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Scoping a future project to address impacts from climate variability and change on key Torres Strait Fisheries

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Final Report for Project Climate variability and change relevant to key fisheries resources in the Torres Strait to Australian Fisheries Management Authority

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Executive Summary

Fishing is a critical activity in Torres Strait supporting both Indigenous and non-indigenous sectors through commercial, subsistence and traditional activities. Pressures on fisheries resources can be localised (e.g. overfishing, increased runoff and turbidity due to land-use changes and extreme rainfall events) and also related to climate change (e.g. ocean acidification, increase in sea surface temperature), which operates at larger scales. Localised and climate change pressures can act in isolation or synergistically to influence fishery resources.

The first objective of this report (presented in Parts 1 and 2) is to provide background information about Torres Strait and review previous projects and other relevant literature to identify environmental drivers that affect recruitment, growth, mortality rates, catches and relevant habitats of selected fisheries (tropical rock lobster (TRL), bêche-de-mer (BDM), finfish, prawns, turtles and dugongs), and potential effects of climate change on these environmental drivers. The review informs the second objective of the project, which is to provide a detailed technical specification of the over-arching data framework, and spatial scales for a future project scope that would address future climate variability and change scenarios for Torres Strait fisheries (Part 3).

Torres Strait is a narrow body of water situated between Papua New Guinea, Indonesia and Australia connecting the Gulf of Carpentaria to the Coral Sea via the continental shelf of the Great Barrier Reef and the Gulf of Papua. Its climate is influenced by considerable ocean and climate variability, dominated by the monsoon and El Niño–Southern Oscillation (contributing to year-to-year variability) and extreme weather events, including changes in sea level and marine heatwaves. Cyclones are relatively rare, but the area is influenced by cyclonic-related storms, strong winds, waves, surges and extreme rainfall. Both air and sea surface temperatures do not vary much throughout the year because of the tropical location. Mean annual rainfall is 1,750mm falling mostly between November and February.

The bathymetry and circulation in Torres Strait are complex, mostly shallow (between 5 and 25m deep) and characterised by high energy conditions and strong tidal currents. The region contains productive ecosystems, including coral reefs, sandbanks, and extensive areas of seagrasses and mangroves, supporting a variety of fisheries.

Anthropogenic impacts (other than climate change) in Torres Strait are relatively minor, but exist in specific locations. Torres Strait is, however, relatively highly vulnerable to shipping accidents, with this being recognised by TSRA, and oil spill risk may be important to consider in an ecosystem modelling framework. Local impacts include, localised oil contamination, mangrove cutting, alteration of hydrology, nutrient and sediment runoff, and chemical contamination.

Fishing is an additional anthropogenic impact source. Most marine living resources have been managed sustainably but there are examples of past overharvesting (most notably sandfish and black teatfish) and this needs to be considered.

Climate change is already affecting Torres Strait fisheries and culture. Expected impacts from climate change include higher sea levels and associated coastal erosion, warmer atmospheric and ocean temperatures, more acidic waters, changes in ocean circulation, and more intense rainfall events. Although relatively minor, simultaneous local impacts (e.g. untreated sewage, chemical, sediment and nutrient runoff, oil pollution, overfishing) act together with climate change impacts, such as sea-level rise, ocean warming, acidification, leading to interactive, complex and amplified impacts for species and ecosystems.

These pressures can manifest directly in the form of changes in abundance, growth, reproductive capacity, distribution and phenology (changes in cyclic and seasonal phenomena such as reproduction and migration), and indirectly through changes in habitats. Invertebrates (TRL, prawns, BDM) are likely to be more impacted by climate change than vertebrates (Finfish, turtles and dugongs). This is *inter alia* because although highly productive, their life spans are short, which makes it difficult for them to move out of a certain area severely impacted over many years before significant losses at the population level happen.

Climate change is likely to cause mostly negative direct effects on the fisheries investigated in this report, but some effects may also be positive, especially in the short to medium-term (e.g. relatively small warming may increase growth rates of sea cucumber and lobsters). If climate-related environmental changes exceed certain limits or ranges for species, they will either move when possible, or have their abundance reduced.

The second objective of the report was to produce an over-arching data and modelling framework at the appropriate spatial scales, as required to address future climate variability and change scenarios for Torres Strait fisheries (Part 3). The objectives of the modelling exercise are to simulate future climate scenarios and assess the impacts of these on fisheries and associated habitats and species through quantitative evaluation. It will support the exploration of responses and strategies to manage the selected Torres Strait fisheries, such as the evaluation of:

1) Interactions between different fisheries and broader ecosystem functioning, including consideration of communities that rely on these resources;

2) Impacts of climate change scenarios on the abundance and distribution of selected species;

3) Impacts of current and future river catchment conditions and management scenarios on fisheries;

4) Impacts of incidents (e.g. oil spills, ship groundings) on fisheries;

5) Combined scenarios of 1-4 to develop strategies that are robust across impacts and fisheries; and

6) Evaluation of alternative adaptation options.

In order to address objectives, some of the desirable features of the modelling framework include: 1) Catchment runoff; 2) Hydrodynamics and transport; 3) Physio-chemical water quality constituents; 4) Biogeochemistry, 5) Fisheries dynamics; and 6) Ecological and socio-ecological relationships.

Data requirements to simulate these desirable features include: 1) biological and fisheries data (catches, catch locations, target species, gear, age and size frequency of catches, species distribution, growth rates, reproduction and maturity, mortality and population size); 2) location, area and species of supporting habitats (mangroves, seagrasses and mangroves); and 3) physical and biogeochemical data (currents, turbidity, temperature (air and sea), tides and water level, light penetration, nutrients, salinity, sedimentation, pH, oxygen, grazing, extreme events, waves, moon phase, diseases and parasites).

There is significant information covering Torres Strait fisheries, key marine species, habitats, geology and physiochemical water quality parameters. However, datasets are sparse both in space and time. A large-scale monitoring program for Torres Strait would support the identification of long-term trends and improve understanding about local and regional processes affecting habitats, species and fisheries, including the impacts of climate change on these.

Most of the understanding about physical and biogeochemical cycles and processes (e.g. currents, tides, primary productivity, nutrients) in Torres Strait have been derived from remote sensing and hydrodynamic models developed in the 2000s and in the early 2010s, each with relatively well-known pros and cons. Limited physical long-term observational data is available as these data were collected mostly in the 1990s. It is therefore recommended to prioritise physical data collection to improve our understanding about regional dynamics and potential impacts of climate change on these.

Habitat, fisheries and ecological data are also sparse, but recent mapping of mangroves, seagrasses and coral reefs combined with survey data on substrate and species collected in large-scale BDM and TRL surveys offer valuable information about the location and health status of such habitats, which can support the development of models to explore impacts and adaptation options.

A number of modelling initiatives are already in place in Torres Strait and it would be worth considering capitalising on these efforts. Given issues with hydrodynamic models previously developed for the region it is recommended that a dedicated regional hydrodynamic model, including physics and biogeochemistry be constructed for Torres Strait (supported by appropriate oceanographic data collection), as the effort to re-run previously developed models will likely be similar to deploying an up-to-date state-of-the-art modelling platform such as eReefs, which has been developed for the Great Barrier Reef (GBR) region.

The Torres Strait region will likely need to integrate a mix of modelling approaches that feed into one another, built in a stepwise fashion. A cost-effective approach would be to couple a regional hydrodynamic model that simulates basic physical and biogeochemical processes with an ecological or socio-ecological model. Although complex to develop, if feasible a socio-ecological approach is preferred as it accounts for the human dimension and hence some of the complex socio-cultural relationships between traditional owners and their marine environment. Given there are already assessment models developed for some of the key species (e.g. TRL, BDM, prawns), a useful starting point would be to combine these in an integrated spatial model using models of intermediate complexity for ecosystem assessment (MICE) for the Torres Strait region. This can form the basis of a more complex ecosystem model or help to ground-truth a larger more complex model.

Starting the modelling exercise using MICE approach sooner rather than later would provide a framework to utilise existing datasets and investigate potential climate change impacts on the fisheries and there are sufficient data to start modelling. So, our recommended approach would be to build the models in a stepwise fashion, adding new data and complexity as these become available or necessary. This also allows time to start obtaining feedback from stakeholders on preliminary model results, which allows time to communicate the usefulness of models as well as how to draw on local knowledge to further refine models.

Many ecosystem models involve coupling together different components and this is also how we envisage development of an ecosystem model proceeding – hence the starting point is to extend and link the current biological models of key species (e.g. TRL, BDM, dugongs), add current known environmental drivers (e.g. SST), gradually add other species (e.g. seagrass, finfish, turtles) and link with prelim hydrodynamic models or model outputs to start adding complexity associated with the oceanographic setting. The development of fully integrated couple hydrodynamic model usually takes a few years and is an expensive process so we recommend starting small and gradually expanding.

The proposed data framework identifies how the physio-chemical and ecological data could be managed and delivered to support the development of models. Datasets can be managed on CSIRO IT infrastructure, utilising relational database systems and enterprise file servers. Datasets will be described using geonetwork (www.marlin.csiro.au) and these descriptions can be made public to allow third parties (non-CSIRO) to access data depending on level of permission granted (i.e. licence restrictions). Datasets can be shared using Open Geospatial Consortium (OGC) standards where appropriate, by using a standards-compliant webserver (geoserver) linked to the collated data. This framework is scalable, robust and compliant with open data/metadata standards, allowing a flexible data delivery method.

The following are the key recommendations from this report:

1. Prioritise physical data collection and further strengthen and expand a large-scale monitoring program for Torres Strait that would support the identification of long-term trends and improve understanding about local and regional processes affecting habitats, species and fisheries, and to support the development of models.
2. Staged approach in the development of an integrated ecosystem modelling framework to investigate the impacts of climate and local changes on fisheries in Torres Strait, via coupling together:
    a. Development and implementation of data framework to support future modelling efforts in Torres Strait
    b. Development of integrated ecological or socio-ecological models capable of integration with a regional hydrodynamic model:
        i. For example, start by combining existing data and models (TRL, BDM, and dugongs) into an integrated spatial MICE, which will form the basis for a hybrid MICE-ATLANTIS ecosystem model;
        ii. Dedicated regional hydrodynamic model, including physics and biogeochemistry for Torres Strait, for example similar to eReefs.

Part 1: Background

1 Introduction

Fishing is a critical activity in Torres Strait supporting both Indigenous and non-indigenous sectors through commercial, subsistence (food security) and traditional activities (Busilacchi et al. 2013). Commercial fishing is one of the most economically important activities in the Torres Strait, providing significant opportunities for financial independence, maintenance of traditions and lifestyle for traditional inhabitants of the region (Plaganyi et al. 2013b, van Putten et al. 2013b, Johnson and Welch 2016). Not surprisingly, impacts on Torres Strait fisheries have profound economic and social consequences to traditional and non-traditional inhabitants of the Torres Strait.

