tilstoni* are more common in warmer tropical waters, both species co-occur throughout the project jurisdictions and are reported to occur as far south as Sydney (Welch et al. 2014). Interestingly, based on genetic analysis, both species exhibit a northern and southern genetic stock on the east coast corresponding to the southern limit of the GBR (Welch et al. 2011). Based on inshore fisheries catches, all life history stages of *C. tilstoni* appear to occupy nearshore coastal habitats, while only neonates and juveniles of *C. limbatus* are caught in in these habitats suggesting that adults generally prefer deeper water towards the edge of the continental shelf (Harry *et al.* 2011). Pupping occurs in inshore waters, sometimes in areas with slightly lower salinity areas, i.e. adjacent to nearshore freshwater sources.

Blacktip sharks are currently the target species in gillnet and longline fisheries in Queensland and the Northern Territory. Historically heavily fished by foreign gillnet fleets in the 1970s and 1980s, populations have since recovered due to much lower domestic catches. The current status of blacktip sharks has been assessed across northern Australia and populations are considered sustainable (http://www.fish.gov.au/report/11-BLACKTIP-SHARKS-2016).

Scalloped hammerhead (*Sphyrna lewini*)

Scalloped hammerhead are found throughout the project jurisdictions and south into NSW and, although genetic studies show a single homogeneous east coast population, vertebral chemistry analyses indicate several separate stocks comprising mainly of juveniles and adult males (Ovenden et al. 2011; Schroeder et al. 2011). The spatial scale of stock separation was in 100's of kilometres with differences among the Far North/Cairns regions, Cairns/Townsville, Mackay/Brisbane and Brisbane/northern NSW (Schroeder et al. 2011). The study sample locations of Schroeder et al. (2011) do not allow discrimination of stocks among jurisdictions north and south of the GBR, however they do provide an indication of the possible spatial scales of population connectivity.

Importantly, the stock structuring shown by Schroeder et al. (2011) was comprised of males and juveniles. Chin et al. (2017) found that, from extensive fisheries observer and monitoring data collected around much of northern Australia, no adult female scalloped hammerheads were recorded on the east coast. They do acknowledge that fisheries on the east coast are nearshore and that, based on observations elsewhere, adult females appear to prefer more offshore continental ridges and edges. Also, Noriega et al. (2011) report some pregnant female scalloped hammerheads recorded in the Queensland Shark Control Program on the east coast, although Chin et al. (2017) express concerns over the accuracy of species identification from this dataset. Numerous adult females however are recorded from adjacent waters of Indonesia and PNG, as well as north-western Australia, suggesting that females may migrate to Australian nearshore waters to give birth. It is likely that distant populations of female scalloped hammerheads are critical to the replenishment of Australian populations (Welch et al. 2011).

Multiple traditional tagging studies are consistent with these results and show scalloped hammerheads sometimes make long distance migrations of up to 3,000 km (Holland *et al.* 1993; Ketchum et al. 2014; Kohler and Turner 2001; Stevens *et al.* 2000b). These movements make the management of this species more difficult when fishing pressures differ between jurisdictions sharing stocks (Chin et al. 2017). Globally, scalloped hammerheads are listed as Endangered by the IUCN Red List of Threatened Species. In 2014 they were added to Appendix II of the Convention on International Trade in Endangered Species (CITES), requiring countries exporting products derived from this species to certify that they were legally sourced and that their capture will not have a detrimental effect on the population. The species was also listed on Appendix II of the Convention on Migratory Species (CMS) in 2015, which under Australian law would require it to be protected, however the Australian Government took a reservation against this listing and so protection was not required. The species is currently being assessed for threatened species listing under the EPBC Act because the species in Australian waters has declined substantially since the 1960s.

Tiger shark (*Galeocerdo cuvier*)

Tiger sharks have a worldwide distribution and although tending to be concentrated in tropical waters are also commonly found in temperate waters (Pepperell, 2010). They are found in all the project jurisdictions and, although they tend to frequent continental shelf waters are also known to take large-scale oceanic migrations (Holmes et al. 2014; Werry et al. 2014). Along the Australian east coast large-scale movements of tiger sharks through Torres Strait, the GBR and Great Sandy Strait are common (Werry et al. 2014).

Using satellite tags Werry et al. (2014) found that mature females displayed the longest migrations and least frequent occurrence on acoustic receiver arrays suggesting they may be the main participants in wide-ranging movements that provide important temporal connections between 'local' groups of spatially separated (i.e. 500 km) tiger sharks. For example, the transient nature of mature females in the Chesterfields (west of New Caledonia) compared to sub-adult and mature male sharks supports the notion that large females may move in three year cycles between pupping and foraging grounds on the east coast of Australia and the west coast of New Caledonia with mating taking place in the oceanic reefs in the Coral Sea. Fitzpatrick et al. (2012) also found year round site presence of tiger sharks in some areas of the Great Barrier Reef.

Werry et al. (2014) estimated that tiger sharks utilised three-dimensional activity spaces averaged at 2360 km^3. They suggested that mature females may be of primary concern for conservation of tiger shark populations in the Coral Sea and that oceanic Coral Sea reefs may be particularly important for this species.

Tiger sharks are caught in fisheries in the project jurisdictions, but the main source of mortality may be shark control programs on the east coast of Queensland, where hundreds are caught each year to protect popular bathing beaches. Data from the shark control program suggest that although catches have declined, catch rates indicate the population is still relatively healthy.

Bull shark (*Carcharhinus leucas*)

The bull shark is a large cosmopolitan species with a global distribution that utilises a wide range of salinities throughout their lifecycle. Neonates occupy low salinity nursery habitats, juveniles live in riverine or estuarine habitats and adults prefer coastal, marine waters. In Australia, bull sharks mainly occur in tropical and sub-tropical coastal waters, estuaries and rivers (Simpfendorfer et al. 2005; Brunnschweiler and Barnett, 2013; Werry et al. 2012).

Previous satellite tagging studies show that bull sharks are capable of long distance movements (Brunnschweiler et al. 2010; Carlson et al. 2010) and Heupel et al. (2015) found that bull sharks regularly move large distances between tropical regions of the GBR south to as far as Sydney Harbor and back again. Their results demonstrated that on the east coast of Australia bull sharks connect disparate tropical and temperate habitats and regularly cross jurisdictional boundaries.

Similarly, Espinoza et al. (2016) found that a large portion of tagged bull sharks (51%) undertook migrations of up to 1,400 km to other coral reefs and/or inshore coastal habitats in Queensland and NSW. Most of these individuals (76%) were mature females, and the timing of migrations coincided with the austral summer (Dec-Feb). Their findings support the apparent importance of coral reef habitats for bull sharks, and since only a portion of the female population undertook seasonal migrations, these migrations were potentially to give birth. Given the wide-ranging movements of bull sharks along the east coast of Australia it is likely that some of these individuals reach the Torres Strait where they are commonly observed. However, tagging and telemetry data are required to validate this connection.

The stock structure of bull sharks has not been studied in the Pacific region, however it has in other parts of the world. In the western Atlantic region evidence of restricted maternal gene flow between populations was found and attributed to female site fidelity to nursery areas (Karl et al. 2011). This suggests, similar to other shark species documented here, the importance of adult female bull sharks to the persistence of local populations. Tillett et al. (2012) investigated reproductive philopatry in bull sharks by comparing mitochondrial and nuclear DNA of juveniles sampled from 13 river systems across northern Australia. Their results of high mitochondrial and low microsatellite genetic diversity among juveniles sampled from the different rivers supported female reproductive philopatry. Geographic distance or long-shore barriers to movement did not further influence genetic structure. Collectively these results suggest that bull sharks are likely to comprise a single genetic stock on Australia's east coast with significant movement of females at least among the respective project jurisdictions. There is little information on the status of the bull shark population on the east coast of Australia. However, their prevalence with marine and estuarine ecosystems throughout the region suggest that the population is healthy and current catches are sustainable.

Grey reef shark (*Carcharhinus amblyrhynchos*)

Grey reef sharks are distributed throughout the Indo-Pacific, occurring mainly in coral reef habitats where they are a commonly observed species in undisturbed systems. In coral reef ecosystems they occupy a meso-predator trophic position consuming mostly planktivorous fishes (Heupel et al. 2014; Frisch et al 2016). Movements of this species are well studied in the GBR with studies in the Central (Espinoza et al. 2015a,b) and Southern sections (Heupel and Simpfendorfer, 2014, 2015). Telemetry data shows that they are mostly resident on individual reefs and have relatively limited home ranges. However, during the breeding season they are more mobile, and some mature males make movements to adjacent reefs. The results from the GBR demonstrate that there is a single genetic stock, likely because of the movement of breeding animals between reefs over time (Momigliano et al. 2017).

The status of the grey reef shark on coral reefs in the Indo-Pacific is quite variable. In some places it is in very high abundance, while in others it has been severely depleted (Nadon et al. 2012). On the GBR there is evidence that historical fishing has caused declines (Robbins et al. 2006). However, the extent of these declines is uncertain, and video monitoring data shows that since re-zoning in 2004 and reduce catch limits in 2009 there has been recovery, at least in no fishing zones (Espinoza et al. 2014).

White spotted guitarfish (*Rhynchobatus australiae*)

This species occurs in northern Australia, Indonesia, Malaysia, Thailand and the Philippines. It is a coastal species inhabiting a wide variety of habitats on the continental shelf, including shallow sandy and muddy nearshore areas, coral reefs and seagrass areas. Within the project jurisdictions it occurs in all except for the Coral Sea.

There are limited movement data for this species. Acoustic telemetry results from the central GBR lagoon (White et al. 2014) have shown that this species has variable levels of residency to shallow coastal embayments. However, it is also known across a wide range of GBR habitats (White et al. 2013) where there is evidence of seasonal changes in preferred habitats. These data suggest limited movements are normal for this species, but given their size and morphology, it is possible that they can at times undertake longer movements. The IUCN Red List gives the global status of this species as Vulnerable given high levels of interactions with coastal fisheries in southeast Asia[3]. In Australian waters there are some interactions with fisheries, mostly coastal gillnets and prawn trawling. However, bycatch rates suggest this species is caught at sustainable levels in northern Australia (Zhou et al. 2008).

Reef manta ray (*Mobula alfredi*)

Reef manta rays are an iconic species in coral reef areas in the Indo-Pacific Ocean. They are large sizes (>4 m wing span) and feed on plankton (Couturier et al. 2013). They are most often sited at cleaning stations on reefs, where they form predictable aggregations.

