National Environmental Research Program

TROPICAL ECOSYSTEMS hub

Tropical Research in Australia's Torres Strait Region

Synthesis of NERP Tropical Ecosystems Hub Torres Strait Research Outputs 2011-2014

Compiled by RRRC

Australian Government
Department of the Environment

Reef & Rainforest RESEARCH CENTRE

Tropical Research in Australia's Torres Strait Region

Synthesis of NERP Tropical Ecosystems Hub Torres Strait Research Outputs 2011-2014

Johanna Johnson, Helene Marsh, Mark Hamann, Norman Duke, Damien Burrows, Scott Bainbridge, Hugh Sweatman, Jon Brodie, Erin Bohensky, James Butler and Susan Laurance

Australian Government

Department of the Environment

Reef & Rainforest RESEARCH CENTRE

Supported by the Australian Government's National Environmental Research Program

National Library of Australia Cataloguing-in-Publication entry:
978-1-925088-56-4

This report should be cited as:

Johnson, J.E., Marsh, H., Hamann, M., Duke, N., Burrows, D., Bainbridge, S., Sweatman, H., Brodie, J., Bohensky, E., Butler, J., Laurance, S. (2015) Tropical Research in Australia's Torres Strait region. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (33pp.).

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's National Environmental Research Program (NERP) Tropical Ecosystems (TE) Hub.

The Tropical Ecosystems Hub is part of the Australian Government's National Environmental Research Program. The NERP TE Hub is administered in North Queensland by the Reef and Rainforest Research Centre Limited (RRRC). The NERP Tropical Ecosystem Hub addresses issues of concern for the management, conservation and sustainable use of the World Heritage listed Great Barrier Reef (GBR) and its catchments, tropical rainforests including the Wet Tropics World Heritage Area (WTWHA), and the terrestrial and marine assets underpinning resilient communities in the Torres Strait, through the generation and transfer of world-class research and shared knowledge.

Cover photograph: J. Carmody

This report is available for download from the NERP Tropical Ecosystems Hub website:
www.nerptropical.edu.au

February 2015

Contents

List of Figures

List of Tables

Acronyms Used In This Report

AFMA	Australian Fisheries Management Authority
AIMS	Australian Institute of Marine Science
BoM	[Australian] Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DATSIMA	[Queensland] Department of Aboriginal and Torres Strait Islander & Multicultural Affairs
DoE	[Australian] Department of the Environment
DFAT	[Australian] Department of Foreign Affairs and Trade
EMQ	Emergency Management Queensland
GBR	Great Barrier Reef
JCU	James Cook University
MTSRF	Marine and Tropical Sciences Research Facility
PNG	Papua New Guinea
QDAFF	Queensland Department of Agriculture, Fisheries and Forestry
RRRC	Reef and Rainforest Research Centre Limited
TSC	Torres Shire Council
TSIRC	Torres Strait Island Regional Council
TSRA	Torres Strait Regional Authority

Acknowledgements

The authors gratefully acknowledge the researchers who contributed to the National Environmental Research Program’s Tropical Ecosystems Hub. Outstanding science by Helene Marsh, Mark Hamann, Norman Duke, Damien Burrows, Ray Berkelmans, Scott Bainbridge, Jon Brodie, Jane Waterhouse, Erin Bohensky, James Butler, Susan Laurance and their research teams has been instrumental in advancing our knowledge of natural systems and communities in the Torres Strait region.

The authors would also like to thank the Australian Government Department of the Environment for funding the National Environmental Research Program, and the Reef and Rainforest Research Centre for supporting this program over the past four years. The involvement of primary end users in this research, including the Torres Strait Regional Authority, Biosecurity Queensland, Australian Fisheries Management Authority, Torres Shire Council, Torres Strait Island Regional Council, Tagai College, and the Queensland Department of State Development, Infrastructure and Planning has ensured that the findings are useful and will inform future decision-making.

About this Report

This report provides an overview and synthesis of the key findings of research conducted in the Torres Strait region under the Australian Government's National Environmental Research Program (NERP) Tropical Ecosystems Hub. This NERP research has built on research under the Torres Strait CRC and Marine and Tropical Science Research Facility (MTSRF) conducted since 2003. The NERP Torres Strait research comprised of six projects in the fields of natural and social sciences, undertaken collaboratively by researchers from the Australian Institute of Marine Science, James Cook University, the CSIRO and the University of Queensland.

The intent of the NERP-funded Torres Strait research was to address issues of concern for the management, conservation and sustainable use of the terrestrial and marine assets underpinning resilient communities in the Torres Strait, through the generation and transfer of world-class research and shared knowledge. There has been a strong focus on documenting the status and trends of natural assets in the region, such as coral reefs, mangrove and freshwater ecosystems and dugongs and turtles, as well as preliminary studies to identify water quality and biosecurity hazards in the region, and building resilient communities.

This report presents a synthesis of the highlights of the NERP Tropical Ecosystems Hub Torres Strait theme, and an overview of key project acheivements within the theme. The report provides an introduction to the Torres Strait region, a synthesis of key ecological and socio-economic project highlights for the region including status and trends, future pressures and threats, how research has informed policy and management, and future research priorities.

This report provides a synthesis of one key theme in the NERP Tropical Ecosystems Hub, and is one of several such reports in a series of information products that summarise NERP research findings relevant to policy and management in tropical North Queensland. Other NERP synthesis products include:

- Carmody, J., Murphy, H., Hill, R., Catterall, C., Goosem, S., Dale, A., Westcott, D., Welbergen, J., Shoo, L., Stoeckl, N., Esparon, M. (2015) The Importance of Protecting and Conserving the Wet Tropics: A synthesis of NERP Tropical Ecosystems Hub Tropical Rainforest Outputs 2011-2014. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (64pp.).
- Devlin, M., Fabricius, K., Negri, A., Brodie, J., Waterhouse, J., Uthicke, S., Collier, C., Pressey, B., Augé, A., Reid, B., Woodberry, O., Zhao, J-x., Clarke, T., Pandolfi, J., Bennett, J. (2015) Water Quality - Synthesis of NERP Tropical Ecosystems Hub Water Quality Research Outputs 2011-2014. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (55pp.).
- Donnelly, R., Sweatman, H., Emslie, M., Russ, G., Williamson, D., Jones, G., Harrison, H. (2015) Effects of Management Zoning on Coral Trout Populations in the Great Barrier Reef Marine Park. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (12pp.).
- Donnelly, R., Yates, P., Schlaff, A., Espinoza, M., Matley, J., Ledee, E., Currey, L., de Faria, F., Moore, S. (2015) Spatial Management and Sharks on the Great Barrier Reef. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (10pp.).

1. Introduction to the Torres Strait region

The Torres Strait region covers an area of 48,000 km^2, of which 2.6% is land, 6.2% is tidally inundated reef flats, and 91.2% open seas, most of which are relatively shallow (20–60 m). The region is protected from swell by the northern Great Barrier Reef (GBR), and has strong tidal currents and irregular bathymetry with a narrow continental shelf. There are more than 247 islands, 18 that are inhabited and support an estimated 7,000 people. There are also numerous coral reefs, cays, sandbanks and seagrass meadows scattered throughout the region, which stretches 200 kilometres from the tip of the Cape York Peninsula to the southwest coast of Papua New Guinea (PNG) (Figure 1).

Figure 1. Map showing the Torres Strait region with the major islands indicated.

The Torres Strait is a region of rich biodiversity and cultural significance, and its ecosystems are amongst the most pristine in the world. The region provides a multitude of habitats for highly diverse Indo-Pacific marine flora and fauna, including dugongs and marine turtles. Dugongs and turtles are of immense spiritual significance to the people of the Torres Strait, and have a vital role in the region's ecology and cultural economy. The Torres Strait has the largest continuous area of seagrass meadows in the world, significant areas of high diversity coral reefs, extensive areas of coastal mangroves, and productive fisheries. The strategic location of the Torres Strait places it at risk from the downstream impacts of shipping, mining, resource over-exploitation, increasing tropical diseases and climate change.

The NERP Tropical Ecosystems Hub research has built on research under the Torres Strait CRC and Marine and Tropical Science Research Facility on the status and risks to Torres Strait ecosystems and the people that live in the region to support future priorities and inform decision-making by Torres Strait Islander leaders. A suite of NERP projects investigated status and trends of marine and coastal habitats, water quality hazards, drivers of community change and resilience, and emerging infectious diseases (Table 1). The projects investigating the diversity, extent and health of coral reefs, mangrove and freshwater habitats, and marine water quality issues has confirmed the importance of key Torres Strait habitats from a regional perspective, as well as nationally and internationally. Participatory community projects have focused on drivers of change to build resilient communities, and detecting vectors of tropical diseases.

Table 1. Suite of NERP projects that conducted research in the Torres Strait region.

Project	Project leader	Institution
2.1 Marine turtles and dugongs of Torres Strait	Dr Mark Hamann & Professor Helene Marsh	James Cook University
2.2 Mangrove and freshwater wetlands of Torres Strait	Dr Norman Duke & Dr Damien Burrows	TropWATER, James Cook University
2.3 Monitoring the health of Torres Strait coral reefs	Dr Scott Bainbridge	Australian Institute of Marine Science
4.4 Hazard assessment of water quality threats to Torres Strait marine waters, ecosystems and public health	Jon Brodie	TropWATER, James Cook University
11.1 Builidng resilient communities for Torres Strait futures	Dr Erin Bohensky	CSIRO
11.2 Determining disease dynamics across Torres Strait	Assoc. Professor Susan Laurance	James Cook University

Research on the ecological function of these key habitats and the threats posed to them supports communities and management agencies in developing appropriate plans and policies, and implementing measures to protect them. NERP research has been highly participatory, with Rangers now employed in all outer island communities in Torres Strait having played an integral role in supporting research and monitoring in culturally appropriate ways. Effective collaboration between researchers, Rangers and communities, facilitated by the Torres Strait Regional Authority (TSRA) Land and Sea Management unit, has ensured that management efforts are well-targeted, based on the best available scientific information, and aligned with community priorities and local and customary knowledge.

2. Research highlights

Torres Strait Islander communities continue to depend on the healthy functioning of their marine and coastal ecosystems for livelihoods and cultural practices. Central to the NERP science projects, is the critical involvement of Torres Strait people and communities in research and monitoring. As key end-users of research findings, great care was taken to ensure that communities were included throughout the program from inception to reporting. This research places Torres Strait communities and the region in good stead for making informed decisions in the process of adapting to future change. It also informs future research priorities and investment focus.