Pressures on fisheries resources can be localised (e.g. overfishing, increased runoff and turbidity due land-use changes and extreme rainfall events) and also related to climate change (e.g. ocean acidification, increase in sea surface temperature) (Welch and Johnson 2013). These pressures manifest directly in the form of changes in fish abundance, growth, reproductive capacity, distribution and phenology (changes in cyclic and seasonal phenomena such as reproduction and migrations)(Free et al. 2019)), and indirectly through changes in foodwebs and habitats (Welch and Johnson 2013, Fulton et al. 2018). Localised and climate change pressures can act in isolation or synergistically to influence fishery resources (Abelson 2019).

Localised and climate-change pressures affect Torres Strait habitats and fisheries indirectly via changes in sea level, sea surface temperature and extreme rainfall events (Marsh and Kwan 2008, Babcock et al. 2019, Smale et al. 2019). Some direct pressures include localised habitat destruction, pollution and over-exploitation (Plaganyi et al. 2013a, Duke et al. 2015, Patterson et al. 2018). Such impacts have reduced Torres Strait Islanders' access to target species (Skewes et al. 2006, Plaganyi et al. 2013a) or caused reduction in catches (Marsh and Kwan 2008). Fisheries management and assessments will need to take account of the implications of future variability and change that may affect stocks. These may manifest through effects on recruitment pathways, growth and mortality rates, and critical habitats among other processes.

Anthropogenic impacts in Torres Strait are minimal, but exist in specific locations. The main drivers are the modernisation and urbanisation of Island communities, and need to connect to mainland Australia and markets. These require built infrastructure such as piped water and sewerage facilities, better housing, jetties, roads/air strips, and shipping routes. Land clearing and associated increase in land-based runoff, localised pollution, changes in water flow and oil spills are some of the risks affecting Torres Strait fisheries (Duke et al. 2015).

Climate change also threatens Torres Strait Islands, their people, fisheries and industries. Current and expected impacts from climate change likely to affect Torres Strait fisheries include higher seas, warmer atmospheric and ocean temperatures, more acidic waters, and changes in ocean circulation (CSIRO-BOM 2015). Climate change is expected to substantially influence marine ecosystems and fisheries in Australia (Fulton et al. 2018). There is no single most important factor affecting all of Torres Strait fisheries as they are site- and fishery-specific. Instead, multiple climate and non-climate stressors interact in various ways to impact fisheries and habitats (Bonebrake et al. 2019). Although localised impacts on ecosystems and fisheries are relatively small in Torres Strait (see Part 2), changes in land-use, resource over-exploitation, and pollution interact with climate change to contribute to changes in Torres Strait habitats and fisheries, influencing ecosystem functioning, services, and human well-being (Duce et al. 2010, Pecl et al. 2017).

Climate change is an emerging issue affecting key ecosystem processes and fisheries resources world-wide, with a relatively large and growing knowledge base, but still with important uncertainties and knowledge gaps (Fulton et al. 2018, Free et al. 2019, Johnson et al. 2020) that need to be addressed, hence the climate change focus of this report.

Predicting exactly how climate will change and the effects of these changes in ecosystems and fisheries is very difficult in Torres Strait because the region lacks high-quality, long-running meteorological records (Green et al. 2010) and its ecosystems are highly variable and poorly studied (Harris et al. 2008, Duce et al. 2010) despite recent progress on the understanding of fisheries, environmental and governance regimes (e.g. Wolanski et al. 2017, NESP Earth Systems and Climate Change Hub 2018, Plaganyi et al. 2018c, Butler et al. 2019, Plaganyi et al. 2019c, Rodgers et al. 2019). The lack of full knowledge about how Torres Strait will change in the future does not preclude action. There is likely enough information from studies in Torres Strait to support decision-making in the short term, but information at the appropriate scale is required for longer-term strategic decisions (NESP Earth Systems and Climate Change Hub 2018). The climate change signal is clear (Suppiah et al. 2010, CSIRO-BOM 2015, Cheng et al. 2019, IPCC 2019b) and expected to affect fisheries in Torres Strait (Norman-Lopez et al. 2013, Plaganyi et al. 2013a, Johnson and Welch 2016, Plagányi et al. 2018). Torres Strait fisheries management will require relevant information to support adaptation planning. The first step in this process is to review the literature to understand potential impacts of localised and climate change on fisheries and supporting ecosystems (Part 2).The review offered in Parts 1 and 2 of the report is used in Part 3 to assess data needs and the spatial and temporal scales required to develop a future data and modelling platform to assess potential climate change (and localised) impacts on the selected fisheries. This future study will be an important aspect required for climate adaptation planning in Torres Strait.

1.1 Objectives of this report

This report will build on detailed findings from a literature review of the main climate change drivers in Torres Strait affecting tropical rock lobster, bêche-de-mer (sea cucumber), finfish, prawns, turtles and dugongs (Table 1) to provide detailed specification and costings for a future project that will produce the over-arching data framework at the appropriate spatial scales, as required to address future climate variability and change scenarios for Torres Strait fisheries. The report will also include detailed information about data availability, and specifications on data storage, management and data accessibility issues.

Table 1. Fisheries investigated in this report. Fishery type: C (commercial), S (subsistence), R (recreational) (from: Johnson and Welch 2016), plus additional Holothurians - Prickly redfish and White teatfish given their increasing economic value and harvest.

Fishery	Common name	Scientific name	Fishery type
Tropical Rock Lobster	Tropical Rock Lobster	*Panulirus ornatus*	C, S
Prawns	Brown tiger prawn	*Penaeus esculentus*	C
	Blue endeavour prawn	*Metapenaeus endeavouri*	C
Finfish	Spanish mackerel	*Scomberomorus commerson*	C, S, R
	Common coral trout	*Plectropomus leopardus*	C, S, R
	Barcheek coral trout	*Plectropomus maculatus*	C, S, R
	Passionfruit coral trout	*Plectropomus areolatus*	C, S, R
	Bluespot coral trout	*Plectropomus laevis*	C, S, R
Beche-de-mêr	Sandfish	*Holothuria scabra*	C
	Black teatfish	*Holothuria whitmaei*	C
	Prickly redfish	*Thelenota ananas*	C
	Curryfish	*Stichopus herrmanni* and *S. vastus*	C
	White teatfish	*Holothuria fuscogilva*	C
Turtle	Green Turtle	*Chelonya midas*	S
	Hawksbill Turtle	*Eretmochelys imbricata*	S
Dugong	Dugong	*Dugong dugon*	S

1.2 Why this report is needed

Semi-quantitative fisheries assessments of climate change impacts and vulnerability have been conducted in Torres Strait (Green et al. 2010, Welch and Johnson 2013, Johnson and Welch 2016, Fulton et al. 2018). However, quantitative considerations are still sparse (but see, Plaganyi et al. 2011, Plagányi et al. 2017a) despite being essential for fisheries management to adequately respond and plan for the future.

2 Approach

This report will synthesise results from previous projects about climate implications for Torres Strait and other relevant literature to identify environmental drivers that affect recruitment, growth, mortality rates, catches and relevant habitats for selected fisheries (rock lobsters, prawns, finfish, *bêche-de-mer*, dugongs and turtles).

In 2010, two major reports about climate change observations and predictions, impacts and adaptation for Torres Strait were published (Duce et al. 2010, Suppiah et al. 2010). These were based on IPCC AR5 models. We will provide a synthesis from the literature identifying key advancements in knowledge since the publication of these reports. References were gathered using search in End Note of Web of Science database using the keywords “Torres Strait” and “Climate Change” and also includes a web search on both climate change impacts and fisheries in Torres Strait (e.g. reports from major research programs, such as the National Environmental Research Program (NESP), as well as State and Commonwealth agencies). References selected for review have their abstracts screened based on their relevance to the focus of the report (climate change impacts on fisheries and supporting habitats) and include information about both observations and models related to climate change, potential impacts on physio-chemical, ecological and biological drivers influencing the selected fisheries.

The main source of information for climate change predictions for Torres Strait is web resource ‘Climate Change in Australia’ (CSIRO-BOM 2015), which presents information for the Wet Tropics of Australia. More recent predictions from peer-reviewed sources are used to update climate change predictions when appropriate.

A draft version of this report was presented in a video-conference technical workshop held on the 14th of October 2020 with relevant scientists and managers to get their inputs and feedback for incorporation into the final report.

3 Torres Strait environmental setting

Torres Strait is a narrow body of water lying between Papua New Guinea (PNG; Western Province), Indonesia (Papua Province), and Australia (Queensland) covering an area of approximately 48,000km^2 (Duce et al. 2010, Butler et al. 2019). It connects the Gulf of Carpentaria (GoC) to the Coral Sea via the continental shelf of the Great Barrier Reef (GBR) and the Gulf of Papua (Wolanski et al. 2013) (Figure 1). Its deeper channels form a major shipping route in which a large proportion of goods flow from and to Australia (Duce et al. 2010, Wolanski et al. 2013).

Torres Strait contains productive ecosystems, including about 750 coral reefs, sandbanks, and extensive areas of seagrasses and mangroves, with more than 270 islands in which 17 are inhabited with a total population of about 8,500 people (Harris et al. 2008, Duce et al. 2010, Butler et al. 2019). The region is culturally, ecologically and economically important (Wolanski et al. 2013), supporting traditional and commercial fisheries, including Tropical Rock Lobster, finfish, crab, trochus and *bêche-de-mer*, marine turtles and dugongs (van Putten et al. 2013b, Johnson and Welch 2016).