Movement data derived from photo identification and telemetry indicates that on the east coast of Australia this species moves along the continental shelf between the GBR and areas as far south as NSW (Couturier et al. 2011) and also moves offshore into the Coral Sea (Jaine et al. 2014). While movement data in the northern GBR and Torres Strait is unavailable, the movements of this species in other areas suggest that movements between the GBR and Torres Strait are likely.

Reef manta rays are listed by the IUCN Red List as globally vulnerable because of demand for their gill plates for use in Chinese traditional medicine and meat as a source of animal protein (Lawson et al. 2017). However, in Australia they are rarely taken in fisheries and shark control programs. The species was listed on Appendix II of CITES in 2014, and on Appendix I and II of CMS in 2014. Their listing on CMS resulted in them being protected in Australian waters under the EPBC Act.

Bony fish

The Great Barrier Reef region supports at least 1,625 species of fish including estuarine, coastal, coral reef, pelagic and deep-water species (http://www.nova.org.au/great-barrier-reef). These species display a vast diversity and complexity in their life cycles and habitat use throughout their lives, and for some species even includes the use of freshwater habitats. Habitat type and latitude (temperature) are the key determinants of the fish species residing in each of the four project jurisdictions (see Table 5). For some fish species, although they may be present in adjacent jurisdictions, their movement across jurisdictional boundaries may be limited during their lifetime. For other species, their natural range limits their movement into adjacent jurisdictions, and many species undergo daily or seasonal movements that transgress jurisdictional boundaries (e.g. see Figure 8). For some species this connectivity is through juvenile and/or adult movement, and for others it is the exchange of larvae that determine connectivity.

[3] http://www.iucnredlist.org/details/41853/0

The main fisheries operating in the region target only a handful of these fish species, however, most fisheries are generally multi-species due to the nature of the gear used. For example, the Reef Line Fishery uses hand lines on coral reefs and generally targets only a few species but historically takes at least 125 different species (Welch et al. 2008). Fish catches in Australian fisheries are better managed than in most parts of the world and so populations of most species are not considered under threat. The following species represent a cross-section of the species that occur within the study area.

Table 5: Usual presence/absence of selected species of fisheries and conservation interest in the respective marine jurisdictions. Colour codes: permanent common = dark green; permanent uncommon = light green; absent = red. Presence is variable due to movement so understanding connectivity can inform management.

Species	Common name	Torres Strait	GBR	Coral Sea	Great Sandy
Carcharhinus limbatus	Blacktip shark	dark green	dark green	light green	dark green
C. tilstoni	Australian blacktip shark	dark green	dark green	red	dark green
Sphyrna lewini	Scalloped hammerhead shark	dark green	dark green	dark green	dark green
Galeocerdo cuvier	Tiger shark	dark green	dark green	dark green	dark green
C. leucas	Bull shark	dark green	dark green	dark green	dark green
C. amblyrhynchus	Grey reef shark	dark green	dark green	dark green	dark green
Lates calcarifer	Barramundi	light green	dark green	red	light green
Pomadasys kaakan	Barred javelin	light green	dark green	red	light green
Plectropomus spp.	Coral trout	dark green	dark green	dark green	light green
Polydactylus macrochir	King threadfin	light green	dark green	red	light green
Lutjanus sebae	Red emperor	light green	dark green	light green	light green
Scomberomorus commerson	Narrow-barred (Spanish) mackerel	dark green	dark green	light green	dark green
Scomberomorus semifsciatus	Broad-barred (Grey) mackerel	light green	dark green	red	light green
Scomberomorus munroi	Spotted mackerel	light green	dark green	red	dark green
Lethrinus miniatus	Red throat emperor	red	dark green	light green	light green
Istiompax indica	Black marlin	light green	light green	light green	light green
Thunnus albacares	Yellowfin tuna	light green	light green	dark green	light green
Gymnosarda unicolor	Dogtooth tuna	dark green	dark green	dark green	light green
Panulirus ornatus	Ornate rock lobster	dark green	dark green	light green	light green
Holothuria scabra	Sandfish	dark green	dark green	red	dark green
Holothuria whitmaei	Black teatfish	light green	dark green	light green	red
Fenneropenaeus merguiensis	Banana prawn	red	dark green	red	dark green
Melicertus (Penaeus) plebejus	Eastern king prawn	red	dark green	red	dark green
Penaeus longistylus	Red spot king prawn	light green	dark green	red	red
Penaeus esculentus	Brown tiger prawn	dark green	dark green	red	dark green
Scylla serrata	Mud crab, giant	dark green	dark green	red	dark green
Amusium balloti	Saucer scallop	red	dark green	red	dark green

Barramundi (*Lates calcarifer*)

Barramundi are a coastal species with a close association with freshwater habitats that form an essential part of their life cycle. They are common throughout the GBR however their range extends south through the Great Sandy Strait to the Noosa River area. They are also present in the Torres Strait however limited to a small region of the jurisdiction due to the small area of coastline and associated river systems (Lawson et al. 2014). Further, they are only taken as subsistence catch in the Torres Strait (http://pzja.gov.au/the-fisheries/torres-strait-finfish-reef-line-fishery/#.WVwxYjOB29Y).

Tagging and genetic studies have found that barramundi stocks are generally localized and linked to major river systems (Davis, 1985; Shaklee and Salini 1985; Salini and Shaklee 1988; Williams 2002). Larval development occurs in nearshore waters and any large-scale mixing is through adult movement. Therefore, although their range extends through different jurisdictions appropriate spatial scales of management are generally small.

The status of barramundi populations is assessed at spatial scales aligning to the highest catches on the east coast. In each region current fishery harvest levels are assessed as sustainable (Stewardson et al. 2016).

Barred javelin (*Pomadasys kaakan*)

Barred javelin are found in nearshore and estuarine waters of tropical and sub-tropical areas of Australia's east coast and are found from Torres Strait to as far south as northern NSW. There is no information on movement or stock structure of barred javelin but are far less abundant in the Great Sandy Strait compared to farther north. There is some anecdotal evidence of spawning aggregations and they have a protracted spawning season (Saunders et al. 2010). The current status of barred javelin in Queensland is unknown.

Coral trout (*Plectropomus* spp.)

There are multiple coral trout species present in all or most of the project jurisdictions, but notably *P. leopardus* (common coral trout), *P. maculatus* (bar-cheek coral trout) and *P. laevis* (bluespot coral trout). Each are common in the Torres Strait and GBR with cross-shelf species-specific patterns evident (Newman et al. 1997; Williams et al. 2008), and to a lesser extent in the Great Sandy Strait, while only *P. laevis* are generally found in the Coral Sea. Multiple stock structure studies on *P. leopardus* and *P. maculatus* suggest limited gene flow occurs across hundreds to thousands of km's and discrete stocks at scales of tens to hundreds of kilometres (see Frisch et al. 2016). Tagging studies on adults also show limited movement (e.g. Matley et al. 2015; Zeller, 1997). Therefore connectivity of *Plectropomus* populations are thought to be maintained through larval movement between discontinuous reef areas separated by intermediate distances (Frisch et al. 2016). Little is known about the stock structure of *P. laevis* and it is possible there is connectivity through larval and/or adult movement between the Coral Sea and jurisdictions to the east.

Spawning for all three species is seasonal and linked to temperature and lunar phase, and occurs from September-December (Frisch et al. 2016). Despite the likely genetic connectivity of common and bar-cheek coral trout populations across the Torres Strait, GBR and Great Sandy Strait regions, they are assessed separately based on the state (GBR) and Commonwealth (Torres Strait) jurisdictions. Currently coral trout fisheries are considered well managed and are assessed as sustainable in the GBR and Torres Strait (Stewardson et al. 2016). Although sustainable catch levels of bluespot coral trout are deemed to be lower than other coral trout species, current catch levels and management measures (slot size limit) mean that current catches are likely to be sustainable (Heupel et al. 2010).

King threadfin (*Polydactylus macrochir*)

King threadfin are endemic to tropical and sub-tropical northern Australia, southern Papua New Guinea and Irian Jaya (Motomura et al. 2000; Motomura, 2004). On the east coast they extend south to the Brisbane region (Motomura, 2004). King threadfin inhabit estuaries and turbid coastal waters typically less than 5 m in depth (Blaber et al. 1995; Motomura et al. 2000) and so are not found in the Coral Sea.

Post-larval (i.e. juvenile and adult fish) are largely sedentary tending to form discrete stocks over relatively small areas that are demographically, and often genetically, distinct and separate to adjacent fish (Newman et al. 2010; Welch et al. 2010; Moore et al. 2011; Horne et al. 2012). From samples collected in the Fitzroy River region (GBR region) and the Brisbane River (south of Great Sandy Strait) genetically discrete stocks were identified (Welch et al. 2010). Further, although Conventional tagging data supports the notion of fine-scale stock structure and showed that only 4% individuals tagged in estuaries on the east coast of Queensland travelled outside of the estuaries in which they were tagged (Moore, 2012; Welch et al. 2010). However, there are occasional long-distance movements (>100 km). These were only observed in very large fish, presumably female, in the Gulf of Carpentaria where it is hypothesised that natural barriers such as major headlands are absent (Welch et al. 2010).

Given the very small coastal mainland area in the Torres Strait, the local population of king threadfin is likely to be relatively low, however stocks in the adjacent Gulf of Carpentaria have been demonstrated as being overfished (Moore et al. 2017). Despite the fine-scale stock structure demonstrated for king threadfin they are assessed based on a single east coast stock with the latest assessment determining they are sustainably fished (Stewardson et al. 2016).

Red emperor (*Lutjanus sebae*)

Red emperor are distributed throughout the Torres Strait, GBR and Great Sandy Strait jurisdictions however they are unlikely to have a significant presence in the Coral Sea. Multiple stocks of Red Emperor have been found to occur along the west coast (Stephenson et al. 2001) and it is likely that multiple stocks are present across northern and eastern Australia. However, a lack of genetic difference within or between the east and west coast of Australia suggests the widespread dispersal of Red Emperor larvae resulting in high levels of gene flow (van Herwerden et al. 2009), since adults exhibit little movement (Stephenson et al. 2001). They do exhibit demographic habitat preferences with juveniles more abundant on nearshore and mid-shelf reefs while adults prefer inter-reefal shelf waters though they do extend onto the continental slope to depths of at least 180m (Kailola et al. 1993; Newman and Williams, 1996).