Key outcomes and knowledge from NERP Tropical Ecosystem hub Torres Strait projects include:

- Torres Strait reefs are a biodiversity hotspot in Australia, and it is likely that more species from the Coral Triangle will be found in the future as the survey area is expanded.
- Reef surveys documented 246 species of hard corals, including 77 new records for Torres Strait and some species potentially being new records for Australia.
- Reef surveys showed that in general Torres Strait reefs are in good to excellent condition with high coral cover, presence of major taxonomic and functional groups, and minimal incidence of coral disease. Small-scale outbreaks of crown-of-thorns starfish (COTS) were observed.
- The good condition of the Torres Strait reefs is in contrast to the situation on the Great Barrier Reef, which has seen a 50% decline in coral cover over the last 27 years (De'ath et al. 2012).
- Reef fish surveys documented 301 species of fish with many being new records for the Torres Strait region.
- Aerial surveys confirm that Torres Strait dugong populations are healthy with >12,000 animals and remain stable, and confirm the region's status as the 'dugong capital' of the world.
- The Mer island group has the most significant green turtle rookeries in the Torres Strait and they are important to the future health and viability of northern GBR populations.
- Aerial surveys also confirm a significant population of large juvenile and adult turtles in western Torres Strait (~600,000 animals).
- There are long-term concerns for the future of green turtles in the Torres Strait population due to chronic recruitment failures at their major rookery, Raine Island in the northern GBR.
- Islands in the western and southern Torres Strait are significant flatback turtle rookeries, and adult females migrate large distances to foraging areas in international waters.
- A coral bleaching temperature/exposure threshold developed for Thursday Island based on 15-years of data determined that 7 days of average daily temperatures above 31°C would be sufficient to cause coral bleaching, as would 3 days above 31.2°C. This threshold has been used to develop a real-time bleaching risk index to inform management.
- Although ocean monitoring and satellite data showed that 2011 – 2014 sea temperatures were cooler than the long-term mean, current Pacific Ocean weather is showing a return to El Niño conditions that are characterised by hot dry summers with much greater risk of coral bleaching and other temperature related stresses.

- Wetland surveys on 20 islands in Torres Strait documented 124 wetland species, including 35 mangrove species (more than half the worlds total) with two being new records for Australia, and two new records for Torres Strait/Queensland.
- Shoreline surveys now provide a georeferenced visual baseline of condition covering 300 km of tidal wetlands and has identified ~31,390 ha of wetland area. Although significantly less freshwater habitat was recorded, 50 species of freshwater fish were documented.
- There are many forces driving changes in wetlands (e.g. erosion, storm damage, feral animals, ghost nets etc.) and these vary considerably between Torres Strait islands. The biggest future threats to mangroves include sea level rise, nutrients, chemical pollution and uncontrolled wood harvesting.
- Resilient communities are able to cope with and persist after unexpected shocks. The Torres Strait is under increasing pressure from a range of factors, and Torres Strait communities have been working to pro-actively plan for the future to address these threats to their islands, their culture, way of life and livelihoods.
- An innovative multi-stakeholder participatory approach to support communities to make decisions in the face of uncertainty has been pioneered and identified some key adaptations for the future to build resilient and sustainable Torres Strait communities.
- A novel method for sampling disease vectors in remote tropical regions has been pioneered and results show that although natural vegetation supports more mosquitos, the disease-carrying mosquitos are almost exclusively found in village sites, with implications for the spread of infectious diseases in the Torres Strait.

2.1 Ecological features of the region

The Torres Strait region is a group of 247 islands located between northeast mainland Australia and PNG. Only 18 of the islands are inhabited and thus the Torres Strait retains a high degree of natural and wilderness value. In addition to the numerous continental islands, the region has large areas of coral reefs, seagrass meadows and mangroves. The massive freshwater and sediment input from nearby coastal rivers in PNG further influence this unique marine ecosystem. The Fly River is the largest river in the region and flood plumes can influence the northern Torres Strait, transporting large quantities of sediment to marine habitats (Gehrke et al. 2011). The influence of runoff from PNG delivered by these large river flows has been identified as a major threat to seagrass in Torres Strait (Coles et al. 2012) and is also likely to affect reefs in the northeast of the region.

The oceanography of Torres Strait is characterised by water circulation driven by wind, tides and circulation in the Coral Sea, the northern Great Barrier Reef continental shelf, the Gulf of Papua, and the Gulf of Carpentaria. The net east-west water flow through Torres Strait is small, and areas of shallow waters or densely covered with reefs and islands are poorly flushed. Only reef passages and reef-free open waters are relatively well flushed as demonstrated by current movements (Figure 2).

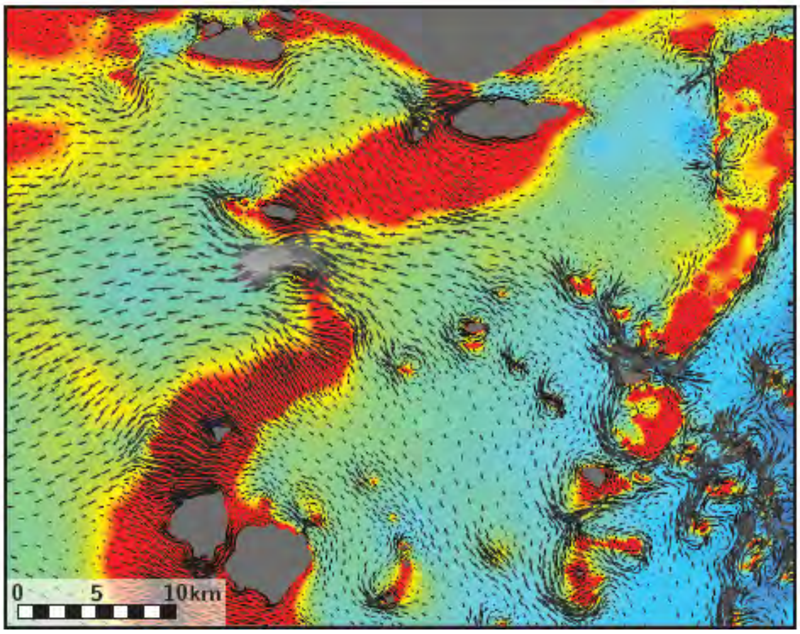

Figure 2. Mean currents (m/s) and general circulation model of Torres Strait (Wolanski et al. 2013).

Strong physical drivers in Torres Strait – large tidal ranges, strong currents and turbidity – have influenced the formation and character of the ~1,200 coral reefs, with an east-west elongation of reefs. Coral reefs dominate in the clear warm waters on the eastern shelf and form the northern extension of the GBR system, 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). The large sediment discharges from the Fly River, PNG affect an area of reefs in the northern Torres Strait (Wolanski et al. 2013), resulting in reefs with muddy carbonate sediments (Sweatman and Berkelmans 2012) while sediments in the south and west are mainly reef-derived with > 80% carbonates. The geological structures of reefs, particularly in the more sediment-rich waters of the western Torres Strait, include extensive reef tops and reef flats covered in soft sediments and seagrasses as well as growing reef edges and slopes that have more hard substrates and corals (Sweatman and Berkelmans 2012).

Coral reefs of the Torres Strait are at the northern tip and part of the GBR province. Despite their ecological connection to the GBR and clear importance to Torres Strait island communities, comparatively few biodiversity surveys have been done on these reefs. As elsewhere, climate change, crown-of-thorns starfish (*Acanthaster planci*) outbreaks, disease, storms, and pollution from river runoff and shipping are threatening the ecological integrity of Torres Strait reefs. A NERP-funded project aimed to establish a monitoring program to enable resource managers to keep abreast of key indicators of coral health and respond to major changes to coral reefs, especially as a result of climate change, as well as to train local rangers to undertake ongoing monitoring (Bainbridge et al. 2015).

The wetland ecosystems on the islands in the Torres Strait region – mangroves, salt marsh and freshwaters – are historically not well documented. For many islands, there has been limited documentation of what wetland types are present, and their biota, condition and status. Whilst freshwater wetlands are rare, most Torres Strait islands have extensive mangrove margins and several islands (e.g. Saibai and Boigu) are predominantly made up of intertidal swamps. Establishing the baseline of wetland status and condition has been the focus of a NERP-funded project, especially as many islands are low lying and the predictions of sea level rise and increased storm surge frequency mean that mangroves and coastal wetlands may be among the most threatened ecological communities in Torres Strait (Duke et al. 2015).

Torres Strait marine habitats support significant populations of dugongs, green and flatback turtles – species of conservation concern (Sobtzick et al. 2014) – as well as sharks, fish and invertebrate species, many of which are important for local fisheries, such as tropical rock lobster and sea cucumbers (Welch and Johnson 2013). In Queensland, dugongs (*Dugong dugon*) are listed as vulnerable under the *Nature Conservation Act 1992*. Green (*Chelonia mydas*) and flatback (*Natator depressus*) turtles are listed as vulnerable under the Australian *Environment Protection and Biodiversity Conservation Act 2000* and the Queensland *Nature Conservation Act 1992* (Hamann et al. 2015a,b).

2.2 Current status and trends of ecosystems

2.2.1 Coral reefs

The NERP supported a project that reviewed past coral reef surveys to inform new baseline and biodiversity surveys of key reefs, and established a network of *in situ* ocean monitoring stations to measure current environmental conditions and potential stressors, such as high sea temperatures. Coral bleaching was reported in western Torres Strait in 2010, coinciding with high water temperatures. The project developed a locally-specific bleaching threshold and installed a real-time weather station at Madge Reef near Thursday Island used to provide early warning of coral bleaching conditions. The bleaching threshold of 7 days above 31°C or 3 days above 31.2°C was implemented with data from the real-time observing station at Madge Reef to monitor bleaching conditions during the 2012/13 and 2013/14 summers (Figure 3). Ongoing data from the temperature loggers and weather station is a legacy for the region that will continue to provide monthly updates of ocean and atmospheric conditions at public kiosks (Bainbridge et al. 2015).

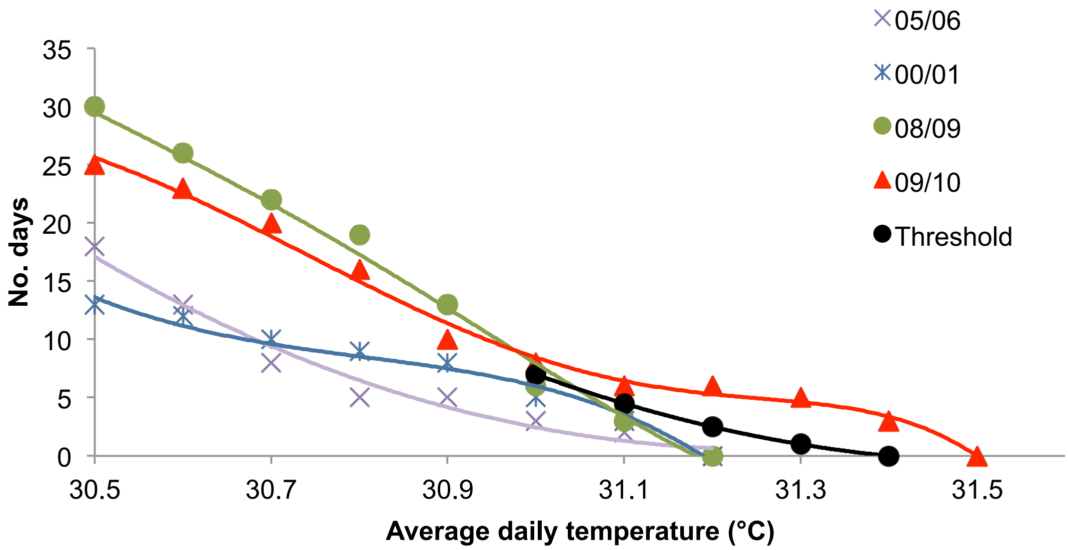

Figure 3. Determining the bleaching threshold that lies between the warmest (non-bleaching) summers of 2008/09 and 2000/01 and the (bleaching) summer of 2009/10 (Bainbridge et al. 2015).