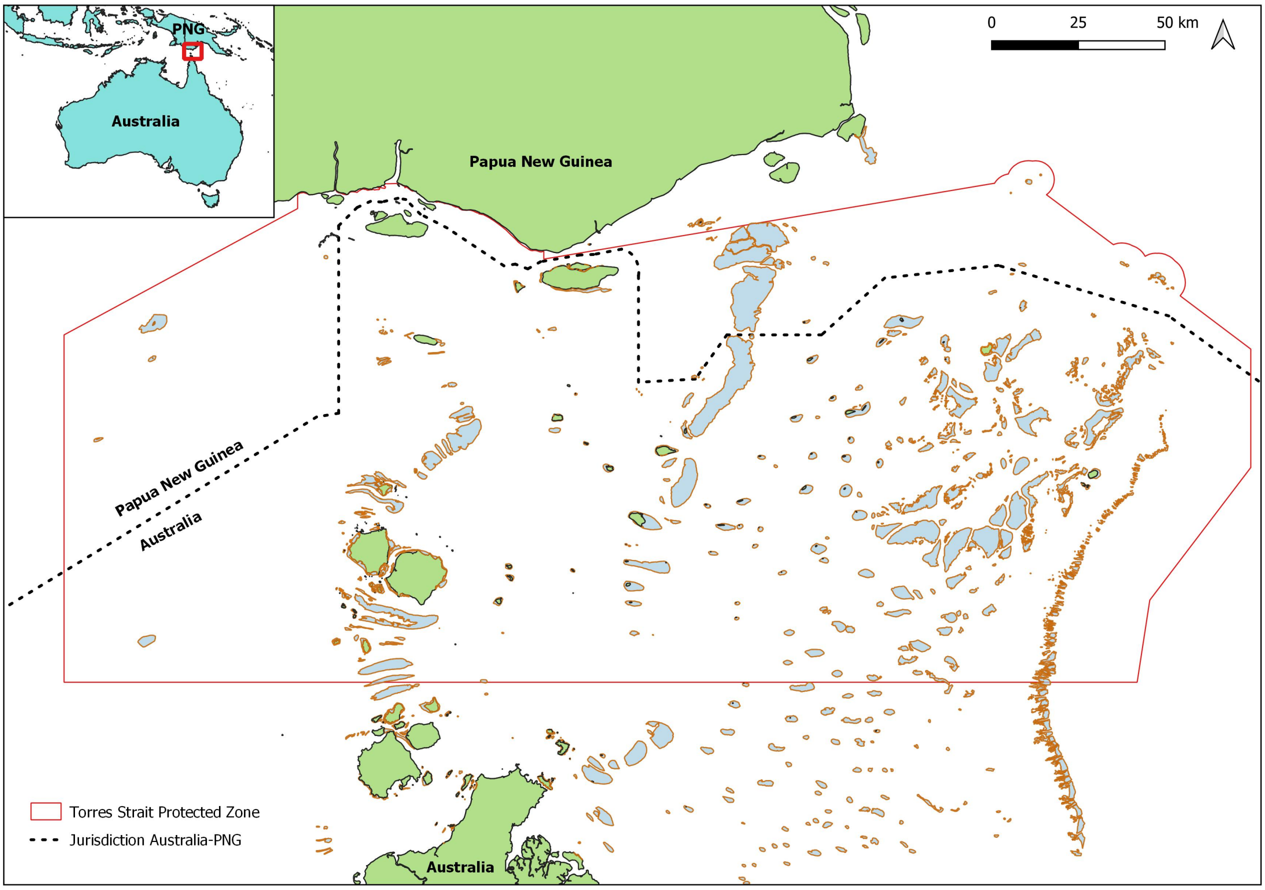

Figure 1. Map of Torres Strait (source: http://www.tsra.gov.au/news-and-resources/annual-reports/annual-report-2016-2017/section-report-of-operations/where-we-operate).

3.1 Climate

The Torres Strait climate is influenced by considerable ocean and climate variability. It is dominated by the monsoon and El Niño–Southern Oscillation (ENSO; contributing to year-to-year variability) and extreme weather events, including changes in sea level, marine heatwaves, tropical storms with associated strong winds, waves and storm surges and extreme rainfall. During ENSO, northern Australia is drier than normal, while during La Niña events it is wetter than normal (NESP Earth Systems and Climate Change Hub 2018).

The Torres Strait climate experiences seasonally reversing winds separated in two seasons: the monsoonal wet season dominated by prevailing north-westerly winds between December and April, and the dry season dominated by prevailing south-easterly winds from May to November (CSIRO-BOM 2015), where north westerlies driven by the monsoon dominate for around 15% of the year (Duce et al. 2010). Winds are stronger in the dry season (April-June), with mean maximum wind speeds up to 15ms^{-1}. Wet season winds are considerably lower with maximum speeds ranging between 10-11 ms^{-1}, while mean wind speeds are less than 4 ms^{-1}(Duce et al. 2010).

Both air and sea surface temperatures do not vary much throughout the year because of the tropical location. Average daily temperatures are 29°C (maximum mean 31.2°C and mean minimum 25.4°C). Wet and dry season mean maximum and (minimum) vary from about 28 (22)°C to 32 (25) ^{o}C (Green et al. 2010). Sea surface temperatures range from 29^{o}C (summer) to 25^{o}C (winter). Mean annual rainfall is 1,750mm falling mostly during the wet season between November and February (Duce et al. 2010).

Cyclones are relatively rare in the region because Torres Strait is located north of the main cyclone belt. However, the area receives cyclonic-related storms and strong wind events, which influence surges (Duce et al. 2010, NESP Earth Systems and Climate Change Hub 2018).

3.2 Bathymetry and circulation

The bathymetry and circulation in Torres Strait are complex, mostly shallow (between 5 and 25m deep) – especially along the axis of the western Torres Strait Islands (~142^{o}15'E) – and characterised by high energy conditions and strong tidal currents (Green et al. 2010, Daniell 2015). The region contains productive ecosystems, including coral reefs, sandbanks, and extensive areas of seagrasses and mangroves (Harris et al. 2008, Duce et al. 2010).

The complexity of oceanographic conditions in Torres Strait is often under-estimated. Tides, currents and waves influence sediment transport and larval dispersion, affecting geomorphology and fish stocks (Duce et al. 2010). Currents are the major mechanism connecting ecosystems by facilitating dispersal of larvae, supporting biogeochemical processes, and the propagation of climate features (Wolanski et al. 2013, Johnson et al. 2018). Water circulation is still poorly understood in the region because of its complex bathymetry (Wolanski et al. 2013). The net flow through is determined by the wind and the sea level difference (Figure 2) – mean sea level (MSL) rises by about 0.1m on the Coral Sea with increasing easterly winds; MSL decreases or increases 0.2-0.3m in the Gulf of Carpentaria according to whether southeast winds (decrease in MSL) or monsoonal winds (increase in MSL) prevail (Wolanski et al. 2013). ENSO also plays a strong role in year to year variability of sea level (NESP Earth Systems and Climate Change Hub 2018).

The complex bathymetry steers the net currents to form zones of net through flow, zones of stagnation, and zones of recirculation (Li et al. 2015). During the dry season, southeast trade winds raise MSL in the northwest Coral Sea and the wind and waves on the outer GBR generate a landward flow from the Coral Sea. The wind pushes the incoming Coral Sea water longshore northward on the GBR shelf. At the latitude of Cape York, a fraction of the wind-driven current waters turns westwards to form the Through Torres Strait current, which flows into the GoC (Gulf of Carpentaria). The remaining wind-driven current waters keep flowing northwards to form the Through Great Northeast Channel Current, exiting Torres Strait and entering the Gulf of Papua (Wolanski et al. 2013). Non-linear interactions between wind and tidal currents in shallow coastal waters in the GoC result in the formation of a coastal Boundary layer on the GoC side of the Torres Strait – these waters are ultimately exported from the GoC and is replaced by an inflow of water from the Arafura Sea. The plumes from the Fly River are entrained in the Coral Sea and at least during strong southeast trade winds this forms an eddy in the Gulf of Papua (Figure 2). A small fraction of the Fly River plume is entrained in Torres Strait by the currents of the Great North East Channel (Wolanski et al. 2013). The East-West flowing currents can reach up to 2-4m.s^{-1} within narrow passages during spring tides (Duce et al. 2010, Daniell 2015).

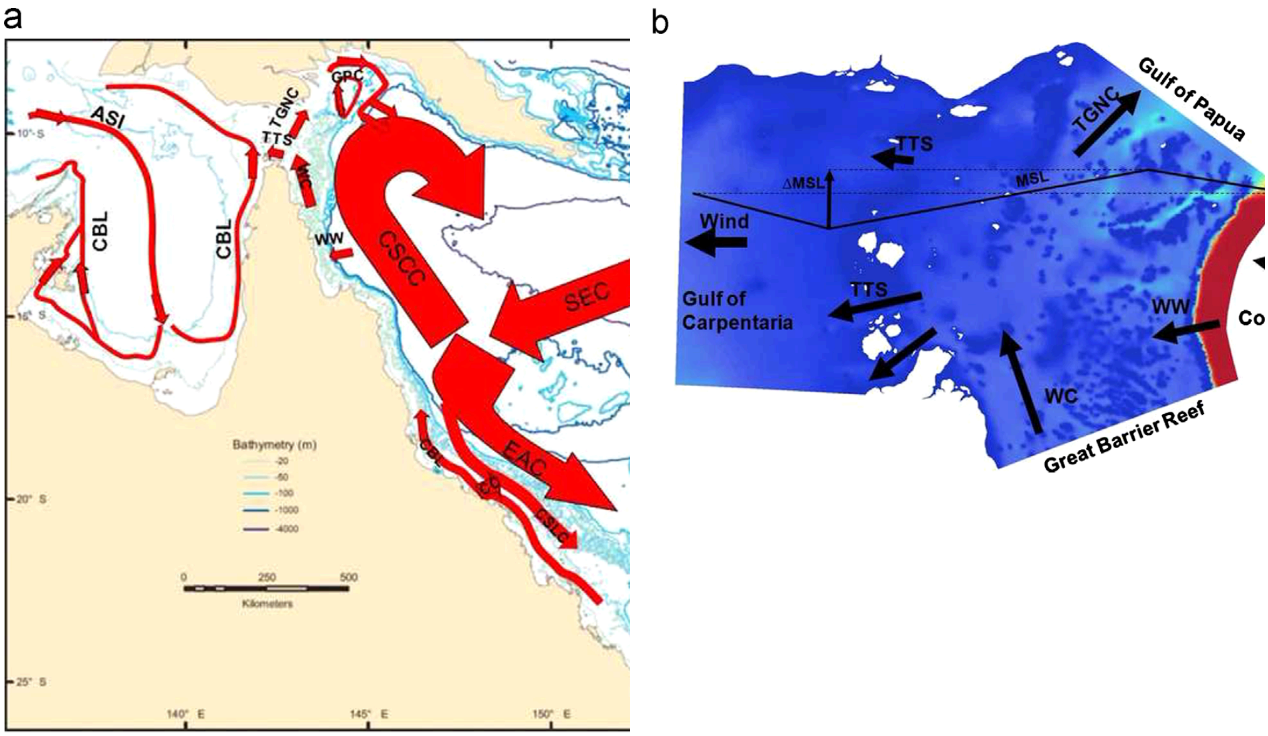

Figure 2. A sketch map of the general surface water circulation during southeast trade winds in (a) the Great Barrier Reef and (b) Torres Strait. MSL (mean sea level; ΔMSL (sea level difference between the Coral Sea and the Gulf of Carpentaria. SEC (South Equatorial Current); EAC (East Australian Current). CSLC (Coral Sea Lagoonal Current) ; CC (Cross Shelf Current as discovered by Andutta et al.(2013); CBL (wind-driven) Coastal Boundary Layer current; CSCC (Coral Sea Coastal Current); WW (inflow from the wind raising these a level in the Coral Sea and wave breaking on the outer reefs); WC (Wind-driven Current). TTS (Through Torres Strait current); TGNC (Through Great North East Channel current; GPC (Gulf of Papua current); ASI (Arafura Sea inflow).The CSCC was the original name given to that current by oceanographers (Andrews and Clegg, 1989) and it is also known as the Hiri current (source: Wolanski et al. 2013).

Tidal regime in Torres Strait is complex and variable because of the combination of strong currents and bathymetry and location of the Strait between two Ocean basins with different tidal regimes (semi-diurnal in the Pacific/Coral Sea and diurnal tides propagating from the Gulf of Carpentaria and the Indian Ocean) (Hemer et al. 2004, Daniell 2015). Tidal range in the Torres Strait depends on location. In the Gulf of Carpentaria it varies between 1.5-6m and in the Coral Sea and Gulf of Papua it varies between 3-7m (Duce et al. 2010).