Most of the east coast red emperor catch is by the recreational sector however commercial catch is not limited with red emperor included in the ‘Other’ species catch limited category. Due to uncertainty from limited data the red emperor stock status on the east coast is determined as ‘undefined’ (Stewardson et al. 2016).

Narrow-barred (Spanish) mackerel (*Scomberomorus commerson*)
Spanish mackerel are found throughout tropical and sub-tropical areas of the Indo-west Pacific from Africa to Fiji. In Australia they extend across the northern coastline throughout continental shelf waters and on the east coast their usual range has a southerly limit of the central NSW coast (McPherson 1981; McPherson 1992), although in some years can be found as far south as Sydney (D. Welch, unpublished data). They are a highly mobile pelagic fish commonly associated with reef edges and headlands and have a preference for shallow coastal and continental shelf waters (Quinn 1993). Therefore they are common throughout Torres Strait, GBR and Great Sandy Strait jurisdictions but do not extend into the Coral Sea.

Stock structure studies have identified a single east coast stock present in Queensland and NSW and a separate Torres Strait stock (Buckworth et al. 2007). It is likely that the Torres Strait stock is shared with PNG and possibly Irian Jaya but this has not been tested. It is also possible that there is some overlap between the Torres Strait stock and GBR waters to the south since stock structure studies are limited by sample locations.

On the east coast an unknown proportion of fish older than two years of age undertake post-spawning migrations into southern Queensland and northern NSW waters. These large-scale migrations are thought to be linked to seasonal warmer currents moving southwards (Donohue *et al* 1982; McPherson 1981b; Tobin and Mapleston 2004). These migratory fish return northwards near to the coast and inshore islands where small-localised fisheries have developed for these larger fish. Patterns in water temperature and baitfish distribution are likely to affect adult distributions throughout the year (Welch et al. 2014). Between-sex differences in dispersal rates is evident, with males likely to be the most active dispersers (Buckworth *et al* 2007; Ovenden *et al* 2007). Well known key spawning aggregation sites are present in the Torres Strait (Bramble Cay) and the GBR (Lucinda area). The spawning season extends from September to December on the GBR and is more protracted in Torres Strait (Buckworth and Clarke, 2001; McPherson, 1981a). The latest assessment has deemed the east coast (including NSW) stock and Torres Strait stock to be sustainably fished (Stewardson et al. 2016).

Broad-barred (Grey) mackerel (*Scomberomorus semifasciatus*)
Grey mackerel are a large and highly mobile schooling fish endemic to northern Australia and southern areas of PNG and prefer turbid nearshore tropical and sub-tropical waters (Collette and Russo, 1984). They occur as far south as Moreton Bay but are not found in the offshore Coral Sea region. Spawning occurs inshore and appears to be at a number of locations and is seasonal occurring between September and December (Welch et al. 2009). Larval and juvenile life history stages are found inshore and often in estuarine environments (Jenkins *et al.* 1984). A major stock structure study that combined multiple techniques concurrently found the east coast was comprised of a single genetic stock, however, other techniques showed there are separate north-eastern and south-eastern stocks with spatial separation somewhere between Mackay and Townsville. Connectivity between adjacent stocks was assumed to be due to larval movement or limited adult movement (Welch et al. 2015). The most recent stock status assessment has determined that both the north-eastern and south-eastern stocks are sustainably fished (Stewardson et al. 2016).

Spotted mackerel (*Scomberomorus munroi*)
Spotted mackerel are a highly mobile nearshore continental shelf pelagic species found throughout northern Australia, including the Torres Strait, GBR and Great Sandy Strait

(Saunders and Welch, 2014). Research encompassing otolith microchemistry, genetic diversity, tagging and reproductive biology as well as seasonal variation in commercial harvesting strongly support the hypothesis that Spotted Mackerel form a single east coast stock with an annual large scale movement along the Queensland east coast to northern New South Wales. This includes Queensland and New South Wales feeding grounds in summer and a return migration in winter to northern spawning grounds (Begg and Hopper 1997, Begg et al 1997; Begg et al 1998; Begg 1998; Cameron & Begg 2002). The most recent stock status assessment has determined that the east coast stock is sustainably fished (Stewardson et al. 2016).

Red throat emperor (*Lethrinus miniatus*)

Red throat emperor is a medium-sized coral reef fish with a narrow distribution on the east continental shelf coast usually extending from around Cairns to Fraser Island (Williams et al. 2006). They occur to depths of at least 130 m and are reported to be found deeper and it is unlikely that they have a significant presence in the Coral Sea. Little is known about their spawning behaviour and early-life history however it has been concluded that they comprise of a single (panmictic) stock across their GBR and Great Sandy Strait distribution (Brown and Sumpton, 1998; Williams et al. 2006). There is also evidence of a disproportionate contribution of the northern portion of the stock to spawning stock biomass with a high proportion of mature but reproductively inactive females in the southern part (Williams et al. 2006). The east coast redthroat emperor fishery is currently assessed as sustainable (Stewardson et al. 2016).

Black marlin (*Istiompax indica*)

The black marlin is one of the largest teleost fish in the world and although they have an Indo-Pacific distribution, they are concentrated near landmasses and spend much of their life history on or near continental shelves. Despite this, tagging studies show they frequently take large-scale movements across oceans and studies have confirmed a single genetic stock across the Pacific Ocean (Pepperell, 2010) and genetically distinct from other populations. Much of the tagging work has been done in the Cairns area or further south on the east coast, and although it is known that many of these animals disperse quickly from these areas, many recaptures occur in the same area in annual increments suggesting fish are returning to the same area on an annual basis. Several spawning areas are known throughout their Pacific range and there is evidence of natal philopatry (Williams et al. unpublished data, http://seaworld.com.au/research-and-rescue/marine-animal-research/fish/black-marlin.aspx).

For the GBR this dispersal occurs in early summer (Pepperell, 2010) and juvenile black marlin are known to appear in coastal NSW waters during the Austral summer/autumn (D. Welch, pers. obs.) suggesting an annual southerly movement possibly associated with the EAC.

Black marlin spawn in the Coral Sea during late spring/early summer. Their early life history is poorly known with catches of fish <10 kg very rare. It is thought therefore that this life history phase occurs offshore in the mid-water zone (Pepperell, 2010). The current status of the black marlin population in the Pacific is unknown.

Yellowfin tuna (*Thunnus albacares*)

Yellowfin tuna are a large oceanic schooling pelagic species found throughout the world's oceans and are common throughout the Pacific Ocean. Genetic studies indicate a single global population, however Peperrell (2010) suggests there are likely to be more localized populations; these are likely to be at the scale of 100's km. Tagging studies indicate that tuna tagged adjacent to Australia's eastern continental shelf in the Coral Sea tend to move north and south with the seasonal rise and fall of sea surface temperatures. Despite some fish showing very large distance movements, the majority tend to remain in waters adjacent to or on the continental shelf. Therefore movements between the GBR and Coral Sea jurisdictions are likely to be frequent and related to changes in SST. With a preference for open ocean water their presence in the Torres Strait region are likely to be uncommon, and although they are found along the eastern seaboard south of the GBR, their presence in the Great Sandy Strait is also likely to be limited. Yellowfin tuna are assessed as a single western and central Pacific Ocean stock and are classified as sustainably fished (Stewardson et al. 2016).

Dogtooth tuna (*Gymnosarda unicolor*)

The dogtooth tuna is an epipelagic, coral reef-associated fish endemic to the Indo-Pacific region (Bentley et al. 2014). Off eastern Australia they are found in tropical and sub-tropical waters to as far south as Coffs Harbour, NSW, and frequent reef drop-offs on mid- and outer-shelf reefs on the GBR, and are common on reefs throughout the Coral Sea (Welch, unpublished data). A recent study found that fish in the Indian and western Pacific Ocean basins were genetically indistinct but also found evidence of fine-scale heterogeneity. The authors concluded that dogtooth tuna have larvae and/or juveniles that are capable of very large distance dispersal and that adults are likely to be more restricted in their movement and at the local scale are important in maintaining population genetic diversity. Dogtooth tuna have been reported to occur at depths of 300 m (S. Newman, pers. comm.) suggesting that adults may also disperse large distances between reefs. In the western Pacific Ocean they spawn during the months of September-December (Welch, unpublished data). The status of dogtooth tuna in the western Pacific region has not been assessed.

Invertebrates

Ornate rock lobster (*Panulirus ornatus*)

The Ornate rock lobster occurs in northern Australia and have a broad habitat use including deep (> 200 m) oceanic waters, reef tops and slopes, to muddy reefal areas adjacent to estuaries and river mouths, which reflects a very wide distribution (Pitcher et al. 2005). In eastern Australia they can be found as far south as Sydney however are uncommon south of the Qld/NSW border and only the east coast and Torres Strait support significant fisheries. They prefer reef habitat and are most common in the Torres Strait (Welch and Robins, 2014). The Queensland east coast fishery and the Torres Strait fishery have been shown to comprise the same lobster stock (Pitcher et al. 2005).

The adult breeding season occurs from November-April when adults undergo an annual migration of between 70 and 500 km into deep continental shelf waters of the Coral Sea for spawning. Breeding sites include deep-water (40 to 120 m) areas on the continental shelf outside the Great Barrier Reef and Yule Island in the Gulf of Papua. Breeding sites on the Great Barrier Reef are predominantly in the far north however breeding sites are known to occur south to at least Townsville (19° S) (Bell et al. 1987). Lobsters that migrate to Yule Island generally do not survive after breeding (Pitcher et al. 2005).

Larvae drift in oceanic waters of the NW Coral Sea for approximately 6 months prior to settlement. Northwest Coral Sea currents are highly important for recruitment dynamics in northeast Australia and Torres Strait (Pitcher et al. 2005; Smith et al. 2009). There appears to be distinct regions that act as recruitment 'sources' and 'sinks' which is determined by the bifurcation of the South Equatorial Current off the GBR approximately adjacent to Cooktown on the northeast Queensland coast. Areas to the north of this bifurcation can be termed both source and sink regions and to the south as a sink region (Dennis et al. 2001; Pitcher et al. 2005). The peak timing of settlement in northeast Queensland occurs during winter (June-August) in most years however the seasonality of settlement is highly variable. The north-eastern Australian stock is currently assessed as sustainably fished (Stewardson et al. 2016).

Sandfish (*Holothuria scabra*)

In Australia sandfish are across northern Australia and extend down the east coast to the Qld/NSW border (Welch, 2014). They are usually associated with sandy, muddy substrates in nearshore coastal environments. Sandfish are capable of spawning year round in warmer equatorial waters (Conand, 1989), and preferred habitat types for settlement appear to be on sea grass leaves (Mercier et al. 2000a).