Reef surveys in the central and eastern reefs documented 246 Scleractinian (hard) coral species of which 77 are new records for the Torres Strait and six are potentially new records for Australia. This includes five species that were new records for the GBR and Torres Strait region: *Acropora spicifera, Cantharellus jebbi, Herpolitha weberi, Montipora palawanensis* and *Pavona bipartite* (Sweatman et al. 2015).

These results indicate that the Torres Strait may be a coral reef biodiversity hotspot. Coral communities from central sites differed from those in eastern sites, reflecting the gradient in turbidity and wave exposure (Osborne et al. 2013). The locations fell into two groups according to a cluster analysis based on species in common. The reefs of the central Torres Strait islands of Poruma, Aureed, and Masig form one group (hereafter Central) and those of the northeast islands, Erub and Mer, form the second group (hereafter Eastern). The similarity between reefs reflects physical location of reefs along the environmental gradient from the ESE to WNW. With the exception of Aureed Reef, the total number of species is fairly consistent across the gradient, implying that species replacement, rather than species loss or gain, is occurring with the changing environmental gradient. Differences in species richness between Central and Eastern reefs were observed for five coral families. Species richness in the Acroporidae and Pocilloporidae was higher on the Eastern reefs than the Central reefs. Conversely, richness of Poritidae, Fungiidae and Mussidae species were higher on the Central reefs than on the Eastern Reefs (Sweatman et al. 2015; Figure 4).

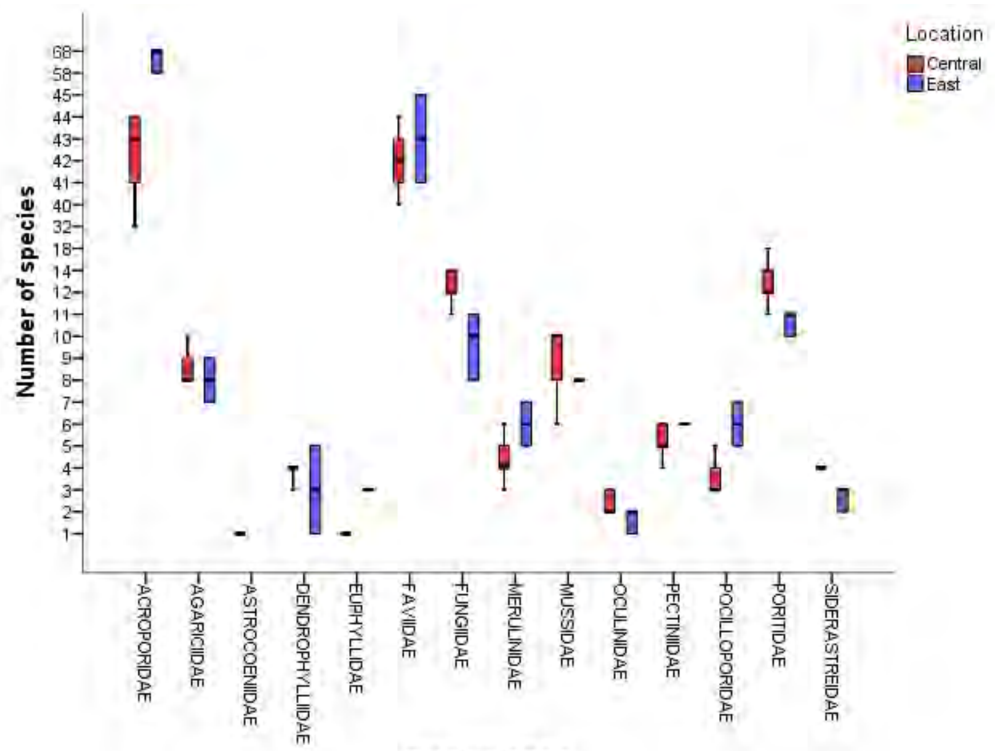

Figure 4. A spatial comparison of the number of species in each scleractinian coral family in the Central and Eastern reefs of Torres Strait (Osborne et al. 2013).

Torres Strait reefs are in good condition with high coral cover, presence of major taxonomic and functional groups, and minimal incidence of coral disease, however there is evidence they are at risk from COTS outbreaks and temperature stress (Sweatman et al. 2015). While the data show no long-term ocean warming, a small temperature rise and calm conditions in 2010 saw widespread coral bleaching for the first time in the region (Bainbridge and Berkelmans 2014). To understand this threat, temperature loggers and ocean monitoring stations have been deployed and satellite images have been used to understand how patterns of warming in the Pacific Ocean impact the Torres Strait. Data show that conditions for 2011 – 2014 were cooler than normal consistent with regional climate conditions, with a corresponding low risk of bleaching. The satellite data however show recent warming in the Pacific, which may drive El Nino conditions that cause warmer ocean conditions in Torres Strait (Bainbridge et al. 2015).

2.2.2 Mangroves and freshwater wetlands

Surveys of wetland condition and biodiversity on 20 islands in the Torres Strait region documented 124 wetland species, including more than 35 mangrove species (more than half the worlds total) with two being hybrids. Surveys also identified two mangrove species new to Australia and two new species for Torres Strait. The species are from 18 genera, representing 14 different plant families. This is very high diversity in such a specific plant habitat group. The best represented family is the Rhizophoraceae with 13 species and hybrids, while the second is the Acanthaceae family with 5, and the Lythraceae with 4[1].

Mangrove maximal species diversity was influenced by island size. Smaller islands had fewer species (i.e. lower diversity) than larger islands. Despite island shape and topography, the islands with greatest areas of mangrove vegetation had the greatest number and diversity of mangrove species present (e.g. Saibai and Boigu).

There are ~31,390 ha of wetland area within Torres Strait, comprising 21 vegetation communities of which three are unique to the region. 83% of wetlands in Torres Strait are tidal, mostly mangrove communities (Boigu and Saibai islands have the largest areas). Wetland condition was also assessed for 463 km of shoreline on 20 islands, providing an extensive, permanent and reviewable archival baseline of wetland condition, against which future changes can be assessed (Table 2).

Table 2. Shoreline mangrove condition (expressed as proportion of mangrove shoreline).

Island	Healthy condition (%)	Poor condition (%)	Poor to healthy condition ratio	Weighted condition score*
Mua	80	20	0.25	11.4
Badu	84	16	0.19	4.75
Mabuiag	71	18	0.25	2.99
Sassie	52	15	0.29	9.61
Zagai	48	24	0.50	10.06
Tudu	64	19	0.30	0.19
Iama	64	13	0.20	1.94
Cap	38	21	0.55	0.33
Gebar	28	34	1.21	6.50
Erub	77	15	0.19	0.95
Buru	39	11	0.28	5.42
Dauan	67	12	0.18	0.83
Boigu	58	15	0.26	13.13
Saibai	59	18	0.31	17.23

*Weighted condition score provides indication of extent of poor condition relative to island size.

In freshwater habitats, 50 fish species were recorded on Torres Strait islands, some are exotic species from PNG (e.g. climbing perch) that have been found on Saibai and Boigu islands. Other exotic fish (e.g. guppies, mosquitofish) have been found in dams on Thursday Island. Surveys

[1] Atlas of Living Australia
http://www.mangrovewatch.org.au/index.php?option=com_wrapper&view=wrapper&Itemid=300390

also recorded the first freshwater crabs and turtles on several Torres Strait islands (Duke et al. 2015).

Observations of the structure of the dominant mangrove vegetation units (based on upper canopy species) on the five northern islands in Torres Strait derived preliminary estimates of standing carbon content on each island and for the region. The overall mean above- and below-ground biomass for each of the five northern islands was 482.5 t.ha-1. Extrapolation of the total carbon stored in the total area of Torres Strait mangroves is ~6,285,528 tonnes of carbon present in living vegetation. In addition, there is likely to be up to 5 times more carbon in sediment peat deposits beneath these mangrove forests. This carbon will only remain bound whist mangrove forests remain intact and healthy (Duke et al. 2015).

Assessments of change in mangrove and freshwater habitat extent on Torres Strait islands documented increases in mangrove area and regrowth. There was an estimated 2% annual increase in mangrove area on Buru, Sassie, Zagai, Iama and Tudu Islands. Mangrove expansion reflects the limited direct anthropogenic pressures on mangrove habitats in Torres Strait. Large mangrove area increases were observed on Erub and Iama Islands due to natural and anthropogenic influences. On Erub Island, mangrove expansion has been facilitated by terrestrial sediment runoff deposited in the tidal zone. Iama Island has undergone large-scale change in mangrove extent in the past 30 years, with a net increase in mangrove area of 13% in 37 years (1974 to 2011). This expansion likely reflects a recent drop in sea level during the 1980's and 1990's potentially facilitated by elevated nutrient loads. Rapid sea level rise in the past 10 years is likely to be starting to reverse the expansion trend, with 13% of mangroves surveyed undergoing perceived change due to sea level increases. On Iama Island, 6% of mangroves are recent regrowth in historically cleared areas. The limited shoreward extent of these regrowth is likely to reflect a new high mean sea level on Iama Island that may be indicative of recent trends. Mangroves are sensitive to variations in sea level and respond rapidly to sea level variations (Duke et al. 2015).

2.2.3 Dugongs and marine turtles

The Torres Strait has some of the most extensive seagrass meadows in northern Australia and possibly the world, with 11 species of tropical seagrasses, mainly in sub-tidal waters. In addition to the meadow habitats, Torres Strait islands and cays support globally significant populations of dugongs, green and flatback turtles (Sobtzick et al. 2014, Hamann et al. 2015a,b). Marine turtles and dugongs are species of high cultural and economic importance to Torres Strait communities and concerns have been raised about their status.

NERP-funded aerial surveys show that the population of dugongs in central and western Torres Strait is estimated at >12,000 animals, the largest in the world. This is the largest aggregation of dugongs globally, with dugongs moving between reef and non-reef areas, using Australian and PNG waters (Figure 5). Aerial surveys since 1987 suggest that the population has not changed significantly over time (Sobtzick et al. 2014). These aerial surveys also found a significant population of turtles (most likely greens; Fuentes et al. in review) in the survey region, including in the Dugong Sanctuary (western Torres Strait).