Part 2: Threats to Torres Strait Fisheries

4 Local threats

Local impacts in Torres Strait include metal pollution from the Fly River (PNG) associated with mining, and construction of future oil and gas facilities, oil palm plantation and associated infrastructure building to support these industries. The required land clearing will increase sediment and pollution runoff, destruction of habitats with impacts on ecosystems and connectivity (Wolanski et al. 2013). Threats to Torres Strait fisheries include oil contamination, ship accidents, mangrove cutting, alteration of hydrology, nutrient and chemical contamination, and over-harvest of marine living resources (detailed below).

4.1 Oil contamination

Ship-and land-based related oil contamination occurs in Torres Strait but seems to be contained to small areas close to boat loading facilities (Duke et al. 2015). Major oil spills have occurred in the past (e.g. 'Oceanic Grandeur' oil spill in 1970) and have the potential to occur again in the region especially because of increased traffic since then.

4.2 Ship accidents

In addition to the risk from oil spills, the physical impact from ship grounding can cause structural habitat damage (e.g. coral reefs, seagrasses) (Carter et al. 2018). Antifouling paint (AFP) scrapped from hulls of grounded vessels (as smears and flakes) is also known to pose a significant risk for marine life. For instance, the exposure of marine life to contaminants present in AFP can cause: a) extensive mortality of resident communities (e.g. corals (Smith et al. 2003)); b) decrease in growth rates of molluscs (Alzieu 1998), corals (Smith et al. 2003), fish (Triebskorn et al. 1994, Shimasaki et al. 2003) and microalgae (Beaumont and Newman 1986); c) negative effects on reproduction, such as inhibition of reproduction in molluscs (Alzieu 1998), reduced sperm counts in fish (Haubruge et al. 2000), reduced coral fertilisation (Reichelt-Brushett and Harrison 1999), larval survival (Negri and Heyward 2001), larval settlement (Negri et al. 2002), larval metamorphosis (Reichelt-Brushett and Harrison 1999, Negri and Heyward 2001, Negri et al. 2002), induced sex reversal (increased masculinisation) in fish (Shimasaki et al. 2003) and molluscs (Horiguchi et al. 1998); and d) hampered recovery of adult populations from other stresses (Smith et al. 2003).

4.3 Mangrove cutting

Mangrove cutting affects a large proportion of mangroves on Boigu, Dauan and Mabuiag and seems to be mostly restricted to these islands. Mangroves are mostly harvested for timber resources (firewood, building material and for carving) (Duke et al. 2015: 71).

4.4 Alteration of hydrology

This is a relatively minor issue associated with the building of infrastructure (mainly air strips, dams and roads), which restrict natural freshwater, overland, and tidal flow into coastal ecosystems such as mangroves, causing localised die-offs (Duke et al. 2015:72).

4.5 Nutrient and sediment runoff and chemical contamination

Sewage treatment plants in Torres Strait have been upgraded in the early 2010s but it has been reported that despite the upgrades they still experience frequent maintenance issues resulting in leaks and untreated sewage discharge, negatively affecting nearby ecosystems (Waterhouse et al. 2013, Duke et al. 2015). The Islands mainly affected by nutrient contamination from sewage treatment plants are Boigu and Iama (Duke et al. 2015).

Chemical leachate in Torres Strait is associated with landfills often located within or directly adjacent to tidal wetland habitats and subjected to tidal inundation during king tides and runoff from heavy rainfall events. Evidence of chemical leachate (albino mangrove propagules) has been found in Saibai and Boigu Islands. Dauan, Boigu, Saibai and Iama Islands have landfills in close proximity of mangroves (Duke et al. 2015).

There is ongoing concern over the implications of sediment-related pollution originating from the Fly River. Saibai, Dauan and Boigu are most affected, though results are currently inconclusive and some species may be more sensitive to impacts from Fly River plumes than others (Waterhouse et al. 2018). Future research is needed to investigate common food sources for metal contamination as well as work to determine historical levels of metals in sediment and corals (NESP Earth Systems and Climate Change Hub 2018).

4.6 Over-harvest of marine living resources

While most fishery stocks in Torres Strait have not been overfished or subject to overfishing (Patterson et al. 2020), unsustainably high harvest levels have occurred in at least two stocks.

Sandfish (*Holothuria scabra*): Catch levels peaked in 1995 but were unsustainable leading to fishing closure (Skewes et al. 2006, Plaganyi et al. 2013a). The fishery is still closed but classified as "not subject to overfishing", because there were no reports of illegal fishing in 2017 (Patterson et al. 2018, Patterson et al. 2020) (see chapter 7.4).

Sea turtles (Chapter 7.5): Hawksbill turtle nesting population in Torres Strait is in severe decline mostly due overharvest in neighbouring nations and potential overharvest of eggs in Torres Strait and in neighbouring nations (NESP Earth Systems and Climate Change Hub 2018). Similarly, Northern Great Barrier Reef stock of Green turtles which utilise Torres Strait is likely to decline due to failing hatchling production at key index sites at Raine Island and Moulter Cay. Targeting of adult females for harvest and overharvest of eggs in some locations in PNG, Solomon Islands and Torres Strait are also primary contributors (NESP Earth Systems and Climate Change Hub 2018).

5 Climate change

The planet is clearly warming (Cheng et al. 2019). Global concentrations of greenhouse gases in the atmosphere continue to increase mainly due to emissions from fossil fuels, and are unlikely to be drastically reduced in the short term because of the inertia of governments (Climate Transparency 2018). Greenhouse gas emissions have increased on average 1.5 percent per year in the last 10 years (United Nations Environment Programme 2019). The opposite was expected if the world is to achieve the Paris agreement goal of limiting warming below 2°C and pursuing efforts to limit warming to 1.5 °C above pre-industrial levels.

The planet has warmed by over 1 °C since records began in 1850, resulting in mass loss from ice sheets and glaciers and sea level rise (over 20 cm since 1880), with the rate of sea level rise accelerating in recent decades (Commonwealth of Australia 2018, IPCC 2019b). A major contributor of global sea level rise is the melting of the Greenland Ice Sheet, driven by oceanographic and atmospheric warming. Greenland Ice sheets are melting seven times faster now than in 1992, with the rate of melting expected to increase due to global warming, on track to reach IPCC's predicted rates for high-end climate warming scenario (Shepherd et al. 2019). As the frozen soil starts to thaw, it releases more organic carbon than what summer plants can sequestrate. This carbon is converted into carbon dioxide and methane (greenhouse gases) further exacerbating climate change (Schuur 2019).

Not surprisingly, long-term observations show that the last 5 years (2015-2019) were the hottest on record and climate change projections made in the last 10 years appear to be conservative as climate is changing faster and stronger and expected to continue this strong warming path, reaching 3-5°C by 2100 (World Meteorological Organization 2019), despite the Paris agreement to limit warming to below 2°C (Lenton et al. 2019). Recent advances in climate science are reducing uncertainties about ice melting in Antarctica and Greenland, and are pointing to faster rates of ice melting compared to predictions in the IPCC 5th Assessment Report (AR5; IPCC 2014) with strong implications to the ice contribution of sea level rise (Shepherd et al. 2018). For example, between 1984 and 2018, sea ice coverage in the Arctic Ocean has declined by one third (Moore et al. 2019) and there appears to be a redistribution of heat from the Earth's atmosphere into the ocean interiors (up to 2,000m deep) (Cheng et al. 2019). Ocean warming appears to be increasing the energy of ocean currents in the last 25 years (Hu et al. 2020).

The future is uncertain but models and observations depict a future in which climate will continue to change, interact with climate variability and non-climate drivers affecting the interactions between oceans, cryosphere and atmosphere, ecosystem goods and services, and people (Commonwealth of Australia 2018, Coffey et al. 2019, IPCC 2019b). Changes in climate and ecosystems are already affecting fisheries worldwide (Pecl et al. 2014, Pecl et al. 2017, Lindegren and Brander 2018). Although some species will benefit from climate change–especially with warming waters– the majority of species will be negatively affected through changes in growth, abundance and distribution (Free et al. 2019).

5.1 Climate Change in Australia

Climate is changing much faster in Australia than in most of the world's oceans (Fulton et al. 2018). Since 1910, air temperatures have risen on average by about 1°C, with most warming post 1950. This has resulted in more extreme events such as heat waves, extreme rainfall events and cyclones (CSIRO-BOM 2015, Frolicher et al. 2018, Babcock et al. 2019, Smale et al. 2019). Natural climate variability in Australia's Tropical Pacific Ocean region is associated with El Niño and La Niña events, which now occurs on top of the warming trend with the potential to modify climate-ocean interactions with flow-on effects on Australia's climate (CSIRO-BOM 2015).

Since 1900 there has been a general increasing trend in rainfall during the northern wet season. There is evidence that heavy rainfall (rainfall extremes) are becoming more extreme, with a higher proportion of total annual rainfall coming from heavy rain days (Commonwealth of Australia 2018). Extreme rainfall events are expected to become more intense because of the relationship between increase in temperature and the water holding capacity of the atmosphere. Total rainfall in heavy rain days is expected to increase by around 7% per degree of warming. For short-duration, hourly, extreme rainfall events, observations in Australia generally show a larger than 7% increase. Short-duration rain extremes are often associated with flash flooding (Commonwealth of Australia 2018).

As a result of climate change, Australian marine ecosystems are already experiencing poleward redistributions of species across taxa and throughout latitudes worldwide (Hobday et al. 2016, Marzloff et al. 2016, Pecl et al. 2017, Fulton et al. 2018).

5.2 Climate change in Torres Strait

Climate change expresses in Torres Strait via extreme events, such as extreme high tides and sea surface temperature (T. Skewes, D. Brewer and J. Rainbird pers. observations). Climate change is impacting fisheries and cultural sites, impacting the exchange of cultural knowledge (Nursey-Bray et al. 2019). Given the current unprecedented emissions and trends (see Chapter 5), we are likely in a high emission scenario path (i.e. in line with IPCC representative impact pathway (RCP) 8.5). We therefore present results for RCP8.5 noting that if trends change it is possible to explore predictions for low and mid-range emission scenarios in the existing tools used in this review (CSIRO-BOM 2015, BOM-CSIRO 2018) (Table 2).