Typically, successful recruitment of low mobility marine organisms such as sea cucumbers require adequate adult densities to ensure successful fertilisation of released eggs. Also, they generally have very low replenishment rates making them susceptible to overfishing and slow at recovering from perturbations. Further, dispersal of recruits is spatially limited resulting in there being multiple discrete stocks throughout Queensland (Uthicke and Benzie, 2001). This would suggest that separate stocks exist in each of the Torres Strait, GBR and Great Sandy Strait regions. Due to overfishing on the Warrior reefs the fishery in Torres Strait for sandfish has been closed since 1999 and stocks have not yet recovered. Also the fishery in the Great Sandy Strait has been closed since 2001 due to declining stocks (Roelofs, 2004).

Banana prawn (*Fenneropenaeus merguiensis*)

Banana prawns are found in tropical and sub-tropical estuarine and coastal areas across northern Australia and along the east coast into northern NSW, however they don't appear to be present in the Torres Strait as they are not taken in the Torres Strait Prawn fishery (Welch and Johnson, 2014). They are thought to have a one-year life cycle with recruitment probably linked to rainfall and riverflow (Robins and Vance, 2014). Post-larval and juvenile prawns inhabit estuarine areas associated with mangrove forests and move from estuaries to coastal areas during summer and autumn as sub-adults where they are trawled usually in depths of 16 – 25 m (Robins and Vance, 2014). Sub-stocks exist along the Queensland east coast and the Gulf of Carpentaria with limited exchange between sub-stocks. Offshore schools of banana prawns are generally associated with major river systems and can be geographically grouped into the following sub-stocks (Tanimoto et al. 2006): Cooktown, Cairns, Tully, Townsville, Mackay, Fitzroy, Gladstone, Burnett, and Moreton. Therefore the SS is likely to be a separate stock to the adjacent stock in the GBR. The eastern Australian stock is currently assessed as sustainably fished (Stewardson et al. 2016).

Eastern king prawn (*Melicertus (Penaeus) plebejus)*

Eastern king prawns are found only on the east coast of Australia and their range extends from near Mackay in the GBR to Tasmania in the south. A single stock is shared between Queensland and New South Wales. Although there are arrangements for collaborative stock assessment, the fishery is managed separately under each state's jurisdiction (Robins and Courtney, 2014). Juveniles develop in nearshore estuarine areas, often in association with seagrass, in the GBR and south to southern NSW while adults move to offshore coastal waters.

There are likely to be multiple spawning grounds for eastern king prawn along the coastline of Queensland and New South Wales, with the Swains Reef Complex thought to be a major spawning ground (Courtney, 1997). Multiple spawning grounds provide this species with flexibility for inter-year variation in "effective" spawning areas i.e., areas providing recruits in any one year (Robins and Courtney, 2014). The eastern Australian stock is currently assessed as sustainably fished (Stewardson et al. 2016).

Red spot king prawn (*Penaeus longistylus*)

The red spot king prawn is distributed throughout the tropical Indo-West Pacific and South China Sea to Malaysia. On Australia's east coast their range extends south to approximately Yeppoon within the GBR (Robins, 2014a). Therefore they occupy waters of the Torres Strait and GBR, but not the Coral Sea or Great Sandy Strait, however they are reported to make up only a very small proportion of the Torres Strait Prawn fishery catch (~4%; Welch and Johnson, 2014). Their stock structure is unknown.

They differ from other key prawn species in that their life cycle is completely offshore. Larvae are pelagic and benthic post-larvae settle between September and May in shallow coralline sandy sediments, often associated with lagoons of coral reefs. Juveniles spend four to six months on reef tops before emigrating to inter-reef areas of the Great Barrier Reef on coralline sandy sediments up to 60 m deep where they live as sedentary adults (Robins, 2014). Red spot king prawns have an extended spawning season (May to October), with peak spawning thought to occur between July and August (Courtney and Dredge 1988). The east coast fishery is currently assessed as sustainable (https://www.daf.qld.gov.au/fisheries/monitoring-our-fisheries/data-reports/sustainability-reporting/stock-status-assessments/stock-status-assessment-2015/red-spot-king-prawn).

Brown tiger prawn (*Penaeus esculentus)* and Grooved tiger prawn (*P. semisulcatus)*

Two species of tiger prawn are harvested in northern Australia: *Penaeus esculentus,* the brown tiger prawn, and *Penaeus semisulcatus*, the grooved or green tiger prawn (Robins and Turnbull, 2014). The brown tiger prawn is endemic to coastal waters of tropical and sub-tropical Australia, and can be found in waters up to 50 m deep (Kirkegaard and Walker, 1969; Racek and Dall, 1965). It is likely that there are separate stocks of brown tiger prawns on the east and west coast of Australia (Courtney, 1997).

The grooved tiger prawn is a tropical species and is more widespread in its distribution than the brown tiger prawn, occurring in coastal waters of the Indian and western Pacific oceans, where it is trawled in waters up 130 m deep (Grey et al. 1983; Kailola et al. 1993). The benthic post-larvae and juveniles of both species of tiger prawn prefer seagrass and algal bed habitats. Adults of the brown tiger prefer habitats with coarse, sandy sediments, while adults of the grooved tiger prawn prefer habitats with a high (50-80%) mud content (Somers 1987b; Somers et al. 1987).

Both species of tiger prawns are fished to the Queensland/NSW border in the East Coast Otter Trawl fishery and there are small quantities taken in NSW. Only brown tiger prawns are taken in the Torres Strait Prawn fishery (Welch and Johnson, 2013). The latest assessment has deemed the east coast stock and the Torres Strait stock to be sustainably fished (Stewardson et al. 2016).

Mud crab, giant (*Scylla serrata*)

Mud crabs of the genus *Scylla* commonly occur throughout tropical to warm temperate areas of the west Pacific and Indian Oceans (Keenan, 1999). Their distribution encompasses the Asian sub-continent and Japan, northern and eastern Australia and from the east coast of Africa across to Tahiti (Ryan, 2003). In Australia, they inhabit regions extending from Exmouth Gulf on the coast of Western Australia, through to the Northern Territory and Queensland to the southern coast of New South Wales (Knuckey, 1999). There is considered to be distinct genetic stocks to the west of the Torres Strait, and south along the east coast (Gopurenko and Hughes, 2002). It is unclear whether Torres Strait animals belong to the western or eastern stock and here we assume they are part of the eastern stock.

Mud crabs usually inhabit estuarine channels, sheltered coastal habitats and shallow tidal flats associated with mangrove communities. Juveniles usually remain in the intertidal zone (in mangroves), whereas adults tend to be more abundant in the sub-tidal zone (Hill et al. 1982).

Mud crab are caught along the entire east coast usually associated with estuaries, however large sheltered water bodies are some of the most productive, including the Great Sandy Strait (Lawson et al. 2014). Much of the catch in the Torres Strait is taken around islands near the PNG coast in the northern part of the PZJA in the Torres Strait (Welch and Johnson, 2013). The eastern Australian stock is currently assessed as sustainably fished (Stewardson et al. 2016).

Saucer scallop (*Amusium balloti*)

Saucer scallops are predominately a sub-tropical species that occur in waters between 15°S and 25°S on the east coast of Australia (Dredge, 2006). They are found in oceanic waters between 15 and 50 m deep, and in Queensland are most abundant in water depths >40 m and south of 20°S. Saucer scallops bury into sediment and as such occur in bare, sandy, rubbly or sponge garden habitats that have a soft but not muddy, sediment (Robins, 2014b).

Larval connectivity has been shown to be highly variable and no one single area is responsible for supplying larvae in the fishery (Courtney et al. 2016). Therefore saucer scallops across the GBR and Great Sandy Strait fishery areas are likely to be a single stock. Research has shown that local environmental drivers have the greatest effect on catch rates (relative abundance) with the Capricorn Eddy having a negative effect while temperature during spawning, freshwater flow and Chl-a have the greatest positive effect (Courtney et al. 2016).

A recent quantitative assessment estimated that the spawning biomass of the east coast stock may be as low as 5–6% of unfished levels (1977) and therefore the management unit is classified as an overfished stock (Stewardson et al. 2016).