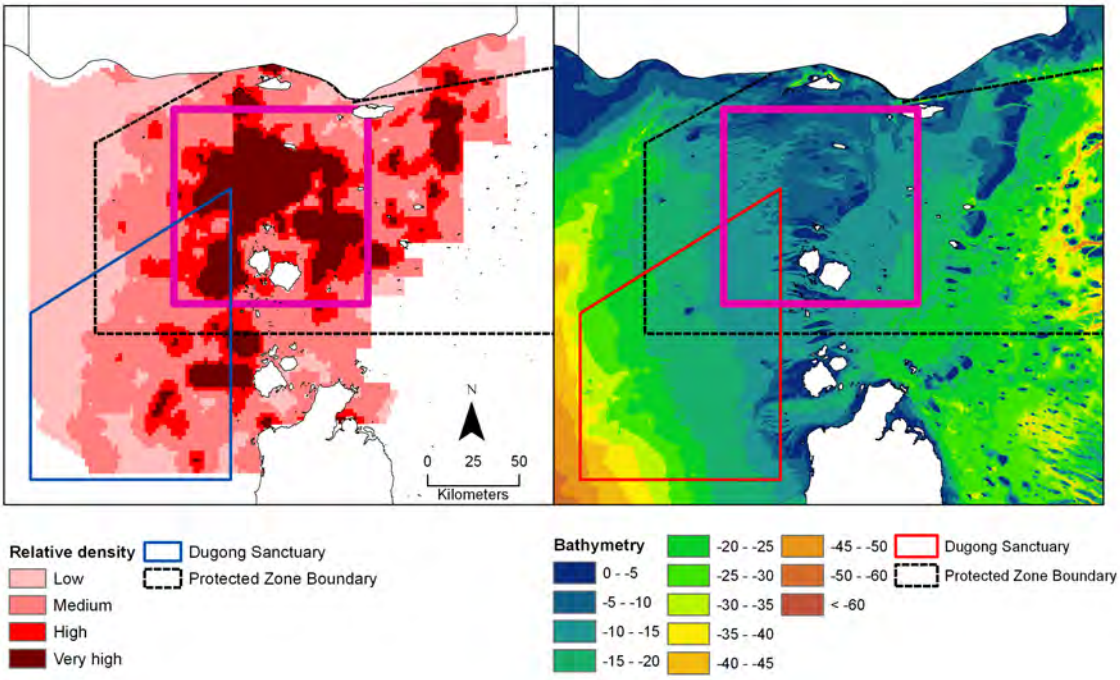

Figure 5. Relative density of the dugong population in Torres Strait (a), and bathymetry of the region showing the concentration of dugongs around shallow areas as well as their use of deeper non-reef areas (b). Source: Helene Marsh.

Monitoring of nesting turtles since 2006 has identified the islands in the Mer group (Mer, Dauar and Waer) and Bramble Cay as the most significant green turtle rookeries in Torres Strait and the main nesting sites for the Torres Strait/northern GBR genetic population. Nesting success (percent of female turtles that emerge each night to lay eggs) at Dauar Island and Bramble Cay was 33% in 2006, 62% in 2007 and 50–60% in 2008/09. Data suggest that rookeries receive around 100 to 3,000 green turtles per year but the size of nesting female green turtles is declining. The largest green turtle population is in the western and central Torres Strait with estimates of ~600,000 large juvenile and adult animals (Hamann et al. 2015a).

The islands of western and southern Torres Strait, plus the adjacent mainland beaches, are important for flatback turtle nesting. Waral Kara (Deliverance Island) is an important flatback turtle rookery and it receives around 100 to 200 turtles per year. It is likely that the rookeries form part of the same genetic population as Crab Island and the Western Cape in the Gulf of Carpentaria. Tracking of flatback turtles demonstrates that they migrate between 100 and 2000 km away towards distant foraging areas in the west as far as the Kimberley coast of Western Australia and to the north into the waters of Indonesia and PNG. Foraging areas are typically large (516 – 4,324 km^2), and larger than green and loggerhead turtles in eastern Australia.

2.2.4 Marine fish biodiversity

Marine fish biodiversity was assessed at five reefs (Aureed Island Reef, Masig Island Reef, Poruma Island Reef, Erub Island Reef and Mer Island Reef) in February 2013. A total of 301 fish species were recorded, of these, 143 were added to the list of known species for the region (Haywood et al. 2007). This brought the list of species of coral reef associated fishes in the

Torres Strait to 326. Fish communities from central sites differed from those in eastern sites, reflecting the gradient in turbidity and wave exposure (Osborne et al. 2013). Fish communities on surveyed reefs included species from the northern GBR and to a lesser extent species normally associated with reefs further north in PNG.

Range extensions were recorded for three species that had previously not been officially recorded in Torres Strait. These included one species previously known from PNG and the north-western Pacific, as well as two species that are rare or absent from the northern GBR. The observation of *Halichoeres richmondi* (Richmond's wrasse) at Erub Reef extends the known range from the Coral Triangle and PNG south into Torres Strait. This was cross-validated with IUCN (2010) and Ocean Biogeographic Information System (OBIS; 2014). The fish community on Poruma Island Reef was particularly interesting because it included species found on the southern GBR that were rare or absent from the northern GBR (Osborne et al. 2013). The range of *Macropharyngodon choati* (Choat's wrasse) has been extended towards the equator as previous records were from the central and southern GBR (IUCN 2010, OBIS 2014). There are few records of *Chilomycterus reticulatus*, but this species appears to be distributed across the Indo-Pacific and this observation at Poruma extends its known range (Sweatman et al. 2015).

2.3 Cultural characteristics and trends in the region

The Torres Strait is a region of rich natural and cultural values, with strong family associations with adjacent Provinces of PNG, and linkages between its environmental assets and the livelihoods of local communities. The region has one of the highest proportions of Indigenous people in Australia with the traditional Islanders being of Melanesian origin, many of whom have strong affiliation with their land and sea and depend heavily on their natural resources for food and livelihoods. Torres Strait shares international borders with PNG and Indonesia, and the Torres Strait Treaty between PNG and Australia establishes the Torres Strait Protected Zone and other mechanisms for the shared governance of the region, including access to and management of its marine resources. The Torres Strait Treaty between Australia and PNG explicitly aims to protect island community livelihoods, and improve them through sustainable economic development. As Australia's northern border with Asia, however, the region is undergoing unprecendented change.

2.3.1 Building resilient communities

The Torres Strait region is under increasing pressure from population growth and resource demand in adjacent PNG, mining development, and exploitation and pollution of shared Torres Strait resources. Global pressures such as increasing oil prices, shipping traffic and climate change will also have complex impacts on environmental assets, particularly when combined with human pressures. This uncertain future will present challenges for achieving resilient Torres Strait communities, but may also provide opportunities for sustainable economic development (e.g. ecotourism and aquaculture).

Rapid change in the Torres Strait region requires the ability to predict potential changes and plan proactively. Through participatory scenario planning with Torres Strait communities and regional stakeholders, informed by integrated ecosystem services, climate and resilience modelling, this project identified 'no regrets' strategies to protect livelihoods and achieve sustainable economic development (Bohensky et al. 2014). Priority strategies identified were:

1. Develop a cultural renewal strategy,
2. Improve garden food production to support food security and health,
3. Enhance community communication, particularly between central islands,
4. Improve marine resource management focussing on green turtles and dugongs, and
5. Develop sustainable industries, including ecotourism and aquaculture.

Comparison of these strategies with current development programs found the greatest implementation gaps were for cultural renewal, marine resource management, and economic development. Marine resource management is intrinsicly linked with cultural renewal, since the cultural benefits of turtle and dugong hunting are more important than food or status in Torres Strait. Recent community surveys identified cultural factors – customary way of life, tradition, community unity, ceremonies and teaching culture to children – as predominant reasons for hunting (Delisle 2013). The gross benefits (market and non-market) of the Torres Strait Indigenous dugong and green turtle harvest exceeds 16% of household income, or is approximately proportional to income spent by the average Australian on mortgage repayments (Delisle 2013). In addion, Torres Strait Islanders share dugong and turtle meat with relatives on the mainland for home consumption or ceremonies but this represents <1% of annual meat consumption (Delisle et al. 2014).

An evaluation of the resilient communities participatory planning process showed that following workshops, participants considered loss of culture to be a greater threat to livelihoods than climate change (Figure 6; Bohensky et al. 2014). Project evaluation also showed that adaptive capacity has been significantly enhanced in the region and change agents, with 'enhanced knowledge of the problem', 'vision for an alternative development pathway' and 'leadership emerging' important for the longevity of the project outcomes and continued adaptation planning through TSRA's community-based climate adaptation planning process for the region (Figure 6; Bohensky et al. 2014).

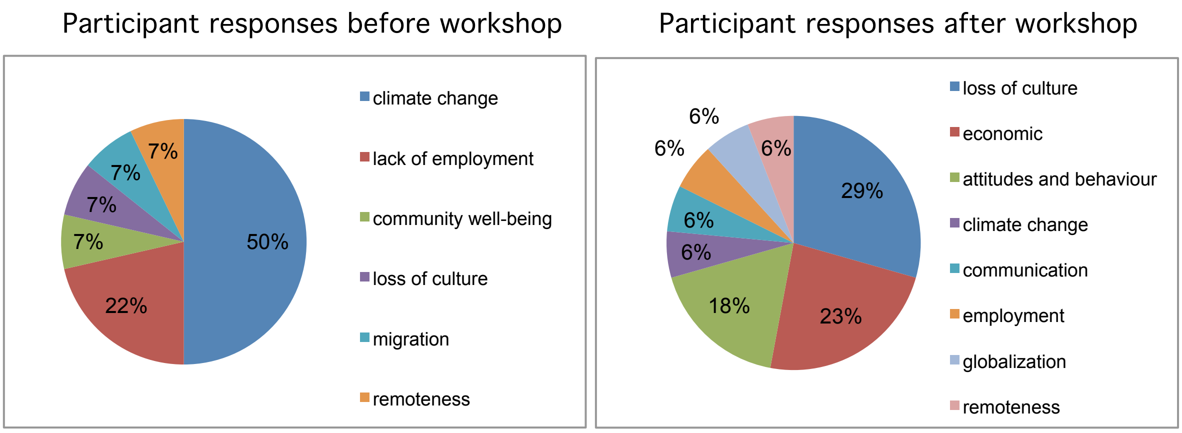

Figure 6. Comparison of community views of the greatest threats or issues for livelihoods on Masig Island before and after a participatory planning workshop conducted in July 2014.

2.3.2 Biosecurity

The Torres Strait has long been recognised as a biological bridge to mainland Australia, including for emerging infectious diseases, and there is concern regarding its potential to facilitate disease movement to the mainland. These diseases represent serious threats to human health, agriculture and biodiversity. A NERP-funded project provided preliminary information on improving our understanding of how diseases move across the Torres Strait and what methods are best for early detection of disease incursions to inform management of outbreaks within the region.

Disease surveillance in remote tropical hotspots is challenging because sampling techniques often rely on vector-attractants that are either unavailable in remote localities or difficult to transport. A novel method of capturing mosquitoes using yeast-baited traps in villages and native habitats proved to be more effective than standard trapping methods. The new sampling method was more robust, efficient and cheaper. The traps captured 11,109 mosquitoes of 34 species and 10 genera. Three times more mosquitoes were caught in natural vegetation compared to villages, which may be partly due to mosquito habitat preference and prevailing wind intensity in coastal villages (Laurance et al. 2014; Figure 7).