Table 2. Current and future climate change projections for Australia Wet Tropics for RCP 8.5 (CSIRO-BOM 2015). Climate data for Present conditions are for Horn Island station (http://www.bom.gov.au/climate/averages/tables/cw_027058.shtml)

Climate Change Attributes	Present (Period)	Prediction 2030	Prediction 2070	Prediction 2090	Recent updates
Annual Mean Surface Temperature (1995-2019)	27.6°C	0.8±0.2°C	2.3±0.5°C	3.2±0.6°C	

Mean Surface Temperature (Wet – Nov-Apr)	32ºC	0.8±0.2ºC	2.3±0.5ºC	3.1±0.7ºC	
Mean Surface Temperature (Dry – May-Oct)	28ºC	0.8±0.2ºC	2.3±0.4ºC	3.2±0.7ºC	
Annual Rainfall (1995-2019)	1,791mm	0% (-3.2±7.2)	0% (-2.0±14.0)	0% (-5.6±17)	
Mean Rainfall (wet) (1995-2019)	1645mm	0% (-3.2±8.2)	0% (-2.1±14.6)	0% (-3±17.3)	
Mean Rainfall (dry)	114mm	0% (-5.5±13.7)	0% (-5.5±26.6)	0% (-5.6±17.0)	
Wind Speed (Mean Annual) (1995-2010)	6.18m/s	1 – 3.09% (1.0±2.2)	> 3.09% (2.1±4.4)	>3.09%	
Wind Speed (Wet) (1995-2010)	5m/s	0% (0.6±3.7)	0% (0.9±7.5)	>3.09% (2.4±5.4)	
Wind Speed (Dry) (1995-2010)	7.4m/s	1 – 3.09% (1.3±1.7)	> 3.09 (2.9±2.9)	>3.09% (2.4±5.4)	
Maximum Daily Temperature (Annual)(1995-2019)	37.9ºC	0.5 – 1.5ºC (0.8±0.2)	1.5 – 3ºC (2.2±0.5)	1.5 – 3ºC (2.9±0.7)	
Maximum Daily Temperature (Wet) (1995-2019)	37.9ºC	0.5 – 1.5ºC (0.8±0.2)	1.5 – 3ºC (2.2±0.6)	1.5 – 3ºC (2.9±0.8)	
Maximum Daily Temperature (Dry) (1995-2019)	35.8 ºC	0.5 – 1.5ºC (0.8±0.2)	1.5 – 3ºC (2.2±0.4)	1.5 – 3ºC (2.9±0.6)	
Sea Level Rise	0	0.12m (0.06 – 0.18m)		0.61m (0.41 – 0.84)	0.84m (0.61-1.1m) by 2100 (IPCC 2019a)
Sea Surface Temperature (Annual)		0.7 ºC (0.5-1ºC)		2.6ºC (2.3 – 3.6)	
Sea Surface Salinity		0.05 g/kg (-0.12 – 0.96g/kg)		-0.28g/kg (-0.81 – 0.89)	
Ocean pH		-0.07 (-0.08 – -0.06)		-0.31 (-0.31 – -0.26)	
Aragonite Saturation		-0.41 (-0.45 – -0.24)		-1.57 (-1.67 – -1.19)	

5.2.1 Air Temperature

Temperatures have increased by around 1.1ºC over the past century (1910-2013) in the Wet Tropics, with the rate of warming increasing since 1960 (CSIRO-BOM 2015). Temperatures are expected to continue to rise in Torres Strait, increasing about 1ºC by 2030, 2.3 ºC by 2070 and >3 ºC by 2100 (CSIRO-BOM 2015).

5.2.2 Sea surface temperature

Late in the 21st century warming of the Wet Tropics coastal waters poses a significant threat to the marine environment through biological changes in marine species, including local abundance, community structure, and enhanced coral bleaching risk. Sea surface temperature is projected to increase in the range of 2.2 to 3.6 °C by the end of the century (RCP8.5; Table 2) (CSIRO-BOM 2015).

5.2.3 Rainfall

In the early 20th century the Wet Tropics of Australia experienced prolonged periods of extensive drying, but annual long-term rainfall shows no long-term trend between 1910-2013 (CSIRO-BOM 2015). Since 1998, despite a general increase in rainfall in northern Australia during the dry season, no changes in rainfall have occurred in Torres Strait. During the wet season, however, Torres Strait has experienced an increase in rainfall in the last 20 years (Commonwealth of Australia 2018).

Future rainfall predictions are highly variable. The high variability in rainfall predictions suggest that little change in mean annual rainfall is expected, but more variable and extreme rainfall events are expected to intensify (CSIRO-BOM 2015, NESP Earth Systems and Climate Change Hub 2018) (Table 2).

The high variability in rainfall projections means that fisheries models need to consider the risk of both increase and decrease in rainfall in the region (CSIRO-BOM 2015).

5.2.4 Extreme Climate Events

These are characterised as statistically rare or unusual climate periods that alter ecosystem function or structure outside normal variability (Smith 2011). In this sense, Torres Strait may be affected by temperature-related and cyclone-related extreme climate events.

Heat Waves

Climate change is likely to bring more hot days and warm spells to the Wet tropics region (CSIRO-BOM 2015). Extreme temperatures are expected to rise at the same pace as mean temperatures. In addition to an increase in mean temperature, changes in seasonal temperature patterns are also expected as well as an increase in the number of hot days (days with temperatures over 35°C) – which can triple in the region by the end of the century (CSIRO-BOM 2015).

Heavy rainfall

The intensity of extreme rainfall events is expected to increase despite the high uncertainty in future rainfall projections for the region. The magnitude of the increases therefore, cannot be confidently calculated (CSIRO-BOM 2015).

Cyclones

Tropical cyclones are projected to become less frequent, but the proportion of the most intense storms is projected to increase (CSIRO-BOM 2015).

5.2.5 Sea level rise

The dominant cause of sea level rise (SLR) since 1970 is Anthropogenic (IPCC 2019a). SLR is driven by a combination of a decrease in land-water storage, thermal expansion of the oceans, melting of glaciers and Greenland and Antarctic Ice sheets (Church et al. 2013, Clark et al. 2016). Global sea level has risen by over 0.20 m since 1880, and the rate has been accelerating in recent decades (IPCC 2019a). The rate of SLR is not uniform across the globe. For example, in Groote Eylandt in Northern Australia, the rate of sea level rise measured between 1993 and 2011 was 9mm/yr-^{1} (NTC 2011), which is consistent, but higher than global trends in accelerating sea levels since 1993 (3.2mm.yr-^{1} between 1993-2015) (Church and White 2006, 2011, IPCC 2019a). In Torres Strait, the rate of SLR is 6mm.yr^{-1} (1993-2010), twice the global average (Suppiah et al. 2010)

Predicting future sea level change is difficult because these drivers respond to climate change at different timescales, ranging from decades to centuries for glacier melting to centuries to millennia for thermal expansion and ice sheets (Clark et al. 2016). The speed of melting of ice has led to alterations in the Earth's gravitational field resulting in regional sea level fluctuations as the land rises with ice melts (Carlson et al. 2008, Church et al. 2013). Other factors that make future sea level projections complex are the effects of the dynamic variations of physical parameters in the water column associated with variations in wind change, changes in atmospheric pressure and oceanic circulation, and associated differences in water density and rates of thermal expansion on the relative sea level, resulting in large-scale temporal and spatial variability in of sea level (Zhang and Church 2012). Therefore, sea level rise depends not only on the complex ocean-atmosphere interactions and time-delays associated with these interactions, but also on the combination of past, present and future greenhouse gas emissions (Nauels et al. 2019). Despite all complexities in predicting future sea levels, confidence in sea level projections have been increasing (Church et al. 2013, IPCC 2019a).

By 2030, the projected range of sea-level rise for the Torres Strait region is 0.06 to 0.18 m above the 1986–2005 level, with only minor differences between emission scenarios (CSIRO-BOM 2015). Between 2031 and 2050, global mean sea level is expected to rise 0.2m (0.15-0.26m under high emission scenario RCP8.5) (IPCC 2019a, Kulp and Strauss 2019 and references within). Beyond 2050, uncertainty in model predictions increases substantially because of uncertainties in emission scenarios and Antarctic ice sheet responses (IPCC 2019a).

Predictions from AR5 suggest that by 2090 sea level will rise 0.40 to 0.87m (RCP8.5), with higher seas expected under certain circumstances (CSIRO-BOM 2015).However, under a high emission scenario (RCP8.5), sea level rise will be greater than in AR5 by 0.1m due to a larger contribution from the Antarctic Ice sheet (IPCC 2019a). In this recent IPCC report, global mean sea level by 2100 is expected to rise 0.84m (0.61-1.1m under high emission scenario RCP8.5) (IPCC 2019a). Sea level rise predictions for 2100 can diverge even more, with some authors estimating the range from 0.7-1m (RCP4.5) and 1-1.80m (RCP 8.5) (Kulp and Strauss 2019, and references within) and other authors proposing a sea level rise exceeding 2m at the end of the century when incorporating Antarctic and Greenland ice sheet melting (Foster and Rohling 2013, Steffen and Hughes 2013, Kopp et al. 2017, Le Bars et al. 2017).

5.2.6 Ocean acidification

Ocean acidification is the increase of partial pressure of CO_2 and associated decline in seawater pH (Enochs et al. 2016). Ocean acidification can affect organisms that secrete calcium carbonate as it decreases the concentration of carbonate ions (CO_3^{2-}) (Evenhuis et al. 2015). Impacts of ocean acidification on fisheries may be direct or indirect. There is already evidence that ocean acidification is directly impacting important fisheries through carapace dissolution (Bednaršek et al. 2020). However, contrary to what has been previously postulated, it has negligible effects on important behaviours of coral reef fishes (Clark et al. 2020a).

Indirect responses are associated with changes in habitats, for example through negative effects of acidification on coral skeletons. Several laboratory studies suggest that more acidified waters impair calcification and accelerate the dissolution of coral skeletons thus weakening coral skeletons, and triggering stress-response mechanisms, which affect the rates of tissue repair, feeding rate, reproduction, and early life-stage survival (Fabry et al. 2008, Kroeker et al. 2010, D'Angelo et al. 2012, Enochs et al. 2015). Possible responses of reef building corals to reduced calcification include a) decreased linear extension rate and skeletal density (Cooper et al. 2008), b) the maintenance of physical extension rate, but reduced skeletal density, leading to greater erosion (Szmant and Gassman 1990), and c) maintenance of linear extension and density but greater investment of energy diverting resources from other processes such as reproduction (Szmant and Gassman 1990, Albright and Mason 2013). By the end of the century the waters of Torres Strait are expected to become more acidic, with acidification proportional to emissions growth (CSIRO-BOM 2015).

6 Critical habitats and identified Impacts

Mangroves, seagrasses and coral reefs support the selected fisheries examined in this report. These three ecosystems are intrinsically connected and impacts on one of them will have consequences to the other two ecosystems (Guannel et al. 2016). In this section we describe each of these ecosystems, focusing in Torres Strait and looking at the fisheries they support, their spatial distribution, current status, impacts and trends.

6.1 Seagrasses

Seagrasses are highly dynamic, responding to a complex suite of physical environmental factors including tides, currents, turbidity, temperature, light, nutrient (N and P), salinity, exposure, and substrate availability that affect the quality and quantity of light reaching seagrass communities (Campbell et al. 2008, Rasheed et al. 2008, Collier et al. 2011, Griffiths et al. 2020). Both day length and maximum air temperature are positively correlated with the monthly seagrass standing crop (Rasheed et al. 2008). However, extreme temperatures and reduced light availability negatively affect photosynthesis, nutrient uptake, flowering and germination (Duarte 2002, Poloczanska et al. 2007). Decrease in salinity due to large flood events has been associated with a decline in seagrasses (Carruthers et al. 2002). Excessive nitrogen loading from terrestrial sources such as sewerage and agricultural run-off can inhibit seagrass growth and survival through direct physiological response and by stimulating growth of epiphytes, phytoplankton and macroalgae leading to reduction of light (Schaffelke et al. 2005, Sheppard et al. 2008) and nutrient fluxes to the seagrass leaf blades, reducing seagrass productivity, density and above- and below-ground biomass (Richardson 2006, Brodersen et al. 2015, Green et al. 2015).