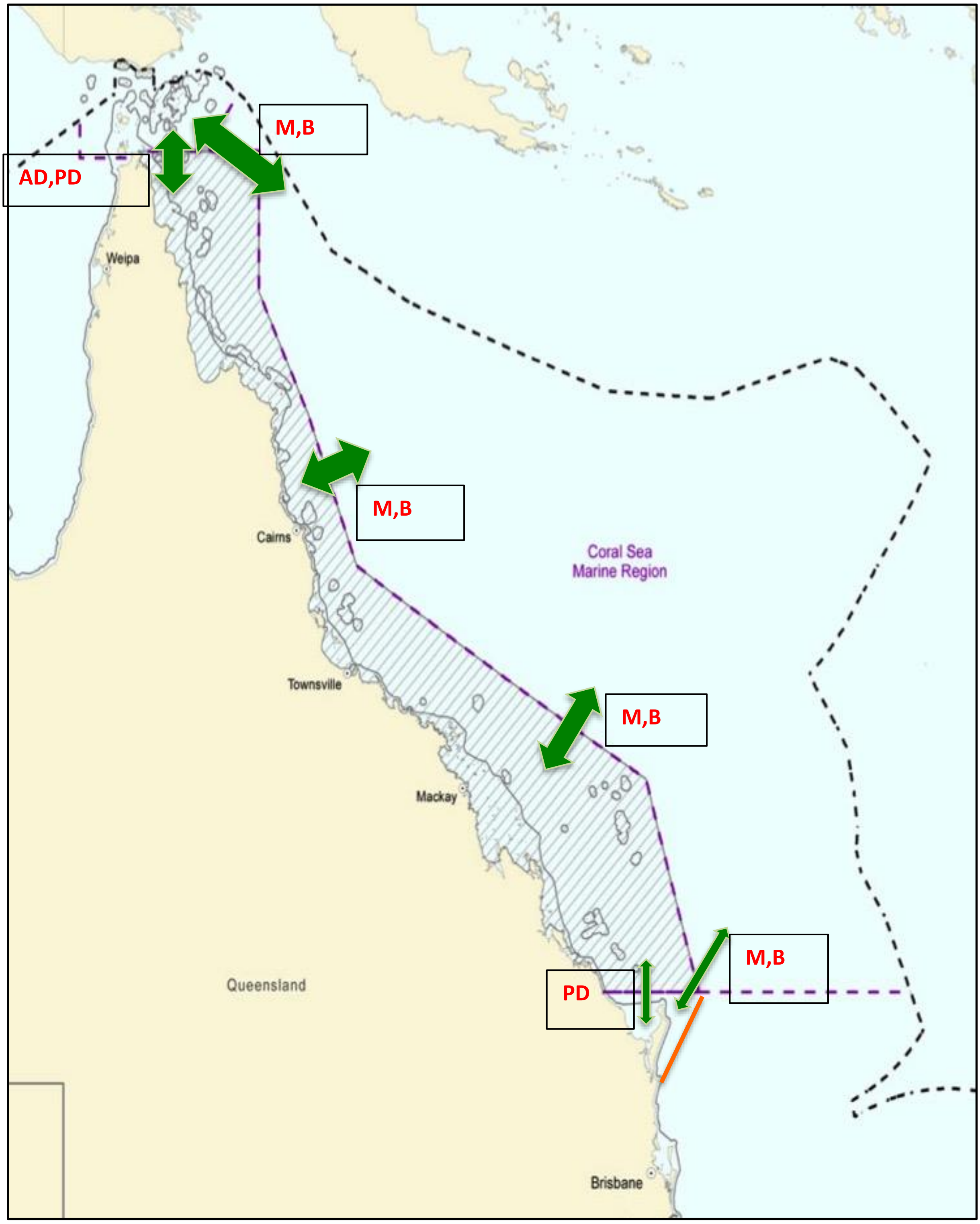

Figure 8: Example map of connectivity for the Common blacktip shark, Carcharhinus limbatus. AD = active dispersal (short-term movement of individuals (post-larval) among areas that maintains demographic connectivity); PD = passive dispersal (longer-term movement of individuals (post-larval or larval) among areas that maintains genetic and/or demographic connectivity); M = migration (predictable, periodic round-trip or cyclic movement of groups of individuals among discrete areas not used at other times of year/s); B = adult sex-specific movement (breeding); L = larval movement (adapted from Ament et al. 2014).

Species with mobile larvae

Many marine species that live in the northeast Australian seascape, including corals, fish and invertebrates, have a two-part life history: a relatively sedentary habitat-attached adult phase, and a highly mobile pelagic larval phase in open water. The larvae of these species can travel hundreds of kilometres on ocean currents, spending their pelagic period in adjacent marine areas and/or international waters before settling. Larvae (typically, 1-20 mm long) are temporary members of the plankton (meroplankton) and spend from 2 – 20 weeks in open water where little is known of their biology during this pelagic period. Most dispersal takes place during this pelagic larval phase, and this is therefore a key connectivity mechanism for many species that do not move large distances as adults.

Understanding the movement of mobile larvae is important for characterizing connectivity between adjacent marine areas in northeast Australia, particularly as it is a source of population replenishment. For example, the larvae of some fishes remain within a few hundred metres of where they were spawned, while others require open waters and travel hundreds of kilometres during their pelagic phase.

2.2 Indigenous Heritage Values

Indigenous cultural resources

<u>Dugongs and green turtles</u>

Torres Strait is a predominately Indigenous area (ABS 2013), which supports large and globally significant populations of dugongs and green turtles. Both species have significant cultural importance for Torres Strait Islanders and have been hunted for millennia (Crouch et al. 2007, Wright, 2011). Several lines of evidence indicate that the contemporary harvest is sustainable (Marsh et al. 2015, Hagihara et al. 2016). As native title holders, the Indigenous residents of Torres Strait are permitted to engage in the customary use (but not sale) of biological resources on their traditional lands and sea in accordance with traditional cultural practices that are compatible with conservation or sustainable use requirements. The customary exchange or sharing of dugong and turtle meat within and among communities is a vital part of the Ailan Kastom (Island Custom) that is widely practised by Torres Strait Islanders irrespective of their place of residence (Watkin 2009). More than 85% (~52,600) of Torres Strait Islanders live on mainland Australia (ABS 2013), including about 22% in Townsville and Cairns, adjacent to the GBR. Torres Strait Islanders use family and kinship relationships and the practice of Ailan Kastom to sustain strong connections between community members living in Torres Strait and their mainland diaspora (Watkin 2009). Torres Strait Islanders take seafood to their relatives in the coastal cities adjacent to the GBR because these people mostly cannot hunt legally outside Torres Strait. It is legal for the Torres Strait Islanders living on the mainland, most of whom are native title holders in Torres Strait, to serve dugong and turtle meat at home, or at ceremonies such as weddings or Tombstone Openings, provided the meat is not sold (Watkin et al. 2016). Motivations for this sharing of dugong and turtle meat are almost exclusively cultural. Torres Strait Islanders living on the mainland consume relatively little dugong and turtle meat throughout the year (<1-2% of annual meat consumption, or < 1 kg per person). Sharing strengthens social capital and reinforces the cultural links between the Indigenous peoples of Torres Strait and their diaspora living adjacent to the GBR.

Similar sharing of dugong and turtle meat may occur between Aboriginal Clan Groups in Hervey Bay and the southern GBR but this practice has not been documented.

2.3 Social & Historic Heritage Values

Non-indigenous communities hold a range of cultural values that can extend across the management boundaries of all four regions. Communities living and working in or near each of the four regions use and depend on the local marine resources and derive a range of benefits from using the marine resource and from living close by. Non-indigenous communities depend on marine resources not only for economic gain but also as place to live and carry out cultural activities such as fishing, boating, recreation and other lifestyle undertakings. They typically develop an “attachment to place”, which is a description of the emotional ties to a place, including the networks and connections that they hold within it, and includes the identity that is developed around living and working in the region. Those communities living in the Great Barrier Reef section report a certain pride associated with being there. These communities further develop an appreciation of the marine resources in terms of aesthetic values, heritage opportunities, and recreational opportunities, and wellbeing. The wellbeing that communities obtain from living and working within each region occurs because each of the marine resources provide physical and psychological security, food security, health, inspirational and spiritual opportunities and the opportunity to be involved in the on-going sustainability of the region (agency).

In summary, the social and cultural values within the region are associated with the range of benefits that people derive from using, and living close by to, the marine resource in each of the four regions.

2.4 Economic Values

Each of the four regions are valued for economic benefits. Economic values have the potential to extend across management boundaries. There are tourism opportunities, fisheries opportunities and recreational opportunities within each of the regions. Tourism and fisheries businesses, such as dive and charter fishing businesses, operate close to all boundaries and on both sides of the boundaries, and some commence within the Great Barrier Reef region and enter into other regions such as the Coral Sea. Commercial fishers that operate within the Great Barrier Reef require a permit to do so from the Queensland Government. This permit does not allow them to cross into the other jurisdictionally different regions, even though target fisheries species may exist in the other regions. However, fishers can hold permits in other regions concurrently. Fishers that operate within the Coral Sea require permits from the Federal Government. Fishers within the Great Sandy Strait require permits from the Queensland Government. Local residents to Queensland are able to fish across the three regions in Queensland, but must observe bag limits, or quotas, whilst in the Great Barrier Reef region. Local residents in either Australia or the Torres Strait are not allowed to cross the international borders in order to fish. Non-indigenous fishers in Torres Strait are subject to both local customary law as well as Australian law if they are married into indigenous communities.

Latest economic figures suggest that the value of commercial fishing within the Great Barrier Reef region is A$200M. Figures are not available for either tourism or commercial fishing within the Great Sandy Strait, Coral Sea or Torres Strait.

3.0 PHYSICAL DRIVERS, CONNECTIVITY AND EXCHANGES

Ocean currents are a major mechanism by which the values across the entire bioregion are both defined and connected, for example by facilitating dispersal of larvae and particles and the propagation of climate features (e.g. marine heat waves that cause bleaching). While a range of research outputs have described elements of physical connectivity in components of the region (e.g. Steinberg 2007, Weeks et al. 2010, Wolanski et al. 2013, Herzfeld et al. 2016, Ganachaud et al. 2011, Sun et al. 2015, Wolanski 2016), there has never 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 a comprehensive review was initiated by GBRMPA of the vulnerability of the GBR to climate change (Johnson and Marshall 2007). This covered a wide range of issues and ecological systems that were thought to be affected by future climate projections. This publication coincided with the implementation of the Integrated Marine Observing System (IMOS) that sought to improve the monitoring network principally with the GBR as the focus, and later an expansion into southeast Queensland to monitor the East Australian Current (EAC) and shelf waters of North Stradbroke Island. Unfortunately there remain significant gaps in the observing network and some of the northeast marine region 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 later a wealth of information has been collected and published that has looked at decadal oceanic and GBR variability rather than just rely on shorter term process based studies as had been the case in the past and to calibrate and validate a number of hydrodynamic models.

Significant progress has been made on the modelling front with the continued development of the Bluelink model (Brassington et al. 2007) from being a regional model to near global with improved near surface resolution (Zhang et al. 2016) and operationalised by BoM as OceanMAPS. The 3D eReefs model builds on the Bluelink effort to bring the model spatial resolution down from 10 km to 4 km and 1 km with far more vertical resolution allowing baroclinic processes to be analysed by CSIRO. This has also been operationalised for research and is in the process of being implemented by BoM. Coverage includes the 3 areas of interest however the central Torres Strait is the western boundary so its suitability to analyse the whole of the Torres Strait is sub optimal though the SHOC model underpinning eReefs has been used in Torres Strait for MTSRF studies (Saint-Cast and Condie 2006). The recent inclusion of biogeochemistry to the eReefs suite has expanded its usefulness to study processes beyond the hydrodynamics that underpin it.

The 2D SLIM model has also been used extensively to look at reef processes at even finer spatial scales including reef circulation and connectivity issues along the GBR and also the Torres Strait (e.g. Thomas et al. 2014, Critchell et al. 2015, Delandmeter et al. 2017, Wolanski et al. 2017). This review draws on the results of these models, *in situ* observations and remotely sensed satellite data recently published. Discussion starts at the larger Coral

Sea scale that is of relevance to the Coral Sea Territories and then focus on the regions adjacent to the GBR for the Torres Strait in the north and Great Sandy Strait in the south.

Circulation

Ocean topography is a major determinant on where and how water can circulate and mix and so it is critical to have a realistic representation of it in any modelling study. Beaman (2010) has produced a higher resolution interpolated product from all the available data for the regions of interest.

The understanding of the prevailing currents and circulation of the Coral Sea has not changed much however recently there has been a focus on understanding variability and the significant role of eddies that can be embedded in the major inflows and on occasion significantly perturb the ocean circulation.