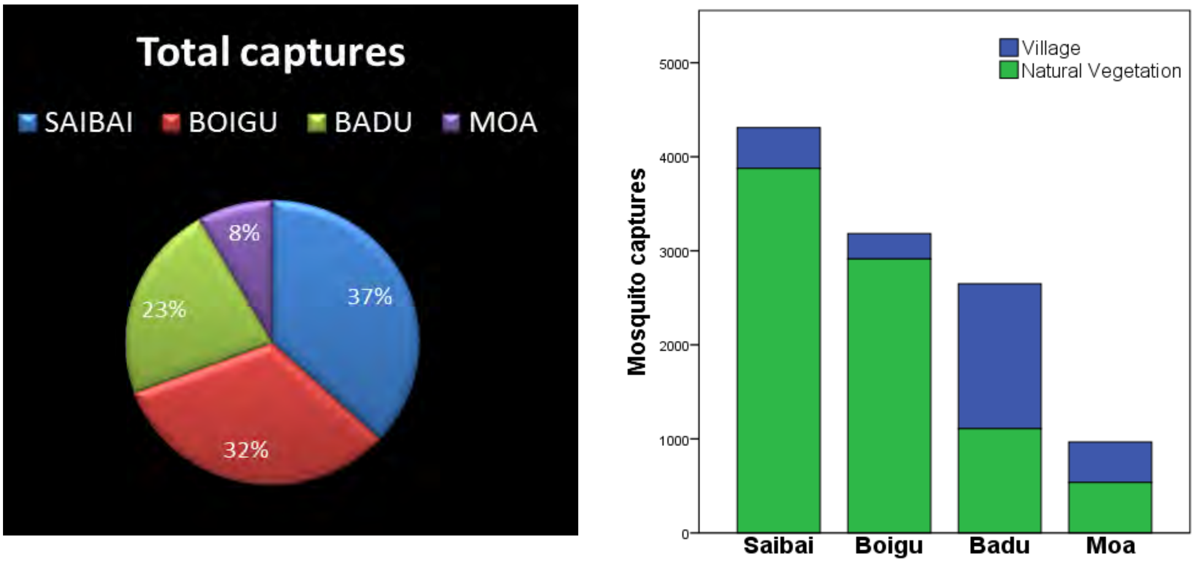

Figure 7. (a) Comparison of mosquito captures between islands, and **(b)** between village and natural vegetation habitats for the four islands sampled.

Mosquito species found in villages tend to be more human-preferring (anthropophilic), which is important from a disease risk perspective. Mosquito communities on the four Torres Strait islands varied between natural vegetation and villages and also between islands. The two low-lying islands (Saibai and Boigu) situated close to PNG shared a very similar mosquito community but distinctly different from the two continental islands (Badu and Moa) that are located further from PNG. Important disease vectors were captured almost exclusively in villages, for example disease vectors for malaria (*Anopholes spp.*) were more frequently captured in villages on the northern islands whereas vectors for dengue and chikungunya were more frequently captured in the southern island group. Furthermore, two of the most important disease vectors in this region are invasive species (*Aedes albopictus, Aedes egypti*), which is one of the key causes of emerging infectious disease expansion globally. Management of vector breeding habitat in towns is the highest priority for managing future disease outbreaks in Torres Strait (Laurance et al. 2014).

3. Pressures and threats: current and future

The Torres Strait is under increasing pressure from a range of regional factors – PNG population growth and resource demand, mining and development impacts, increased shipping, and climate change – as well as local factors – resource exploitation, emerging tropical diseases and poor waste management (Table 3). Exogenous drivers affect the whole region, namely climate change and shipping. Endogenous drivers show some differences between the Australian Torres Strait Islands and the Western Province region and Treaty Villages in PNG (Butler et al. 2015). Employment, education and health are improving in the Torres Strait, and this is reflected in a relatively high Human Development Index (HDI) of 0.736, which is also likely to be increasing. In Western Province and the PNG Treaty Villages these indicators are declining, and the very low HDI of 0.260 is unlikely to be improving, as indicated by the chronic occurrence of drug-resistant tuberculosis and cholera (Butler et al. 2015). Natural resource extraction is also escalating in Western Province, and related infrastructure. Population growth is occurring on both sides of the border, but is approximately double in Western Province and the PNG Treaty Villages (1.5% per annum) compared to the Torres Strait Islands (0.91%). Island population densities are increasing in most cases, but this is of greater concern for the PNG islands of Daru and Parama where infrastructure and services are poor and declining, and carrying capacities may already have been exceeded. A synthesis of trends in drivers of change for the Torres Strait region is provided in Table 3 (Butler et al. 2015).

Table 3. Synthesis of trends in drivers of change for Torres Strait region. Where: ⇧ increasing trend; ⇧⇧ rapidly increasing trend; ⇩ decreasing trend; ⇔ no change; NA not applicable. Source: Butler et al. 2015.

Driver of change	Indicator	Regional trend	Torres Strait Islands trend	Western Province PNG trend
Climate change	Annual surface temperature	⇧		
	Annual rainfall	⇔		
	Sea level rise	⇧		
Economic and social development	Employment, education, health		⇧	⇩
	Human Development Index		⇧	⇔
	Oil, gas and mining		NA	⇧⇧
	Logging and infrastructure		NA	⇧⇧
	Shipping	⇧		
Population change	Population		⇧	⇧⇧
	Island population densities		⇧	⇧⇧

3.1 Water quality

An understanding of the status of water quality in Torres Strait and its influence on marine foods, human health, marine ecosystems and ecological processes in the region is important. A preliminary study of potential water quality issues identified regional pollution – discharge of metal (and other) pollutants from the Fly River associated with mining, the port at Daru, other mines in PNG and land clearing – local pollution – sewage and stormwater discharge – and pollution associated with shipping (dredging, oil spills, ship groundings, shipyards, see Section 3.1.2).

A review of all available research on water quality in the Torres Strait region coupled with hydrodynamic modelling, analysis of remote sensing of flood plumes, and site inspections on eight islands determined the activities that pose the greatest water quality risks to the region, now and into the future. The NERP supported the development of a 2D SLIM hydrodynamic model of the transport of water-bourne material to determine the delivery and fate of pollutants since many potential issues are large-scale and derive from outside the region. The model revealed the large-scale flow dynamics in Torres Strait, highlighting that some areas are flushed relatively quickly while water tends to stagnate in other shallow areas. The model also revealed the prevalence of highly energetic small-scale flow dynamics near shoals, reefs, islands and passages (Wolanski et al. 2013). Preliminary analysis of MODIS satellite images suggests that high turbidity levels along the PNG coast are constrained to the coast, and that intrusions of Fly River plumes in the Torres Strait region are limited to the northeastern Torres Strait. High turbidity levels recorded along the south-western PNG coast suggest a combined influence of turbid outflows from the several rivers draining the southern New Guinea margin, enhanced by bottom resuspension in the shallow coastal zone (Petus 2013).

Information on the current status of pollutant sources (including future potential sources) in the region identified three main pollutant sources for the Torres Strait:

1. Local island waste management, including sewage and waste disposal,
2. Shipping, commercial vessels and marine infrastructure, and
3. Large-scale developments in adjacent areas (such as PNG).

While the study identified a number of local pollutant sources that pose a risk to the ecological values of the Torres Strait region (e.g. issues with wastewater management including marine outfalls and general waste management), with potential threats associated with the current and future risks from the transit of large ships (Waterhouse et al. 2013).

3.2 Shipping and mining

Located at the junction of the Arafura Sea and Pacific Ocean, the Torres Strait marine environment is of national and international significance and is a major shipping route between the Indian and Pacific Oceans. Shipping and associated hazards (oil spills, groundings, ghost nets) appear to pose significant potential threats to the Torres Strait. The shipping route through Torres Strait is already an obvious bottleneck for Australian east coast shipping traffic. With the expansion of ports, especially coal loading ports, on the Australian east coast in response to proposed large increases in coal export (GBRMPA 2013) large increases in shipping traffic along the Queensland coast are predicted. Additional increased shipping through the Torres Strait will also result from the construction of a major port at Daru. Under these scenarios, a large increase in shipping traffic through the Torres Strait is predicted over the next decade. These increases will result in greatly increased risk of accidents in the Torres Strait (Waterhouse et al. 2013).

Currently there is very limited capacity to respond in any meaningful way to a large oil spill in the Torres Strait. The area is remote in Australia with strong winds and currents and a matrix of reefs and islands on which oil could impact. Any large oil spill could have devastating consequences for the populated islands as well as severe environmental consequences. While new management strategies may mitigate the increase in risk, the likely increase in shipping traffic is considered a major water quality and environmental threat to the Torres Strait environment and people (Waterhouse et al. 2013).

Large-scale development in PNG including gas platforms, oil palm expansion and Daru port development may also be significant. Preliminary analysis of proposed developments in western PNG suggest that although large-scale developments are planned, adverse effects in the Australian part of the Torres Strait are likely to be restricted to the northern islands – Boigu, Saibai, Erub and Ugar – and potentially the Warrior Reef complex, which is an important fishing ground. This is because both the hydrodynamic modeling and remote sensing analysis (see Section 3.1.1) show that excursions of water from the Fly River drainage basin predominantly move to the east into the northern Coral Sea and along the PNG coast towards Port Moresby and are uncommon to the west of the river mouth. In addition the currents in this western region are generally from east to west both in the central Torres Strait and along the PNG coast (Waterhouse et al. 2013).

3.3 Resource use and loss

Despite the cultural importance of dugong and turtle hunting to Torres Strait Islanders, hunting does not occur in much of the high density dugong or green turtle habitats in the region. Most hunting in Torres Strait is in ~7% high density dugong areas and ~10% high density turtle areas. The remaining high density areas are only infrequently visited due to their remoteness, gear restrictions, logistics, low incomes and high fuel prices (Grayson 2011). These factors mean that much of the Torres Strait acts as an unofficial sanctuary, protecting large areas of high density dugong and green turtle populations (Figure 8).

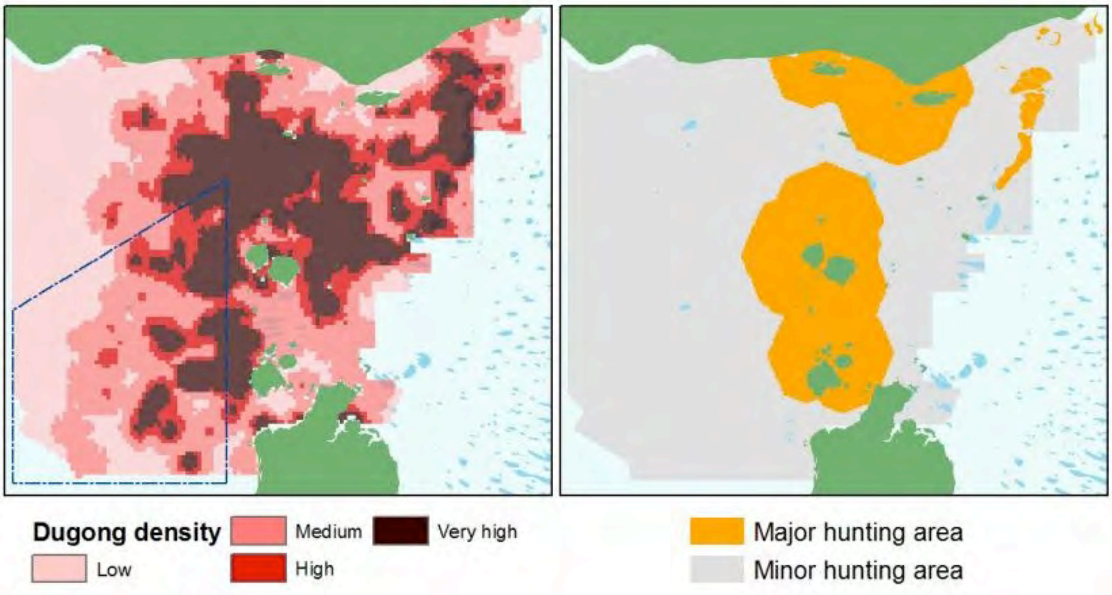

Figure 8. Maps showing area of high density dugong population in Torres Strait (a), and the major hunting areas (b), with 62% of high density dugong area not hunted. Source: Grayson, Grech and March data.