Torres Strait extensive seagrass meadows represent about one quarter of Australia's seagrass area (Carter et al. 2018). These habitats are dynamic, varying seasonally and annually spreading from between 13,425 km^2 and 17,500 km^2 (Carter et al. 2014, Marsh et al. 2015).

Twelve seagrass species from 3 families occur in intertidal and subtidal meadows in Torres Strait (Carter et al. 2014). Seagrass flora include species that are highly adapted to high-light conditions (*Syringodium isoetifolium* and *Cymodocea serrulate*) and low-light conditions (*Halophila ovalis* and *H. decipiens* and *Halodule uninervis*) (Campbell et al. 2008). Species adapted to low-light conditions tend to be opportunistic, colonizing new substrate after disturbances, nutritious and less fibrous and preferred by marine herbivores such as dugongs and turtles (see Chapters 7.5 and 7.6). Taller species that are adapted to high-light conditions are unable to maintain biomass and survive in low-light conditions. These characteristics optimize survival of smaller species during periods of reduced light penetration (e.g. due to strong rainfall events associated with sediment and nutrient runoff) (Campbell et al. 2008), benefiting herbivores such as turtles and dugongs (Campbell et al. 2008).

Torres Strait seagrasses are influenced by sporadic environmental stress (strong currents, tidal exposure, extreme rainfall affecting salinity) and herbivory (e.g. dugongs and turtles) (Bridges et al. 1982). Their abundance seems to increase during the north-west monsoon, possibly a consequence of elevated nutrients, lower tidal exposure times, less wind, and higher air temperatures. Their abundance diminishes during the dry season, which coincides with the presence of greater winds and longer periods of exposure at low tides (Mellors et al. 2008).

Seagrass and algae dominate the epibenthos of Western Torres Strait and are commonly found in less than 10m deep in sandy substrate (Haywood et al. 2008). Regions containing high seagrass biomass include the Warrior Reefs, the eastern edge of the Dugong Sanctuary subtidal meadow, and reef top meadows and surrounding islands between Prince of Wales Island and Orman Reefs, while very little is known about seagrasses in the North of the Dugong Sanctuary, Prince of Wales Island to western Cape York, and Eastern Cape York and south east Torres Strait (Carter et al. 2014).

6.1.1 Key fisheries

- Dugongs
- Turtles
- Bêche-de-mer
- Prawns
- Tropical Rock Lobster

6.1.2 Total Area

13,425 km^2 - 17,500 km^2

6.1.3 Ecosystem services

Seagrasses provide the following key ecosystem services in Torres Strait (Carter et al. 2014):

1. Food for herbivores like dugongs and sea turtles
2. Cycling of nutrients
3. Stabilisation of sediments
4. Improving water quality
5. Marine carbon sinks
6. Provision of critical habitats and food sources for commercial and traditional fisheries in Torres Strait such as globally significant populations of green turtles (*Chelonya midas*), largest dugong (*Dugong dugon*) population in the world, bêche-de-mer, prawns and tropical rock lobster (Carter et al. 2014, Marsh et al. 2015, Carter et al. 2018).
7. Cultural and spiritual links
8. Food and income: Torres Strait Islanders rely on seagrasses as they support subsistence, commercial and traditional fisheries and income and have also strong cultural and spiritual links with them (Carter et al. 2018).

6.1.4 Current status and impacts

Torres Strait seagrasses are generally in very good condition (Carter et al. 2014, Marsh et al. 2015, Carter et al. 2018). Substantial diebacks of seagrasses have occurred in Torres Strait in the early 1970s, 1991-1992, and 1999-2000. The cause of the first dieback was never confirmed, but likely to be associated with overgrazing by an unusually large number of dugongs and green turtles (Marsh and Kwan 2008). The last two dieback episodes were associated with high turbidity and reduced light penetration resulting from increased rainfall and sediment runoff from rivers in Papua New Guinea coincident with an El Niño Southern Oscillation (ENSO) (Long et al. 1997, Marsh et al. 2004). Turbidity-related light stress and reduced salinity due to excessive rainfall and river flow has been identified as a major driver of seagrass habitat structure in northern Australia (Campbell et al. 2008, Carter et al. 2018). Such diebacks are believed to be natural (Marsh and Kwan 2008), known to have increased local dugong mortality (Marsh et al. 2004) and were also associated with dramatic declines in tropical rock lobster abundance in Torres Strait in 1991 and 1992 (Long et al. 1997).

Epiphytes benefit from increased nutrient inputs, which can negatively impact seagrasses. Nutrients also increase primary productivity and phytoplankton, thus reducing light availability with negative effects on seagrasses. In most cases, epiphytes do not seem to cause any harm to the seagrass host. However, increased nutrient enrichment can cause phytoplankton, macroalgae and epiphyte 'blooms', reducing light and nutrient fluxes to the seagrass leaf blades, reducing seagrass productivity, density and above- and below-ground biomass (Richardson 2006, Brodersen et al. 2015, Green et al. 2015). Threats to seagrasses in Torres Strait include ship-related oil spills and structural habitat damage, climate change and diebacks (Carter et al. 2018).

6.1.5 Climate change implications

Reduction in the extent of seagrasses meadows or diebacks are expected as temperature increases and sea level rises due to climate change. Sea level rise will increase coastal erosion and turbidity, which will negatively affect seagrasses due to reduction in light penetration. Increase in water depth may also open up new areas for seagrass colonisation, but the increased turbidity associated with coastal erosion can prevent seagrass expansion to new areas.

Seagrass loss is expected to adversely affect life history and reproductive rate of female dugongs, the effect of which cannot be separated from a possible density-dependent response to changes in dugong population size (Marsh and Kwan 2008).

Climate change effects such as increase in intensity of extreme rainfall events (see Chapter 5.2.4) will affect river discharge volumes. In the GBR, six consecutive very wet years 2007-2012 where annual discharges were ~65% higher than normal have negatively affected seagrass communities because the impacts of prolonged (multi-year) and associated continuous resuspended material within the coastal zone obliterates light penetration thereby shrinking seagrass meadow areas. The prolonged reduction in water clarity reduces the capacity of seagrass to build energy storage which negatively affects reproduction and seed production. With a healthy seedbank and adequate light seagrass meadows recovery time ranges from 1-2 years (dominated by *Halophila* spp.), however, recovery times are less predictable when seedbanks and adult populations are lost (Wooldridge 2017).

6.2 Mangroves

Mangroves are the most common vegetation community in the Torres Strait (Stanton et al. 2008). They cover an area of 26,054 ha (in 2014), represented by 35 mangrove species from 18 genera, 14 families, including 2 varieties and 2 hybrids (Duke et al. 2015). This is considered as 'high diversity for a numerically small plant habitat assemblage' (Duke et al. 2015). The description of mangroves presented below is based on Duke et al. (2015) unless otherwise stated.

Boigu, Saibai, Sassie, Zagai and Buru are the five predominantly 'mangrove' islands in Torres Strait, with dense and tall (>20 m height) mangrove forests, which have developed on shallow sandy substrate deposited on, and adjacent to, exposed coral reef flat, providing important habitat and breeding grounds for fish and mud crabs, shorebirds, bats, reptiles, Torres Strait Pigeon, Saltwater Crocodile and Turtles (Sassie Island – a mangrove Island– is the world's largest Hawksbill Turtle rookery).

Mangroves are influenced by wind, waves and tidal currents, type and size of sediments, nutrients, sedimentation, and chemical pollution. They are threatened by direct human impacts in Torres Strait including pollution (e.g. nutrients from sewage treatment plants and septic tanks and chemical leachate from poorly located refuse sites), urban development (land clearing to accommodate air strips and roads), mangrove cutting (for firewood, building material and traditional carving) and alteration of coastal zone hydrology. Other factors influencing mangroves in the region include feral animal, root burial, fire, vehicle damage, and sea level rise (Duke et al. 2015). They are also linked with Torres Strait Island culture and are a strong component of the Islanders identity.

6.2.1 Key fisheries

Mangroves sustain a variety of fisheries, such as crabs and a variety of fish species. However, no direct link has been found with the key fisheries investigated in this report, apart from Sassie Island (mangrove Island) being the world's largest Hawksbill Turtle rookery (Duke et al. 2015) and that king prawns may be more abundant in sparse seagrasses close to mangroves (Skilleter et al. 2005)

6.2.2 Total Area

26,054 ha

6.2.3 Ecosystem services

Mangroves provide the following ecosystem services to Torres Strait Islanders (Ewel et al. 1998, Shnukal 2004, Duke et al. 2015 and references within, Himes-Cornell et al. 2018):

1. Fish and wildlife habitats for commercial and traditional species (e.g. Hawksby turtles; prawns, crabs, fish)
2. Provision of food: Biyu sama are slimy balls of cooked mangrove seed-pod pulp, soaked and then cooked in an earth-oven to render it edible
3. Medicinal resources
4. Provision of raw material: timber to make tools, arts and crafts, for firewood and construction
5. Provision of water
6. Erosion control / Shoreline protection: including maintenance of soil fertility / nutrient cycling, moderation of extreme events, regulation of water flow, and trap sediments
7. Regulate air quality
8. Biological control
9. Climate regulation
10. Water quality improvement
11. Carbon storage
12. Support local and genetic biodiversity, coastal productivity and direct connectivity (fringing mangroves) with adjacent terrestrial habitats
13. Maintenance of life cycles of migratory species
14. Aesthetic information
15. Resting places on long sea voyages

16. Information for cognitive development
17. Spiritual experience
18. Opportunities for tourism and recreation

6.2.4 Current status and impacts

Duke et al. (2015) provides a useful summary of current status and impacts on Torres Strait mangroves and is used unless otherwise specified. Mangroves are subjected to high levels of stress (wind and wave activity) and are also very dynamic with some forests expanding (e.g. Erub and Iama Islands) and others retreating (e.g. Gebar Island). About 59% of mangroves in Torres Strait are considered 'healthy', while mean shoreline mangrove in 'poor condition' is 18%. The proportion of poor condition shoreline mangroves is relatively high given the minimal human environmental modification and influence.

Mangrove expansion likely reflects a recent drop in sea level during the 1980's and 1990's and has potentially been facilitated by elevated nutrient loads. Mangroves exposed to excessive nutrients are more susceptible to stem breakage, which reduce their ability to respond to natural wind and wave impacts, sea level rise, cyclones and storm surges, limiting their effectiveness in protecting coastlines because they become more likely to topple. Conversely, nutrient enrichment can assist mangrove accretion in response to elevated sea level and may also improve osmoregulatory function in some species increasing mangrove tolerance to increased salinity from greater tidal exposure.

Mangrove cutting is the most frequent human impact in Torres Strait, mostly for timber resources (firewood, building material and for carving). Mangroves are protected plants under State Fisheries Legislation (Section 54; Queensland Fisheries Act 1994) but in Torres Strait it is unclear whether they fall under similar traditional use exemptions as exists for turtles and dugong (Duke et al. 2015: 71).

Chemical leachate from waste disposal is likely entering mangrove habitat. Dauan Boigu, Saibai and Iama Islands have landfills in close proximity of mangroves and may be contaminated – albino propagules indicate contamination by heavy metals and hydrocarbons and were found in Saibai and Boigu Islands. Chemical leachate is likely to be affecting mangrove fauna and poses a localised threat to human health.