The broad westward flowing Southern Equatorial Current which is the northern arm of the South Pacific Gyre is forced around the many island archipelagos and coral reef complexes on the way toward the GBR, They split into Jets to the north and south of these topographic barriers and so there are multiple pathways. As they make their way to 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 9).

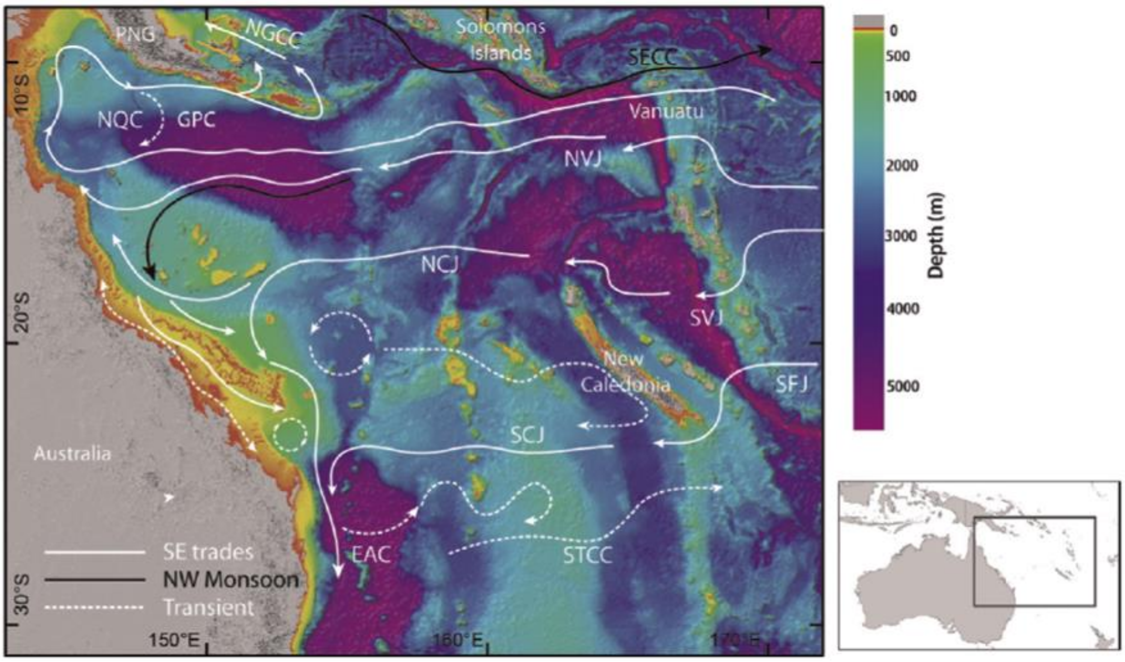

Figure 9. Bathymetry and currents in the Great Barrier Reef NGCC: New Guinea Coastal Current, mirroring the deeper New Guinea Coastal Undercurrent; NQC: North Queensland Current that is part of the Gulf of Papua Current (GPC); SECC: South Equatorial Countercurrent; Jets of South Equatorial Current (SEC): 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 2015 & Steinberg 2007).

Recent studies by Hristova have also looked at the eddy fields in the regions. The eddies can be cyclonic or anti-cyclonic and are generated by flow instabilities (Figure 10). Rousselet et al. (2016) from *in situ* and satellite observations has tracked an anticyclonic eddy moving south west away from the North Vanuatu Jet moving into the region where the of North Caledonia Jet waters.

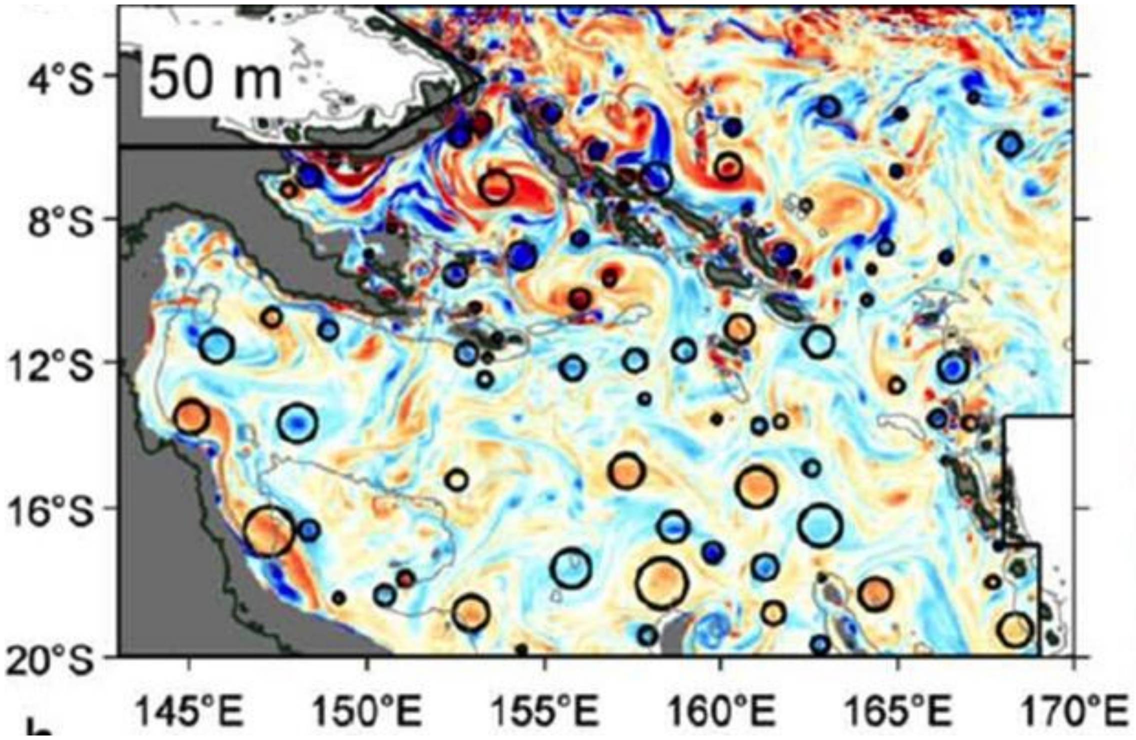

Figure 10: Modelled eddy vortices (red + anti-cyclonic vortices, blue - cyclonic) (Adapted from Rousselet 2016).

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Appendix 1. Northeast Australian seascape values and attributes characterised

VALUES	NATURAL HERITAGE							INDIGENOUS HERITAGE	SOCIAL & HISTORIC	ECONOMIC
COMPONENTS	Coral reefs	Mainland beaches & islands/cays	Estaurine and tidal habitats	Seagrass meadows	Inter-reefal habitats	Mobile adults	Species with mobile laruae	Indigenous culture	Social & historic culture	Industry sectors
Attributes	Hard coral	Casuarina & Pandanus	Mangroves	Seagrass – *Zostera muelleri*	*Halimeda* banks	Dugong	Ornate rock lobster	Location of Sea Country	Location of historic shipwrecks	Location of tourism destinations
	Crustose coralline algae	*Pisonia grandis*	Saltmarsh	Seagrass – tropical spp. (*Thalassia* etc.)	Inter-reef gardens	Flatback turtle	Black teatfish	Tangible cultural resources	Places of social significance	Location of commercial fishing activity
	Acropora larvae	*Argusia argentia*		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

Appendix 2. Great Barrier Reef 40 non-reef bioregions

Table 6: Bioregion ID (e.g. NA1), Bioregion Name and description/justification of each Bioregion (described in 2000 – updated in 2013).

NA1 Coastal Strip	Sand rather than mud, low carbonate and low nutrient. Dry tropic influence from land. Very dense seagrass in places – some areas important for dugong and turtle feeding. Boundaries of bioregion along the coast match changes in shoreline type.
NA3 High Nutrients Coastal Strip	Terrigenous mud and high levels of nutrients from the adjoining land. Seagrass in sheltered sites only. Good turtle and dugong feeding habitat. Wet tropic influence for much of the coast.
NA4 Inshore Terrigenous Sands	Strong Broad Sound tidal influence. Very mobile sands, little algae or seagrass.
NB1 Inshore Muddy Lagoon	High carbonate sand, prawn habitat. Rich soft-sediment sponge fauna, 24 per cent not yet recorded elsewhere.
NB3 Inner Shelf Seagrass	Very sandy area with distinct invertebrate and fish communities. Seasonal seagrass in patches. Distinct gorgonian fauna, associated with low wooded islands. Boundary for sponges and gorgonians extends south to Cape Grafton only.
NB5 Inner Mid-Shelf Lagoon	Coarse sediment from land influences (medium-high land input). Sparse seagrass.
NB6 Inner Shelf Lagoon Continental Islands	Strong currents, gravel and hydroids around Pine Peak Island. Some gorgonians and low reef sites, water very turbid. Seagrass meadows in some bays
NB7 Mid-Shelf Lagoon	Muds dominate, minimal algae or seagrass. Leeward parts of Hook and Bait Reefs are geomorphologically different. Very steep, extensive benthos, gravel, low sponge diversity but only 21 per cent of species are similar to those in southern lagoonal reefs. Mobile sand dunes influenced by strong East Australian Current.
NB8 Capricorn Bunker Lagoon	Halimeda and seagrass up to 50 per cent cover. Mixing of southern inshore and tropical inshore sponge species, 28 per cent not yet found elsewhere.
NC Mid-Shelf Inter-Reef	Seagrass: Fine sediments, high carbonate content between a large number of reefs. Contains deep water shoals.
ND Mid-Shelf Inter-Reef	Shelly sands, almost no fine sediments. Very little seagrass. Abundant crinoids (feather stars).
NE Outer Shelf Lagoon	*Halimeda* Banks. Caulerpa goes only as far as the inner edge of the shelf edge. Eastern boundary follows the inner boundary of the Ribbon Reefs.
NF Halimeda Banks	Some coral: Halimeda and Caulerpa banks with deep rubble reef or sparse coral patches. Note NE/NF boundary follows Pollard Channel
NH Mid-Shelf Sandy Inter-Reef	Sandy, low-density seagrass beds, known turtle-foraging sites.
NI Halimeda Banks	Dense *Halimeda*, almost no coral, some seagrass.
NJ Princess Charlotte Bay Outer Shelf	Sandy, change to carbonate sediments. Red-spot king prawn grounds.
NK Princess Charlotte Bay	Muddy bay surrounded by silica sand deposits with low nutrient levels. Some seagrass.
NL1 Outer Shelf Algae and Seagrass	Areas of medium-density seagrass and medium density algae, diverse solitary corals. High diversity of sponge species at Lizard Island and North and South Direction Groups, 28 per cent not yet recorded elsewhere on the GBR
NL2 Outer Shelf Seagrass	Shelly sands (very coarse) with smaller areas of seagrass and algal gardens (low density).
NL3 Outer Shelf Inter Reef	Central: Shelly sands with very sparse algae and seagrasses
NL4 Outer Shelf Inter Reef - Southern	High currents. Coarse sediments. Available data indicates low biomass and high diversity of biota.
NL5 Swains Inter Reef	Rich sponge fauna, 26 per cent not yet recorded elsewhere on Great Barrier Reef, and only 31 per cent of species occurring in both Swain and Capricorn Bunker regions. Complex and rocky in places, with lower tidal current than in NL4. Fuzzy boundary with NL4. Some *Halimeda*, and some seagrass in patches in middle Swains.