Despite their importance for coastal protection and carbon storage, mangroves continue to be destroyed and degraded by poor catchment and coastal zone management (Duke et al. 2015). Globally, 30% of the world's mangroves have been lost in the past 30 years (Duke et al. 2007) and in Queensland, mangroves are protected under the Fisheries Act 1994, yet here too they continue to be destroyed for development (Duke et al. 2003). Mangroves in Queensland are increasingly threatened by urban development, pollutants and altered hydrology in the coastal zone (Duke et al. 2007). In Torres Strait, mangrove cutting is threatening mangrove habitat with 2% of mangroves in Torres Strait are estimated to be impacted by cutting (Duke et al. 2015). These factors can reduce mangrove extent, as well as influence habitat quality, reducing the capacity of mangroves to provide ecosystem services.

3.4 Biosecurity and emerging diseases

Emerging infectious diseases are on the rise with future outbreaks predicted to occur in frontier regions of tropical countries. The Torres Strait has long been recognised as a biological bridge to mainland Australia, including for emerging infectious diseases, and there is concern regarding its potential to facilitate disease movement to the mainland. Inadequate surveillance is one reason why tropical frontier regions are considered "hotspots" for emerging infectious disease. The Torres Straits is one of the most vulnerable communities in Australia with respect to mosquito-borne diseases and early detection of disease outbreaks as well as preventative measures, such as reduction of vector breeding habitat near towns must be a high priority to ensure the continued health of Torres Strait communities (Laurance et al. 2014).

Torres Strait remains a potentially significant pathway for serious pest fish species to enter Australia from PNG, which already hosts many such exotic pests. Exotic species of fish, like the newly introduced climbing perch, were found commonly in the northern islands of Torres Strait. The artificial waterbodies on Horn and Thursday Islands are in special need of systematic sampling for the presence of pest fish, one species of which (Gambusia) has already been observed on Thursday Island (Duke et al. 2015).

3.5 Reef disturbances: Crown-of-thorns starfish

Reef surveys in the central and eastern Torres Strait recorded crown-of-thorns starfish (COTS) at all reefs that were surveyed by manta tow recorded outbreak densities at Aureed and at Waier and Dauar reefs (Sweatman et al. 2015). COTS have been known from Torres Strait for a long time, with COTS recorded at Mer in 1913, but CSIRO survey results (Murphy et al. 2011) suggest that COTS numbers have been increasing regionally in recent years. On the GBR, outbreaks follow a reasonably distinct pattern of spread, but the timing and spread of COTS outbreaks in the Torres Strait have not been recorded. While COTS outbreaks in the GBR are thought to be linked to elevated nutrient levels in floods, the cause of COTS outbreaks in the Torres Strait remains unknown. Although COTS – coral eating starfish native to coral reefs in the Indo-Pacific region – are a natural and important functional species on healthy coral reefs, feeding on the fastest growing corals such as staghorns and plate corals, allowing slow growing coral species to form colonies, the population frequently increases to a point where predation exceeds coral growth and recovery and the cover of many coral taxa decreases dramatically as a result. Any future increase or spread of the COTS population poses significant risks to coral cover, and would be a major driver of reef condition.

3.6 Climate change

Climate change poses a significant threat to communities and natural ecosystems around the world, and the Torres Strait is no exception. The unique cultures and environments of the Torres Strait that have weathered change over many millennia, now face a very uncertain future. Island communities, ecosystems, infrastructure, livelihoods, wellbeing, culture and identity are all threatened by the many impacts of a changing climate over the coming decades.

Mangrove habitat degradation greatly reduces the capacity of mangroves to respond to the impact of future climate change (Gilman et al. 2008, Ellison 2014). The location of mangroves at the shoreline edge places them in the direct line of climate change impacts; sea level rise, more severe and frequent storms and more frequent drought and floods (Nitto et al. 2014). A broad-scale baseline assessment of mangrove habitat in Torres Strait identified that the mangroves of Torres Strait are likely to be threatened by climate change, including more severe and frequent storm events, sea level rise and altered rainfall patterns (Green et al. 2010). While it is not possible to prevent climate change at the local scale, it is possible to reduce direct human related impacts that are likely to reduce capacity of mangroves to resist and recover from climate change impacts. The capacity of mangroves to respond to climate change impacts depends directly on improving local mangrove management (Gilman et al 2008). NERP-funded research showed that mangrove shorelines seem to have responded to changes in sea level over the last 10-15 years, and sea level rise appears to be directly threatening 13% of Torres Strait mangrove habitat (Duke et al. 2015).

Turtle environmental monitoring has identified climate change issues for turtle nesting beaches in Torres Strait, including increasing sand temperatures and sea level rise (Hamann et al. 2015a,b). Dauar Island is the only significant rookery for green turtles that is shaded by vegetation and is an elevated island, making it important for the future of the population. Temperature monitoring indicates that Dauar Island will produce hatchlings with a female bias sex ratio (Hamann et al. 2015a,b).

Consistent with the global situation for coral reefs, Torres Strait reefs are threatened by a variety of local and global agents including climate change, particularly thermal stress that can cause coral bleaching and increase incidence of coral disease. Widespread coral bleaching was recorded for the first time in Torres Strait in 2010 (Bainbridge and Berkelmans 2014). NERP-funded coral reef surveys at Mer recorded a reduced abundance of temperature-sensitive corals in the genus *Seriatopora* compared with records for the same location from in1913, which could be the result of thermal bleaching in recent years (Osborne et al. 2013). The projected increase in SST in Torres Strait of +1.65 to +3.01 °C by 2070 (Suppiah et al. 2010) will result in further bleaching events that can undermine the structure and function of coral reef habitats. Effects may be evident as early as 2030, when mean SST is projected to be +0.62 to +1.27 °C warmer and the maximum even greater, temperatures above the bleaching threshold (Bainbridge et al. 2015).

NERP-funded monitoring since 2011 shows that ocean conditions remained at or below long-term means, and during late 2014, the Torres Strait region experienced neutral to strong negative SST anomalies (Bainbridge et al. 2015), as measured both by MODIS satellite and *in situ* seawater temperature instruments. Meanwhile, the NOAA CRW outlook indicates increased coral bleaching thermal stress for the Torres Strait for the 2014/15 austral summer (November 2014 to February 2015) (Figure 9).

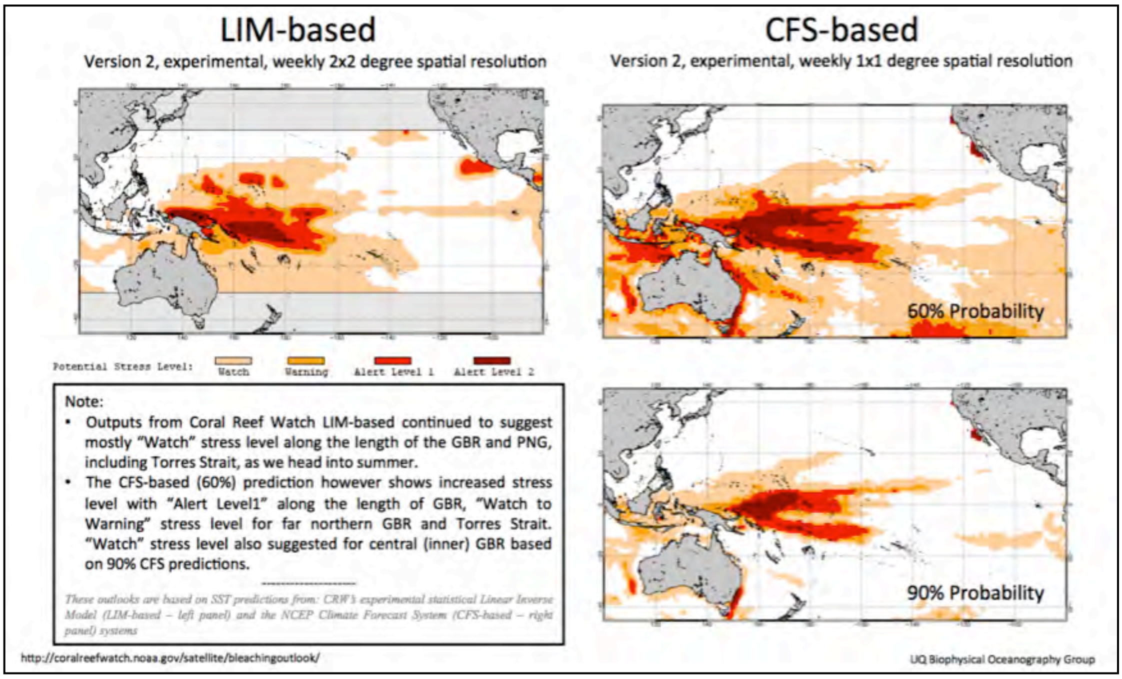

Figure 9. NOAA Coral Reef Watch (CRW) seasonal coral bleaching thermal stress outlook for November 2014 to February 2015 showing increased potential stress level for the Torres Strait region.

Collectively, the NERP-funded projects have identified a range of potential impacts on Torres Strait resources from climate change, as well as concerns from communities on the implications for their livelihoods and tropical disease dynamics (see Section 2.3). These results are supported by additional projects that have examined the potential impacts of climate change on Torres Strait resources, including fisheries (Welch and Johnson 2013), seagrass (Coles et al. 2012, McKenzie et al. 2010, Rasheed et al. 2014), and island communities (Parnell et al. 2012, McNamara et al. 2011) including during extreme water level events (Harper 2011). The results from both NERP-funded and other research can be used to inform effective management actions and policy decisions, as well as future research investment.

4. Research informing policy and management

The findings of NERP Tropical Ecosystem hub research are directly relevant to managers of the Torres Strait region and its natural assets. Projects have provided valuable information on populations of dugong and turtle, mangrove and freshwater ecosystems, coral reefs, community futures and disease dynamics that have current and future applications for management and policy.