Only a small proportion of mangroves (<1%) are at risk from localized oil and fuel spills due to close proximity to boat loading facilities affecting (e.g. Mua Island). Major oil spills have occurred in the past (e.g. 'Oceanic Grandeur' oil spill in 1970) and have the potential to occur again in the region especially because of increased traffic since then. Of concern are the ecologically sensitive and important mangrove areas on Sassie and Zagai Islands and traditional and commercial fisheries that may be affected if a large oil spill occurs in Torres Strait.

Sea level rise may be exacerbating the effects of wind on shoreline mangrove forest, resulting in reduced resilience in Torres Strait (Duke et al. 2015). Mangroves are sensitive and respond rapidly to sea level variations. Sea level affects mangroves both directly (e.g. erosion and accretion of sediments) and indirectly (e.g. changes in salinity and frequency of inundation). Assumed sea level impacts were observed in all mangrove islands in Torres Strait, except Tudu. About 10% of mangroves were observed to be potentially impacted by sea level rise. Root burial may also be associated with sea level rise as transgressive coastlines may deposit sand within the mangrove forest smothering mangrove aerial roots, with the potential to cause death.

The construction of infrastructure (e.g. air strips, dams and roads) is a minor issue affecting mangroves in Torres Strait via the alteration of local hydrology. It restricts natural freshwater, overland, and tidal flow into mangrove channels, causing localised die-offs.

6.2.5 Climate change implications

Duke et al. (2015) found that mangroves have expanded in Torres Strait between 2008 and 2014 by 6% (average annual expansion rate of 2%). This is contrary to global measurements, which show declining mangrove areas on an average rate of 1% per year. Mangrove extension in Torres Strait seems to be associated with i) low level of direct anthropogenic pressure on mangrove habitats, and ii) a localised drop in sea level between 1987 and 1998, which helped establish new mangrove communities. Excess nutrients from sewage treatment plants may have caused a positive impact on the new established mangroves. Sea level rise that has been occurring at a fast rate since the late 1990s is likely to cause the retreat of the newly established mangroves in the coming years, despite localised mangrove expansion observed in some Islands (e.g. Erub and Iama).

The low topographic relief of these islands makes them highly susceptible to sea level rise and their future is uncertain. Mangrove resilience to climate change is dependent on maintaining healthy habitat such that the ecosystem can adequately and effectively respond to change (Duke et al. 2015).

Sea level rise in the Torres Strait may be exacerbating the effects of wind on shoreline mangrove forest, resulting in reduced resilience. Salinity is another important factor likely to be altered with climate change. Improving the understanding of salinity dynamics in mangroves will be important to monitor changes in mangroves low-lying islands (e.g. Boigu and Saibai)(Duke et al. 2015). Rising sea levels may increase mangrove vulnerability to strong winds during the monsoonal season through toppling. The expected increase in the incidence of heat waves (see chapter 5.2.4) may pose a threat to mangroves in Torres Strait.

6.3 Coral Reefs

In Torres Strait there are about 750 coral reefs (Harris et al. 2008) – with 684 reefs larger than 0.15 km^2 – covering an area of 3,972 km^2 (Lawrey and Stewart 2016). These reefs produce about 8.7 million tonnes of $CaCO_3$ per year, which are comparable to those reported at the GBR (Leon and Woodroffe 2013). Recent surveys have documented 275 coral species, of which approximately 75 are new records for the region. The reefs are in good to excellent condition with high coral cover, presence of the major taxonomic and functional groups and minimal incidence of coral disease (Bainbridge et al. 2015). They have the highest diversity of fungiid corals (mushroom corals) in the Eastern Coast of Australia (Hoeksema 2015). For both corals and reef fishes, the communities from central sites differed from those in eastern sites, reflecting a gradient in turbidity and wave exposure (Osborne et al. 2013).

Local morphology and spatial distribution of reef platforms are controlled by the strong tidal currents flowing through Torres Strait, shallow water depth and narrow dimensions of the shelf (Leon and Woodroffe 2013).

Coral reefs are intrinsically linked with mangroves and seagrasses. They form a mosaic of habitats which sustain fish productivity, supporting fishing industries and livelihoods. Healthy coral reefs interconnected with seagrass meadows and mangroves effectively protect the coastline against erosion (Moberg and Folke 1999, Guannel et al. 2016). In Torres Strait, the geological reef structures and hydrodynamic characteristics facilitate the deposition of soft sediments on reef tops and reef flats, often covered by seagrass; while reef edges and slopes are dominated by consolidated substrate and corals (Welch and Johnson 2013:27)

Coral reef distribution is limited by water temperature, pH, light, turbidity/sedimentation, salinity, and water depth (Aronson and Precht 2016), predation (e.g. the Crown-of-Thorns-Starfish (COTS) and *Drupella* spp.; both well-known corallivores (Berthe et al. 2016, Bruckner et al. 2017)), intra and inter-specific competition (e.g. competition between corals and algae, and between different coral species for space), reproductive and regenerative capacity, and their ability to cope with pollutants, nutrients and sediments (Rogers 1990, Kleypas et al. 1999, Guinotte et al. 2003). This means that alterations to any of these factors seriously threaten the existence of corals and their ability to build reefs.

Coral reefs around the world have been declining since the 1970s due to climatic and non-climatic factors. World-wide mass bleaching events are related to above average sea surface temperatures and heat waves (Obura and Mangubhai 2011, Lough 2012, Hughes et al. 2017). Loss of coral reefs is expected with rising sea surface temperatures, owing to interactions between warming, extreme events, ocean acidification, sea level rise and pollution (Barros and Field 2014, Babcock et al. 2019, IPCC 2019a, Lenton et al. 2019). Climate-related events cause mixed effects on coral reefs and adjacent ecosystems upon which corals interact (e.g. seagrasses and mangroves) (Hassenruck et al. 2015, Guannel et al. 2016, Albert et al. 2017), act synergistically with non-climate drivers further impacting reef corals (Wiedenmann et al. 2013, Chazottes et al. 2017, Wooldridge et al. 2017), and are expected to increase due to increased carbon dioxide (CO_2) emissions (causing ocean acidification) and consequent warming of the oceans (Gattuso et al. 2015).

Coral responses to climatic and non-climatic pressures are similar and include bleaching (expulsion of zooxanthellae that live in their tissue (Aronson and Precht 2016, Chazottes et al. 2017)), reproductive and growth impairments (Albright and Mason 2013, Sheridan et al. 2014, Fabricius et al. 2017), and coral-algal phase shifts (from coral-dominated to algae-dominated reefs) (Done 1992, Hughes et al. 2007). The end result of sustained stresses on corals is a simplification of coral community structure and reductions in live coral cover (Bruno and Selig 2007) and species coral trait diversity (Darling et al. 2013), with negative consequences for fisheries that depend on these ecosystems.

6.3.1 Key fisheries

- Bêche-de-mer
- Finfish (coral trout and Spanish mackerel (highly dependent on coral reefs for spawning and feeding)

- TRL
- Prawns
- Dugongs
- Turtles

6.3.2 Total Area

About 750 coral reefs (Harris et al. 2008), occupying an area of 3,972 km^2 (Lawrey and Stewart 2016).

6.3.3 Ecosystem services

Coral reefs provide the following ecosystem goods and services (Moberg and Folke 1999):

1. Provision of renewable resources such as Seafood, Pharmaceutical (anticancer, AIDS-inhibiting, antimicrobial, anti-inflammatory and anticoagulating), agar and carrageenan, manure, mother-of-pearls, souvenirs (red coral), marine aquarium market. Corals were used as bone graft operations. corals were used as bone graft operations.
2. Provision of building materials, production of lime, mortar and cement
3. Provision of physical structure services: protection of the shoreline, wave energy dissipation, creation of favourable conditions to the development of mangroves and seagrasses ecosystems, sediment generation
4. Biotic services: spawning, nursery, breeding and feeding areas for a multitude of organisms, maintenance of biological diversity, genetic library, keystone species that regulate ecosystem processes and functions, provision of species or group of species responsible to keep reef resilience
5. Biotic services between ecosystems: migration back and forth between adjacent ecosystems, such as mangroves and seagrass meadows
6. Biogeochemical services: Nitrogen fixation, carbon dioxide sinker, calcium precipitation
7. Information Services: long-term chemical recorder of temperature, metals, salinity and climate
8. Social/cultural services: recreation, aesthetic values, support of cultural and spiritual values

6.3.4 Current status and impacts

Despite the lack of long-term coral reef data (e.g. composition and abundance of coral species, bleaching, diseases), surveys have shown that Torres Strait reefs are in good to excellent condition (Bainbridge et al. 2015). Resurvey of sites have shown a decline in the abundance of temperature-sensitive corals (e.g. genus *Seriatopora*) (Osborne et al. 2013, Bainbridge et al. 2015).

Extensive coral bleaching was observed for the first time in Torres Strait in 2010 (Bainbridge et al. 2015) and subsequently in 2016 and 2020 (Hughes and Pratchett 2020). Bleaching, outbreaks of

COTS and coral diseases have been observed in the region and are considered the major threats to Torres Strait coral reefs (Osborne et al. 2013, Bainbridge et al. 2015, Hughes and Pratchett 2020).

6.3.5 Climate change implications

Simultaneous climate change drivers, such as sea-level rise, ocean warming, acidification, act together with local drivers (e.g. untreated sewage, chemical, sediment and nutrients runoff, oil pollution, overfishing) leading to interactive, complex and amplified impacts for species and ecosystems (Barros and Field 2014, Valmonte-Santos et al. 2016). For example, calcification rates are affected by both ocean pH and temperature. Current maximum calcification rates are just 2-3 ^{o}C below the maximum temperature corals can withstand before thermal bleaching (Evenhuis et al. 2015). When corals bleach, calcification is further supressed because photosynthetic products from the zooxanthellae are essential for the calcification process (Evenhuis et al. 2015).

Despite the evident negative effect of sea level rise (SLR) on coral reefs (Nurse et al. 2014), it may also provide some opportunities to corals (Saunders et al. 2016). Corals grow vertically and, in principle, additional depth provides extra 'accommodation space', in which corals could expand in intertidal areas and also colonise new inundated areas – provided that suitable substrate is available (Woodroffe and Webster 2014, van Woesik et al. 2015, Saunders et al. 2016) – thus increasing live coral cover (Albert et al. 2017). Some reefs can persist under SLR rates of around 4mm.yr^{-1} (commensurate with RCP 2.6 scenario) (Kench et al. 2018). However, it is unclear whether islands (including in Torres Strait) will continue to maintain their sizes under rising seas of 1.1+m by 2100 (RCP 8.5) (Kench et al. 2018, IPCC 2019a). Under such scenario it is more likely than not that rising seas will inundate coastal areas, destruct mangrove forests (see chapters 5 and 6) and further increase coastal erosion in a positive feedback loop (Barros and Field 2014, Kench et al. 2018), thus increasing turbidity and sedimentation in coastal waters and negatively affecting corals and other reef organisms (De'ath and Fabricius 2010, Brown et al. 2017a, Brown et al. 2017b).