<table>
<tr><td>NM Mid Shelf Seagrass</td><td>Dense seagrass beds. Very muddy area with distinct invertebrate and fish communities. High diversity of sponges near Turtle Islands group with 36 per cent not yet recorded elsewhere in GBR region.</td></tr>
<tr><td>NN Capricorn Bunker Banks</td><td>Pre-reef Halimeda deposits around Capricorn Bunker reefs. Diverse sponge fauna (187 species), mostly different from southern fauna (NB8), slightly more similar to northern island-group faunas (NL5).</td></tr>
<tr><td>NO Capricorn Trough</td><td>Deep oceanic influence. Mix of pelagic (e.g. foraminifera) and Halimeda seabed deposits. Very fuzzy boundary between NO and NB7.</td></tr>
<tr><td>NP Eastern Plateau</td><td>Based on depth, region broadens towards Eastern Plateau; mostly fine pelagic sediments.</td></tr>
<tr><td>NQ Steep Slope:</td><td>Very steep slope dropping off to depths below 2500m; slopes prone to slippages.</td></tr>
<tr><td>NR Queensland Trough</td><td>More moderate slope than NQ; mostly fine pelagic sediments.</td></tr>
<tr><td>NS Intermediate Broad Slope</td><td>Widening of slope with lower gradient; mostly fine pelagic sediments. 23</td></tr>
<tr><td>NTW Western Pelagic Platform</td><td>Gentle, broad slope; number of sediment drifts (mobile sand banks formed under East Australian Current); mostly fine pelagic sediments punctuated by many coral shoals. Oceanic sharks and large bluespot trout present.</td></tr>
<tr><td>NTE Eastern Pelagic Platform</td><td>Gentle, broad slope. Mostly fine pelagic sediments with several long (30 n. mile) E-W shoals of extensive plate corals to 5-10 m depth. A number of mobile sand banks have formed under East Australian Current.</td></tr>
<tr><td>NU Terraces</td><td>Characterised by hard substrate seafloor terraces at depths of 90-300 m; terraces punctuated by shoals to depths of around 10 m.</td></tr>
<tr><td>X1 Far Northern Offshelf</td><td rowspan="8">These deepwater, offshore areas extend from the edge of the continental shelf to the eastern border of the GBR World Heritage Area. They were described largely from physical information. For the purposes of the Representative Areas Program, and until further information is gained, they are treated as separate bioregions.</td></tr>
<tr><td>X2 Offshelf Queensland Trough</td></tr>
<tr><td>X3 Outer Far Northern Inter Reef</td></tr>
<tr><td>X4 Capricorn Bunker Inter Reef</td></tr>
<tr><td>X5 Outer Central Inter-Reef</td></tr>
<tr><td>X6 Central Offshelf</td></tr>
<tr><td>X7 Central Inter Reef</td></tr>
<tr><td>X8 Southern Embayment</td></tr>
</table>

Note: With regard to *Halimeda dominated bioregions: McNeil et al. (2016) "Distribution and mapping of* Halimeda *bioherms in relation to GBRMPA's* (2000) *bioregion classifications are inconsistent due to a lack of high-resolution data previously available. These new estimates of bioherm spatial distribution and morphology have implications for understanding the role these geological features play as structurally complex and productive inter-reef habitats, and as calcium carbonate sinks…"*

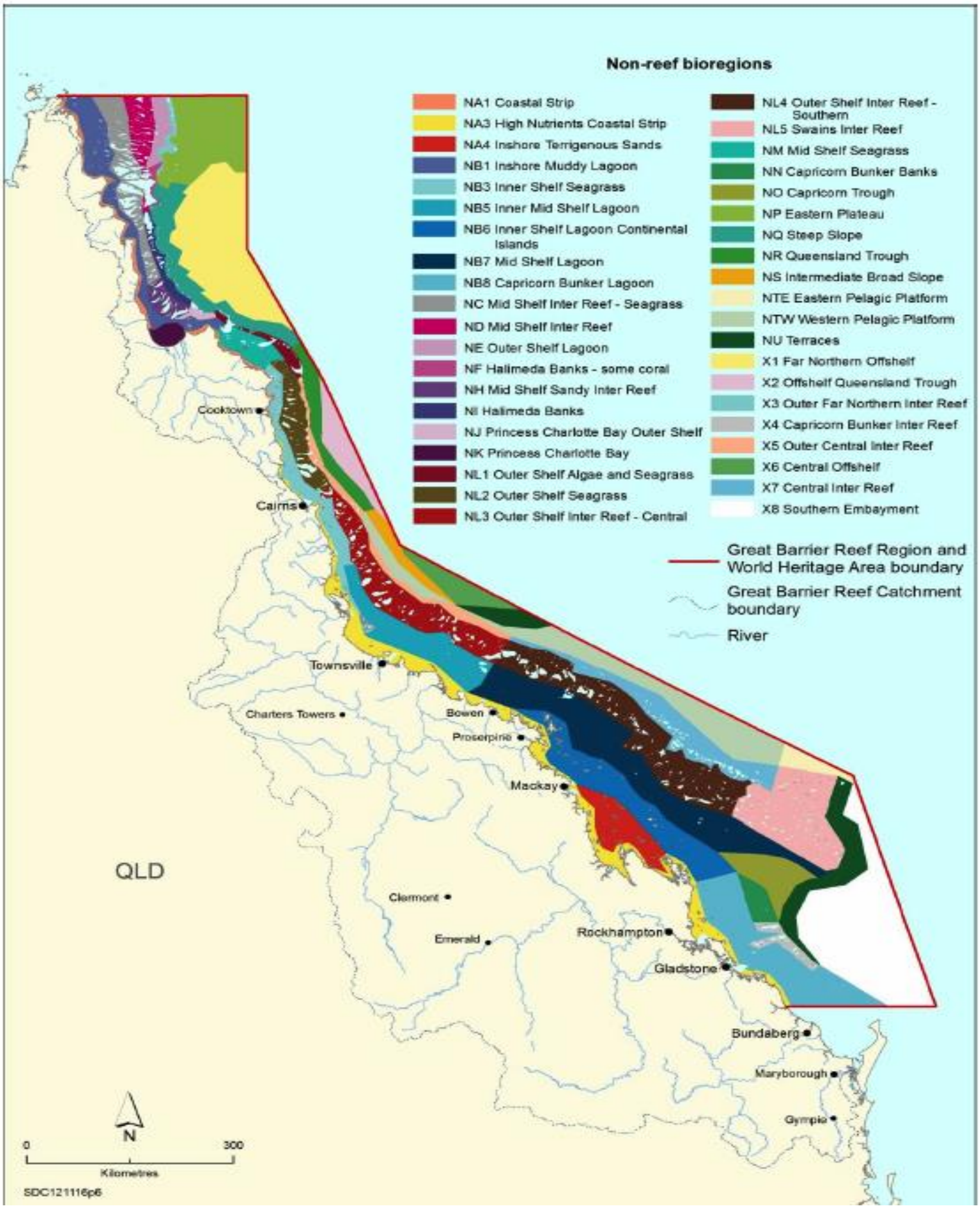

Figure 11: Non-reef bioregions of the Great Barrier Reef (Source: GBRMPA 2000).

Appendix 3. Geomorphic features in the Coral Sea, Torres Strait and Great Sandy Strait

Table 7: List of previously described geomorphic features on the northeast margin. Features are numbered (left hand column) on Figures 12 and 13. (Adapted from Harris et al. 2005).

No.	Geomorphic Feature	Feature Type	References
1	Adolphus Channel	Channel (10)	Harris (1991)
2	Bligh Canyon	Trough (7)	Winterer (1970)
3	Bligh Entrance	Channel (10)	Hopley (1982)
4	Bligh Trough	Trough (7)	Winterer (1970)
5	Capricorn Channel	Channel (10)	Hopley (1982)
6	Cato Trough	Trough (7)	Hill (1994)
7	Coral Sea Basin	Basin (8)	Winterer (1970)
8	Coringa Reef	Reef (9)	Davies et al. (1989)
9	Cruiser Pass	Channel (10)	Harris & Baker (1988)
10	Curtis Channel	Channel (10)	Hopley (1982)
11	East Fields Reef	Reef (9)	Hopley (1982)
12	Endeavour Strait	Channel (10)	Harris (2001)
13	Flinders Reef	Channel (10)	Harris & Baker (1988)
14	Flora Passage	Channel (10)	Dunbar et al. (2000)
15	Grafton Passage	Channel (10)	Harris & Baker (1988)
16	Great Barrier Reef	Plateau (15)	Davies et al. (1989)
17	Great North East Channel	Channel (10)	Harris (2001)
18	Hydrographers Passage	Channel (10)	Harris & Baker (1988)
19	Kenn Plateau	Plateau (15)	Wilcox (1981)
20	Lihou Reef	Reef (9)	Davies et al. (1989)
21	Louisiade Plateau	Plateau (15)	Gaina et al. (1999)
22	Magnetic Passage	Channel (10)	Harris & Baker (1988)
23	Marion Plateau	Plateau (15)	Davies et al. (1989)
24	Marion Reef	Reef (9)	Hopley (1982)
25	Mellish Rise	Plateau (15)	Gaina et al. (1999)
26	Missionary Passage	Channel (10)	Harris (2001)
27	Osprey Reef	Reef (9)	Davies et al. (1989)
28	Palm Passage	Channel (10)	Harris & Baker (1988)
29	Pandora Trough	Trough (7)	Winterer (1970)
30	Papuan Plateau	Plateau (15)	Davies et al. (1989)
31	Queensland Plateau	Plateau (15)	Davies et al. (1989)
32	Queensland Trough	Trough (7)	Winterer (1970)
33	Saumarez Reef	Reef (9)	Hopley (1982)
34	Swains Reef High	Plateau (15)	Hopley (1982)
35	Tasman Basin	Basin (8)	Hill (1994)
36	Tasmantid Seamounts	Seamount (13)	McDougall & Duncan (1988)
37	Townsville Trough	Trough (7)	Struckmeyer et al. (1994)
38	Tregrosse Reef	Reef (9)	Davies et al. (1989)
39	Trinity Opening	Channel (10)	Harris & Baker (1988)