In addition, NERP-funded projects have enhanced capacity within local and regional management agencies, and supported the establishment of long-term initiatives that will benefit employment, livelihoods and knowledge in the region. For example, TSRA Rangers are now employed in most island communities in Torres Strait, and have played an integral role in supporting NERP research and monitoring taking place in a culturally appropriate way. Effective collaboration between researchers and Rangers, facilitated by the TSRA Land and Sea Management unit, has ensured that policy and management efforts are well-targeted, based on the best available scientific information, aligned with community priorities, and local traditional knowledge.

4.1 Policy applications

NERP-funded projects have provided Torres Strait communities and management partners with reliable and robust information about dugong and turtle populations in the region, their spatial distribution and threats to populations. The information generated by NERP projects has translated into management actions at a regional (including international negotiations with PNG) and local scale, including in relation to the potential northern expansion of the Torres Strait Dugong Sanctuary, inclusion of turtles in the protective regime, and voluntary community-level seasonal and spatial hunting closures. NERP projects have been highly complementary to the successful community-based management approach for dugongs and turtles that the TSRA has facilitated since 2008, and their findings reinforce the importance of maintaining strong support for this process into the future to ensure the sustainability of these species.

There are other findings with implications for policy, for instance, most flatback turtles spend part of their migration route and/or foraging time in international waters that are known to have high incidence of ghost net entanglement. Flatback turtles are a shared resource with Indonesia and PNG and Australian recovery and management documents need to consider overseas threats such as fisheries bycatch and ghost net entanglement.

In terms of specific policy recommendations for dugong and turtle, advice is that high priority is given to: (1) implementing a program to record robust estimates of the current dugong and turtle harvest from all the major hunting communities in Torres Strait, (2) sharing learnings from the catch monitoring process with the agencies responsible for managing the dugong and turtle harvest (such as AFMA); and (3) continuing negotiations with PNG through the Protected Zone Joint Authority (PZJA) about extending spatial closures in Torres Strait.

NERP-funded research has also generated a series of policy recommendations in relation to shipping in Torres Strait, as this was identified as a high risk in the region. In particular, compulsory pilotage in the Prince of Wales Channel should be enforced. While it appears that the Prince of Wales Channel has a form of compulsory pilotage, in effect this is still at the discretion of each vessel and when vessels choose not to take a pilot, Australia does not refuse passage. A complete review of shipping risk response in the Torres Strait is needed given the likely increase in shipping and therefore shipping incidents.

4.2 Management applications

Management actions for improved wetland protection will be island specific. For example, Saibai, Boigu and Mua Islands have the greatest extent of mangroves in poor condition, and Mua Island has the highest number of mangrove management issues in terms of dieback and high exposure risk, making them high priorities for management effort. Other mangrove islands – Sassie, Zagai and Buru – have unique and important mangrove habitats in the Torres Strait region and should be afforded high conservation status. Ideally, the protection and management of mangrove areas in Torres Strait should be reviewed for all islands.

There are also key threats to freshwater habitats, especially from introduced animals such as pigs, deer and cane toads, and weeds that have management implications. With so few freshwater habitats present in Torres Strait, some of these introduced species may need to be the focus of management attention to control their spread and impacts on the environment. Discussion are currently underway with management agencies and traditional owners to find actions to address these threats, which could include fencing to exclude these large introduced animals.

Reef surveys documented baseline data for central and eastern Torres Strait reefs, and have used this data to draft a coral reef monitoring plan that describes a long-term monitoring program utilising local capacity for the Torres Strait. Regular monitoring, combined with real-time ocean and satellite data, will provide key information for the management of Torres Strait reefs. Improved knowledge of Torres Strait coral reefs and monitoring their status and health will help identify problems and enable managers to respond accordingly.

All NERP-funded projects worked closely with local Rangers and island communities, in many cases providing training to enable a long-term legacy for the region’s resources. Capacity building efforts were successful in training local Rangers in coral reef surveys, logger deployments and first-level ocean monitoring station diagnostics, Mangrovewatch observations and dugong and turtle surveys. Capacity was also built among Torres Strait community members and leaders in participatory development of future scenarios and adaptation planning. Development of local capacity and expertise in these areas has built a strong foundation to continue the NERP-funded work into the future.

In addition, local communities were included in highly participatory processes to build resilient futures for the Torres Strait. The TSRA is now adapting and implementing the NERP-pioneered planning approach and tools for their community-based climate adaptation planning process for the region. Additionally, the Queensland Government (DATSIMA) community consultation process for the Torres Strait Island Regional Council Draft Planning Scheme is being modified to include the results and approach of NERP work. Project results have been incorporated into the joint Australia-PNG Torres Strait Treaty process, and DFAT has included sustainable development forums as an annual event at the meetings.

NERP-funded research has also been the foundation of other newly established TSRA programs, in particular, addressing water quality risks in the region. Recommendations for monitoring and responding to potential water quality impacts have been adopted by TSRA, with a number of management activities commencing in 2014. These include measurement of the influence of the Fly River through analysis of remote sensing imagery and heavy metal analysis using water quality loggers, oysters and artificial bivalves at locations across the region. This study is the first regional hazard assessment of water quality risks and provides guidance for managers to make decisions regarding the relative importance of pollutant sources at a range of scales.

Local issues are also being addressed as a result of NERP-funded research, with all wastewater and waste management recommendations sent the the two local councils responsible to review and update their operating procedures, training and maintenance schedules. In addition, reducing disease vector breeding habitats close to human homes, schools and workplaces has been a management priority in the region, and this must continue to be the responsibility of the whole community.

5. Conclusions

The Torres Strait is a unique and remote tropical region of Australia that has recently received significant focus for ecological and cultural research. The NERP Tropical Ecosystems hub Torres Strait theme included a suite of projects that built on earlier research conducted under the Torres Strait CRC and MTSRF since 2003. The focus of projects was on increasing our understanding of the ecosystems and communities in Torres Strait through the collection of baseline data and fundamental community information. Results clearly demonstrate the uniqueness of the natural environments in Torres Strait, with high diversity endemic ecological communities in a healthy condition. In fact, the Torres Strait can now be considered a biodiversity ‘hotspot’ with representative species from the Coral Triangle as well as from the GBR to the south. It may also provide a refuge for many marine species, such as dugongs, turtles, corals and mangroves, from anthropogenic pressures that are causing declines in other marine ecosystems around the world.

Research has also documented the cultural and social importance of the Torres Strait natural resources to island communities, and their connection and reliance on their marine and coastal environments. Priorities and aspirations important to island communities have been identified, and actions that can help build a sustainable future. Despite the varying focus of the six NERP-funded projects, there are synergies in terms of the pressures that are expected to drive change in the future. The many drivers of change in the region range from global external pressures to local internal issues that all have the potential to affect Torres Strait ecosystems, culture and livelihoods. In particular, the downstream effects of development and mining in PNG threaten water quality in the region, emerging tropical diseases are on the rise, threats from potential shipping incidents are increasing, and climate change poses a risk to both ecosystems and people. NERP-funded research has provided a solid platform for understanding the Torres Strait environment to inform future management, and to respond to the inevitable pressures that will drive change. The relatively healthy condition of ecosystems in the Torres Strait and the strong sense of identity and islander culture will aid in the success of future actions. The next generation of research can build on these outputs, and deliver even more benefits for the ecosystems and island communities in the region.

6. Future research directions

The NERP Tropical Ecosystems Hub generated significant research outcomes for informing the design and implementation of Torres Strait monitoring, evaluation and management programs. The research also identified knowledge gaps and new areas of research that should be progressed to inform continuous improvement of management of resources in the Torres Strait region. The future research directions are summarised below.

6.1 Research priorities

A theme of future research need in the region is a more systematic exporation of biodiversity of the Torres Strait region, particularly marine biodiversity, to inform future management and environmental reporting. In particular:

- Examine the role of reefs in Torres Strait in terms of the long-term ecological health of the GBR.
- Invest in high-resolution geo-coded underwater video and transect surveys of key reef areas as a permanent record of the current status of selected representative areas against which future change can be compared.
- Develop a joint project with AMSA/MSQ and key marine research agencies to better understand the oceanography of the region with a view to predicting future conditions from current measurements and to support the work of AMSA and MSQ.
- Develop tools to prioritise management actions for dugongs and turtles in Torres Strait (among and within stocks/regions) and measure efficacy of current management.
- Collect geo-referenced data on dugong diving behaviour in Torres Strait as a high priority to improve the corrections for availability bias in the Pollock et al. (2006) method.
- Modelling to determine the likely efficacy of spatial closures as the main method of regulating the dugong and green turtle harvests.
- Consider the feasibility of using Unmanned Aerial Vehicles for dugong aerial surveys in the Torres Strait to reduce the risks associated with using manned low flying aircraft in remote areas, when the technology matures (see Hodgson et al. 2013).
- Establish international research collaborations for studying hawksbill turtles that migrate large distances and spend periods outside Australian waters.
- Assess the likely impacts of noise pollution on marine wildlife in Torres Strait based on current knowledge to inform Torres Strait management practices, particularly in and adjacent to the Torres Strait shipping channel.
- Some introduced freshwater species may occupy different habitats to their native range, thus studies on the ecology and environmental tolerances of these species within their new Torres Strait habitats are needed.
- Develop new technologies to detect the presence of introduced freshwater species from their DNA in water samples; this would greatly increase monitoring detection efficiency.
- Undertake more detailed historical mangrove change assessment using original aerial imagery for Torres Strait islands.
- Conduct detailed assessments of the impacts of timber harvesting on mangrove forests to develop criteria for sustainable harvesting.

- Review and assess mangrove foreshore changes to explore correlations with local changes in sea level.
- Establish acceptable nutrient load limits for mangrove habitats in Torres Strait to inform management of terrestrial activities.
- Investigate pollutant levels in mangrove fauna on Boigu, Saibai, Iama and Dauan Islands.
- Undertake further investigation of potential sea level rise impacts on Torres Strait Islands.
- Desktop review of the large oil spill that occurred in Torres Strait in the 1970s using environmental and hydrological data to determine the impacts including a massive seagrass dieback observed soon after.
- Scale up resilient communities participatory planning approach to adjacent PNG Treaty Villages.
- Apply participatory planning approach to build future development scenarios for the region to assess impacts on water quality.

6.2 Monitoring priorities

- Establish a long-term coral reef monitoring program that can build on the baseline data collected with NERP funding, particularly focusing on coral reef and fish communities, range expansions, species loss, and responding to reef disturbances, such as COTS outbreaks.
- Implement Coastal Health Archive and Monitoring programs using shoreline monitoring techniques established for the MangroveWatch program, and extended under the NERP-funded aerial shoreline surveys.
- Incorporate regional Mangrove Management Plans into Torres Strait management.
- Dugong (and turtle) aerial surveys continue at regular (typically 5-year) intervals for the combined area of the northern GBR and Torres Strait with the next survey occurring in November 2018.
- Improve dugong and green turtle population estimates through the use of: (1) dive and GPS trackers, and (2) local sacle helicopter surveys, to determine the species composition of large juvenile and adults observed from the air.
- Continued monitoring of dugong and green turtle mortality, hatchling production (annual), juvenile recruitment and impacts of climate change in Torres Strait populations.
- Establish a long-term comprehensive seagrass monitoring program for the northern GBR and Torres Strait with particular emphasis on seagrass habitats that support significant densities of dugongs and green turtles, and that is co-ordinated with the aerial surveys for these species.
- Support formal establishment of a well-considered plan for rapid response, assessment and monitoring of severe large disturbance incidents affecting coastal environments, like large oil spills, severe cyclonic storms, and large tsunami waves.
- Develop a community program to report sightings of exotic freshwater species to prevent the spread of introduced freshwater species in combination with routine monitoring.