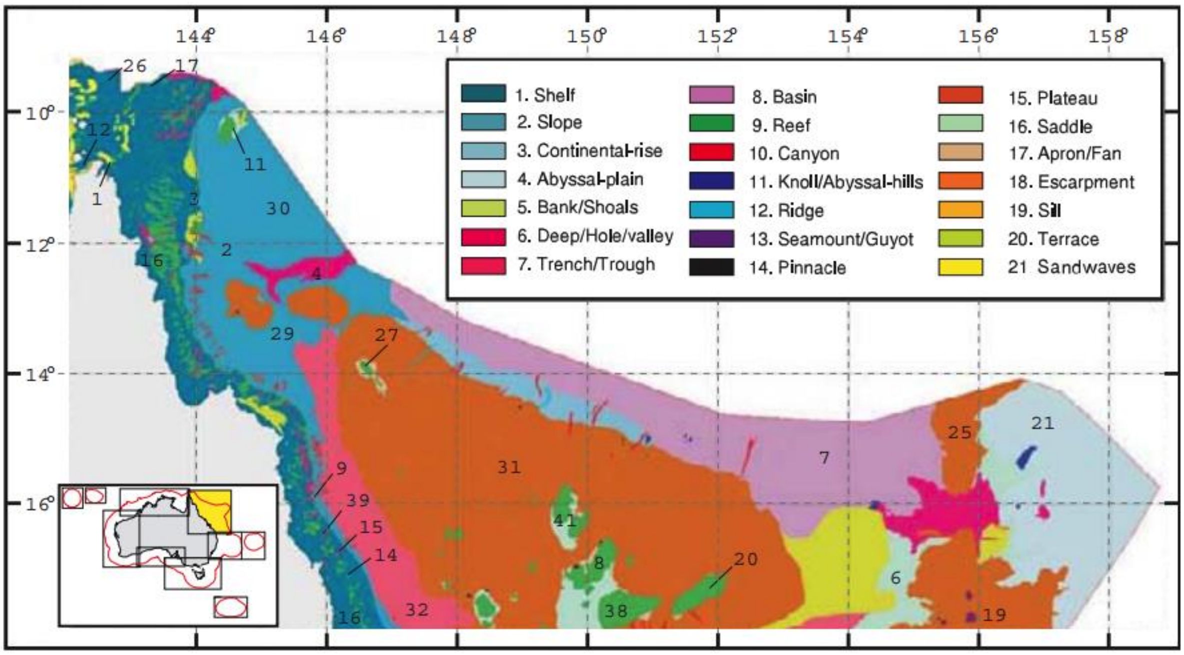

Figure 12: Geomorphic features on the northeast margin adjacent to the Great Barrier Reef. See Table A2 for key to place names

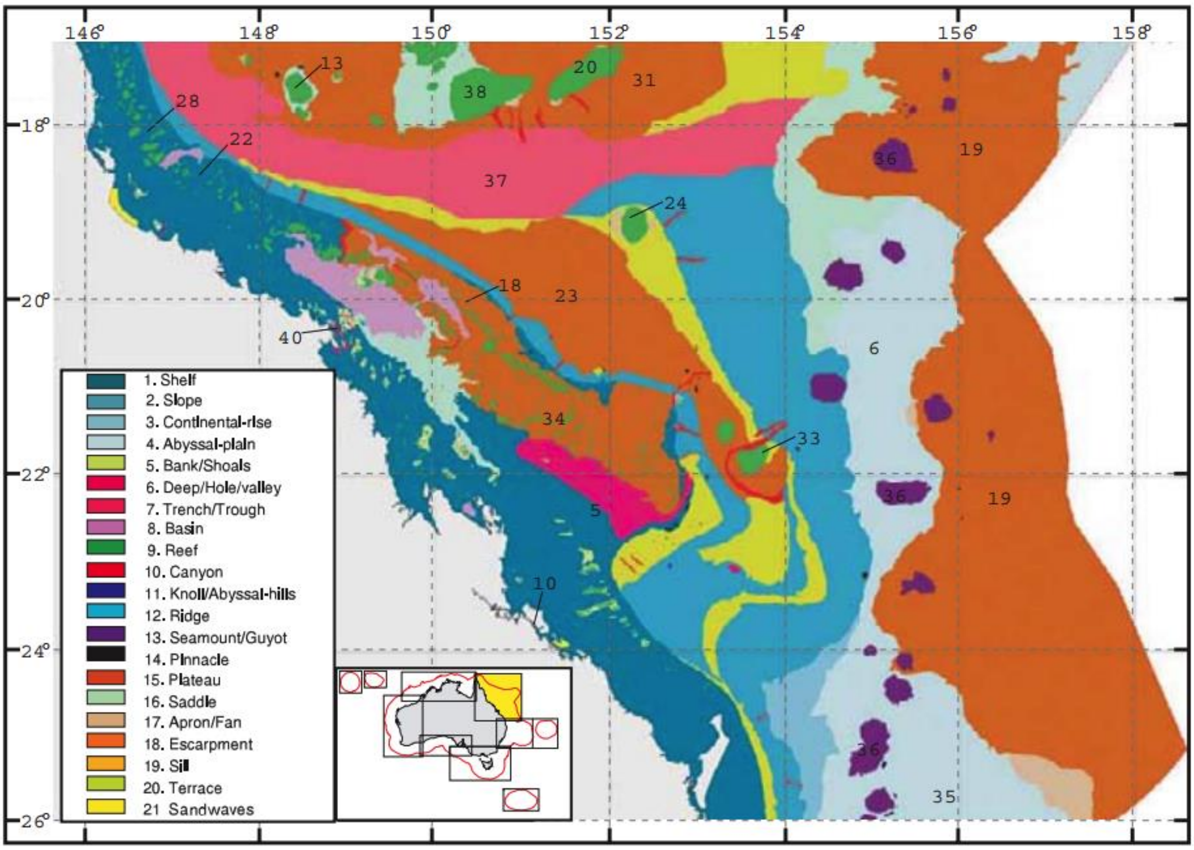

Figure 13: Geomorphic features on the northeast margin adjacent to the Great Barrier Reef. See Table 7 for key to place names.

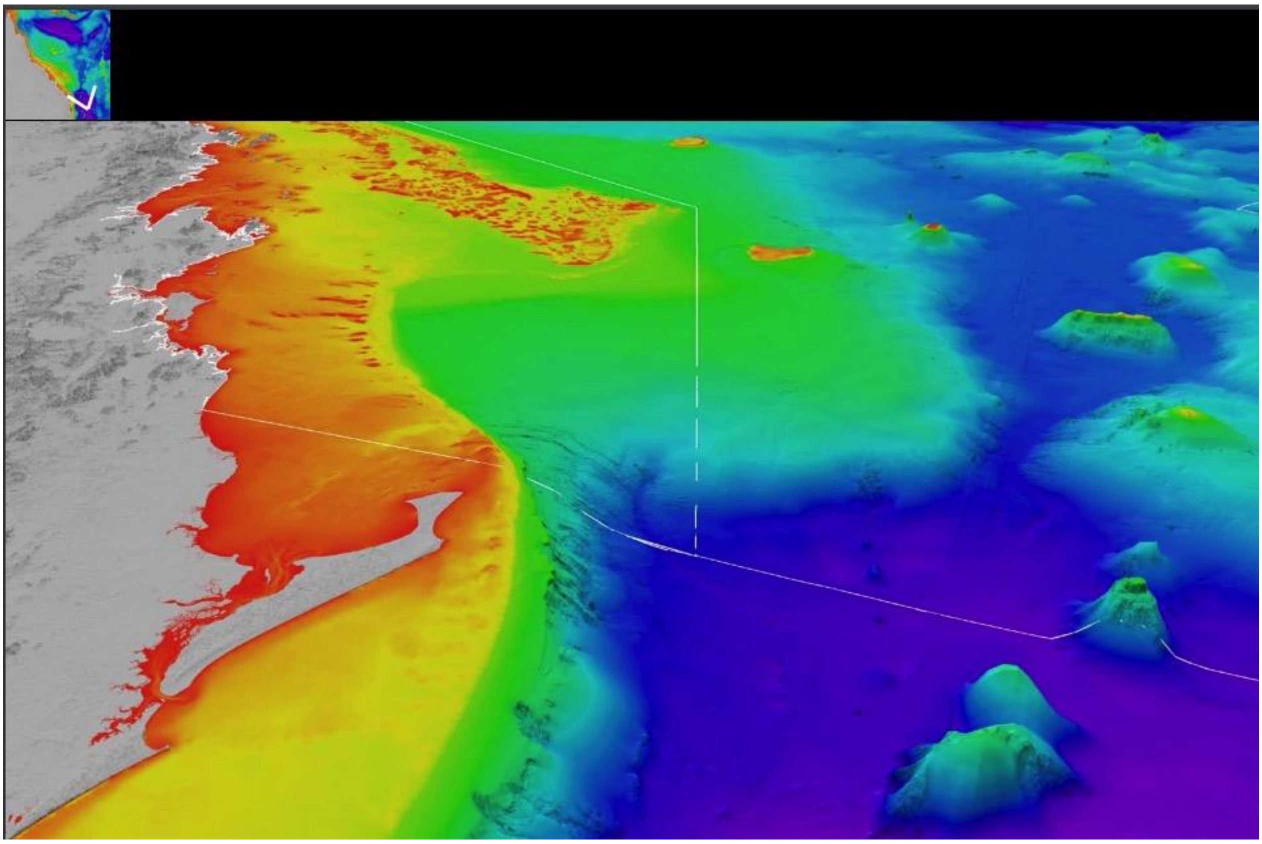

Figure 14: Screen shots taken from Rob Beaman's 'DeepReef' website showing Great Sandy Strait, southern part of GBR and a small part of the Coral Sea.

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