- Understanding the salinity dynamics of wetlands on low-lying islands (e.g. Boigu and Saibai) given the likelihood of sea level rise affecting these islands, including monitoring any changes that are the result of seawater inundation.
- Ongoing regular surveillance and monitoring of disease vector populations and viruses, which can be achieved using simple and inexpensive equipment, and through trials of novel methods, with a long-term aim of community surveillance and independence.

7. References

Note: All references generated through NERP TE hub research are indicated by an asterisk (*).

*Bainbridge, S.J., Berkelmans, R., Sweatman, H. and Weeks, S. (2015) Monitoring the health of Torres Strait Reefs – Final Report. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (93 pp).

*Bainbridge, S. and Berkelmans, R. (2014) The use of climatologies and Bayesian models to link observations to outcomes; an example from the Torres Strait. Environmental Science: Processes & Impacts, 16(5): 1041-1049.

*Bohensky, E., Butler, J.R.A., Rainbird, J., Skewes, T., McGrath, V., Nai, F., Maru, Y., Hunter, C. and Morseau, F. (2014) Adaptation integration workshop – the Masig Island example. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (25 pp).

* Bohensky, E., Butler, J.R.A., Rainbird, J., Skewes, T., McGrath, V., Nai, F., Maru, Y., Morseu, F. and Lankester, A. (2014) Mabuiag Yesterday, Today and Tomorrow: Community Future Scenarios and Adaptation Strategies. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (49 pp).

*Butler, J.R.A., Bohensky, E., Skewes, T., Maru, Y., Busilacchi, S., Rochester, W., Katzfey, J. and Wise, R.M. (2015) Drivers of change in the Torres Strait region: status and trends. Report to National Environmental Research Program. Reef & Rainforest Research Centre Limited, Cairns (60 pp).

Coles, R., Grech, A., Rasheed, M. and McKenzie, L. (2012) Evaluating risk to seagrasses in the Tropical Indo-Pacific Region. Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9-13 July 2012. Mini-Symposium 15b – Seagrasses and seagrass ecosystems.

De'ath, G., Fabricius, K., Sweatman, H. and Puotinen, M. (2012) The 27-year decline of coral cover on the Great Barrier Reef and its causes. PNAS, 109(44): 17995-17999.

*Delisle, A. (2013) A socio-economic investigation of the Torres Strait Indigenous dugong and turtle fisheries. PhD Thesis, James Cook University, Townsville, Australia (334 pp).

*Delisle, A., Watkin Lui, F., Stoeckl, N. and Marsh, H. (2014) The sharing and consumption of dugong and turtle meat outside Torres Strait: Management strategies and options. Final Report to the Australian Marine Mammal Centre (Project #11/6). James Cook University, Townsville.

*Duke, N.C., Burrows, D. and Mackenzie, J.R. (2015) Mangrove and Freshwater Wetland Habitat Status of the Torres Strait Islands. Biodiversity, Biomass and Changing Condition of Wetlands. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (100 pp).

Duke, N. C., Meynecke, J.O., Dittmann, S., Ellison, A.M., Anger, K., Berger, U., Cannicci, S., Diele, K., Ewel, K.C. and Field, C.D. (2007) A world without mangroves? Science, 317: 41-42.

Duke, N.C., Lawn, P., Roelfsema, C., Phinn, S., Zahmel, K., Pedersen, D., Harris, C., Steggles, N. and Tack, C. (2003) Assessing historical change in coastal environments. Port Curtis, Fitzroy River Estuary and Moreton Bay regions.

Ellison, J.C. (2014) Vulnerability of mangroves to climate change. Mangrove Ecosystems of Asia. Springer, 213-231.

*Fuentes, M.M.P.B., Bell, I., Hagihara, R., Hamann, M., Hazel, J., Huth, A., Seminoff, J.A., Sobtzick, S. and Marsh, H. (in review) Improving in-water estimates of marine turtle abundance by adjusting aerial survey counts for perception and availability biases. Journal Experimental Marine Biology and Ecology.

GBRMPA [Great Barrier Reef Marine Park Authority] (2013) Great Barrier Reef Region Strategic Assessment Demonstration case: Shipping, Townsville, Australia.

Gehrke, P.C., Sheaves, M.J., Terry, J.P., Boseto, D., Ellison, J.C., Figa, B.S. and Wani, J. (2011) Chapter 7: Vulnerability of freshwater and estuarine fish habitats in the tropical Pacific to climate change. In: Vulnerability of tropical Pacific fisheries and aquaculture to climate change (Eds. Bell, J., Johnson, J.E. and Hobday, A.J.) Secretariat of the Pacific Community, Noumea, New Caledonia.

Gilman, E.L., Ellison, L., Duke, N.C. and Field, C. (2008) Threats to mangroves from climate change and adaptation options: a review. Aquatic Botany, 89: 237-250.

Grayson, J. (2011) Characteristics of traditional dugong and green turtle fisheries in Torres Strait: Opportunities for management. PhD Thesis, James Cook University, Townsville, Australia.

Green, D., Alexander, L., Mclnnes, K., Church, J., Nicholls, N. and White, N. (2010) An assessment of climate change impacts and adaptation for the Torres Strait Islands, Australia. Climatic Change, 102: 405-433.

*Hamann, M., Smith, J. Preston S. and Fuentes, M.M.P.B. (2015a) Nesting green turtles of Torres Strait. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (13 pp).

*Hamann, M., Smith, J. and Preston, S. (2015b) Faltback turtles of Torres Strait. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (8 pp).

Harper, B. (2011) Torres Strait Extreme Water Level Study. Systems Engineering Australia. www.tsra.gov.au

Haywood, M.D.E., Browne, M., Skewes, T., Rochester, W., McLeod, I., Pitcher, R., Dennis, D., Dunn, J., Cheers, S. and Wassenberg, T. (2007) Improved knowledge of Torres Strait seabed biota and reef habitats. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns (115 pp).

Hodgson, A., Kelly, N. and Peel, D. (2013) Unmanned Aerial Vehicles (UAVs) for surveying marine fauna: A dugong case study. PLoS ONE, 8(11), e79556.doi:10.1371/journal. pone.0079556.

International Union for Conservation of Nature [IUCN] (2010) Halichoeres richmondi. The IUCN Red List of Threatened Species. Version 2014.3 See: http://maps.iucnredlist.org/map.html?id=187507.

International Union for Conservation of Nature [IUCN] (2010) Macropharyngodon choati. The IUCN Red List of Threatened Species. Version 2014.3 See: http://maps.iucnredlist.org/map.html?id=187388.

McKenzie, L., Yoshida, R., Grech, A. and Coles, R. (2010) Queensland seagrasses. Status 2010 – Torres Strait and East Coast. Fisheries Queensland (DEEDI), Cairns (6 pp).

McNamara, K.E., Smithers, S.G., Westoby, R. and Parnell, K. (2011) Limits to climate change adaptation for low-lying communities in the Torres Strait. Final report to the National Climate Change Adaptation Research Facility.

Murphy, N.E., Skewes, T.D., Dovers, E., Rochester, W. and Long, B. (2011) Incipient outbreak of Crown-of-thorns starfish (*Acanthaster planci*) in Torres Strait, Australia. Final Report to AFMA. CSIRO Wealth from Oceans, Dutton Park (30 pp).

Nitto, D.D., Neukermans, G., Koedam, N., Defever, H., Pattyn, F., Kairo, J. and Dahdouh-Guebas, F. (2014) Mangroves facing climate change: landward migration potential in response to projected scenarios of sea level rise. Biogeosciences, 11: 857-871.

*Laurance, S.G.W., Meyer Steiger, D. and Ritchie, S. (2014) Detecting Emerging Infectious Diseases in the Torres Strait: A review of mosquito-borne disease studies. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (17 pp).

Ocean Biogeographic Information System [OBIS] (2014) Data from the Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. Available at: http://www.iobis.org

*Osborne, K., Miller, I., Johns, K., Jonker, M. and Sweatman, H. (2013) Preliminary report on surveys of biodiversity of fishes and corals in Torres Strait. Australian Institute of Marine Science, Townsville, Australia.

Parnell, K.E., Smithers, S.G. and Ischenko, L. (2012) Understanding climate change driven coastal erosion and inundation impacts on Torres Strait communities and the development of adaptation options. Report for the Department of Climate Change and Energy Efficiency, Australia.

*Petus, C. (2013) Application of MODIS remote sensing imagery for monitoring turbid river plumes from PNG in the Torres Strait region: A test study. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (20 pp).

Pollock, K., Marsh, H., Lawler, I. and Alldredge, M. (2006) Modelling availability and perception processes for strip and line transects: An application to dugong aerial surveys. Journal of Wildlife Management, 70, 255-262.

Rasheed, M.A., McKenna, S.A., Carter, A.B. and Coles, R.G. (2014) Contrasting recovery of shallow and deep water seagrass communities following climate associated losses in tropical north Queensland, Australia. Marine Pollution Bulletin, 83(2): 491–499.

*Sobtzick, S., Hagihara, R., Penrose, H., Grech, A., Cleguer, C. and Marsh, H. (2014) An assessment of the distribution and abundance of dugongs in the Northern Great Barrier Reef and Torres Strait. A Report for the Department of the Environment, National Environmental Research Program (NERP). August 2014.

Suppiah, R., Bathols, J., Collier, M., Kent, D. and O'Grady, J. (2010) Observed and future climates of the Torres Strait region. CSIRO report for the Torres Strait Regional Authority.

*Sweatman, H., Johns, K., Jonker, M., Miller, I. and Osborne, K. (2015) Report on second monitoring field trip to Torres Strait, January 2014 Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (10 + iv pp).

*Sweatman, H. and Berkelmans, R. (2012) Summary of existing information on coral reef communities of the Torres Strait. NERP project 2.3 Report, Australian Institute of Marine Science, Townsville (7 pp).

*Waterhouse, J., Brodie, J., Wolanski, E., Petus, C., Higham, W. and Armstrong, T., (2013) Hazard assessment of water quality threats to Torres Strait marine waters and ecosystems. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (70 pp).

Welch, D.J. and Johnson, J.E. (2013) Assessing the vulnerability of Torres Strait fisheries and supporting habitats to climate change. Report to the Australian Fisheries Management Authority. C_2O Fisheries, Australia (114 pp.).

*Wolanski, E., Lambrechts, J., Thomas, C.J. and Deleersnijder, E. (2013) A high-resolution model of the water circulation in Torres Strait. NERP project 4.4 Report. TropWater, James Cook University, Townsville, Australia.