There is high scientific confidence that anthropogenic-induced ocean warming is impacting coral reefs through thermal coral bleaching (Davies et al. 1997, Cumming et al. 2000, Rotmann 2001, Adjeroud et al. 2009, Obura and Mangubhai 2011, Kleypas et al. 2015). During bleaching events, corals stop growing and can die by starvation as it depends on photosynthetic products from an algal symbiont. Coral bleaching affects colony size (favours smaller size corals), the time of coral spawning (Paxton et al. 2016) and reduces coral calcification rates (De'ath et al. 2009, Nurse et al. 2014). Bleaching can also affect coral reproduction as it slows down swimming of coral larvae and reduces the number of viable recruits (Singh 2018), thus influencing mass coral spawning events over large geographical areas (Keith et al. 2016). Higher temperatures also lead to increase in bioerosion (Chaves-Fonnegra et al. 2017), and acts synergistically with nutrients and sediments amplifying bleaching effects and also influencing the recovery period from bleaching (Riegl et al. 2015).

Underwater heatwaves in the summers of 2015/2016 and 2016/17, as part of the longest global coral bleaching event on record, devastated coral reefs worldwide (Hughes et al. 2019). Widespread thermal coral bleaching occurred in the Torres Strait in 2009-2010 (Osborne et al. 2013, Bainbridge and Berkelmans 2014, Bainbridge et al. 2015). Coral loss in Torres Strait can have nuance but important negative consequences to reef fish. For example, it can lead to unstable energetic shifts (Morais et al. 2020), causing negative social-ecological consequences, such as decreased fish catches and coastal protection, and biodiversity loss (Adam et al. 2014). These consequences are very relevant to Torres Strait due to the reliance Islanders have on coastal and marine resources for cultural reasons, income and food (Busilacchi et al. 2013, Plaganyi et al. 2013b, McNamara et al. 2017, Johnson et al. 2018).

Ocean acidification can also negatively impact Torres Strait coral reefs. The most significant consequence of ocean acidification to corals is the decrease in the concentration of carbonate ions (CO_3^{2-}) which decreases calcification rates as coral skeletons are made of calcium carbonate (Pandolfi et al. 2011). Weaker reef systems will be far more susceptible to other pressures including bioerosion, eutrophication, coral disease, intense storms and bleaching because coral skeletons become more fragile (Meissner et al. 2012, van Hooidonk et al. 2014, Nuttall and Veitayaki 2015).

By 2100, Torres Strait coral reef fish and invertebrates communities will be highly vulnerable as they are likely to exceed their upper realised thermal limit (Stuart-Smith et al. 2015). Changes in circulation in Torres Strat (see Chapter 3.2 and also Johnson et al. (2018)) may also affect sediment transport and deposition processes, burying reefs and negatively affecting TRL habitats.

7 Key fisheries and identified impacts

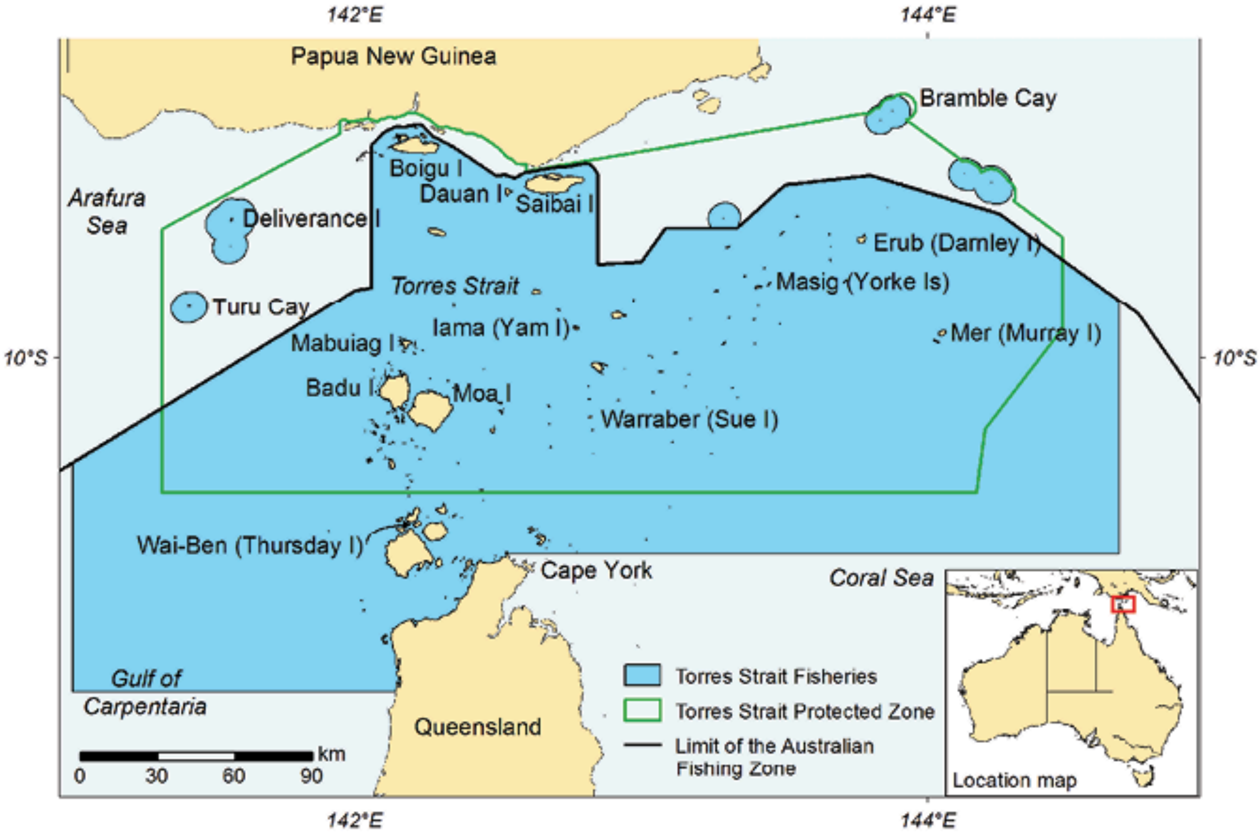

Figure 3 Area of the Torres Strait Fishery (from: Patterson et al. (2018))

7.1 Rock Lobster (*Panulirus ornatus*)

7.1.1 Description

Torres Strait Islanders and Papua and New Guineans have traditionally relied on the tropical rock lobster (TRL) *Panulirus ornatus* for subsistence and cultural uses, and it is currently the region's most economically important fishery. In general, palinurids show significant recruitment variability due to environmental factors, including currents, temperature, winds and moon phase (Plaganyi et al. 2018c). Lobsters are ecologically important in a range of marine habitats, playing a key role in mediating regime shifts, prey on benthic species such as sea urchins, and are prey of larger fish and sharks (see Plaganyi et al. 2018c and references therein).

The TRL fishery is comprised of three sectors; two in Australian waters and a third in PNG. In Australia, the two main Torres Strait fishing sectors are the Traditional Inhabitant Boat (TIB) licence holders, who typically conduct day trips harvesting lobster from dinghies only (van Putten et al. 2013b), and the Transferable Vessel (licence) Holders (TVH) sector consisting mostly of non-indigenous owned commercial vessels (a mother-ship with tenders/dinghies).

As TRL is a shared stock, within Australia it is managed by the Commonwealth. The same species is also fished to the south of Torres Strait, off Queensland's East Coast but is separately managed by the Queensland State Government.

Management recommendations for the past 31 years have been underpinned by scientific surveys of the lobster population and targeted ecological research (Ye et al. 2005, Dennis et al. 2015). The survey and stock assessment methods have been developed through consultation with traditional owners and their representative bodies, in addition to federal and state fisheries managers, independent scientists, non-indigenous fisher representatives and flow-on business stakeholders. Representatives from these groups, and particularly the Tropical Rock Lobster Resource Assessment Group (TRLRAG), have made significant contributions to the development of the fishery-independent surveys, commercial catch and effort monitoring and the integrated fishery model through consultative meetings.

Extensive tagging studies (~20,000 tags) were conducted in Torres Strait and Queensland waters and recaptures showed the 550 km breeding migration that starts in August and September, from Torres Strait to the eastern part of the Gulf of Papua, as well as clear separation of the Torres Strait and Queensland sub-populations (Moore and Macfarlane 1984, Skewes et al. 1997b, Dennis et al. 2001). As a result of the complex life-history comprising a 6 month larval life, the stock is naturally highly variable and the fishery focuses largely on a single 2 year old age-class only.

Recommended Biological Catch (RBC) needs to be set annually in such a way as to ensure biological and economic sustainability consistent with the principles of the Australian Commonwealth Harvest Strategy as well as the TRL fisheries and Protected Zone Joint Authority (PZJA) objectives. An annual pre-season survey of one-year old recruits is conducted as close to the start of the fishing season as possible (November) to inform on the likely biomass of the fishable cohort the next year. The recently implemented empirical (data-based) Harvest Control Rule (eHCR) uses catch, survey indices and CPUE (Catch-Per-Unit-Effort) as inputs (https://pzja.govcms.gov.au/sites/default/files/final_topical_rock_lobster_harvest_strategy_nov_2019.pdf).

7.1.2 Trends and current status

The stock assessment uses an Age Structured Production Model (ASPM) and is an integrated assessment that takes into account all available sources of information (Plaganyi et al. 2019a). The most recent stock assessment was conducted in 2019, and with the switch to use of an eHCR to produce an RBC, stock assessments will be conducted every three years. The stock is naturally highly variable but is considered to have been fluctuating about a high average mean throughout most of the stock's history, with the exception of a concerning downward trend in 2017 and 2018 that has been attributed to anomalous environmental factors (Plaganyi et al. 2019a). However, the 2018 and 2019 preseason surveys recorded high recruitment of 1+ lobsters, resulting in much higher TACs being set for 2019 and 2020.

The most recent stock assessment results indicate that the TRL spawning biomass $B(2019)^{sp}$ is approximately 93% of relative unfished biomass $B(1973)^{sp}$, which is well above the agreed target reference point of 65 per cent unfished biomass under the harvest strategy. The target reference point is relatively higher compared with other Australian fisheries and guidance under the Commonwealth Harvest Strategy Policy. This was deliberately designed to meet the objectives of the TRL fishery and protect the traditional way of life, and livelihoods of traditional inhabitants in Torres Strait. The model estimated a spawning stock biomass $B(2019)^{sp}$ of 4,467 tonnes.

Based on the eHCR, the 2019-20 season RBC is 582 tonnes. Most of the lobsters that are caught are exported live to China, but under travel restrictions imposed in repose to the 2019/2020 coronavirus outbreak, exports have ceased at the time of writing this report and the consequences on this year's fishery catch, economics and livelihood of dependent stakeholders are not currently known.

7.1.3 Value

Most lobsters are now caught live for export to China which has substantially increased the value of the fishery (Plagányi et al. 2017b). The average annual total catch from 2010 to 2019 was 632t. The gross value of production (GVP) of the Australian fishery (not including PNG) fluctuates annually due to the large variability in the stock, with annual estimates ranging from around $12.2 to $20 million.

7.1.4 Issues

Larval circulation models suggest that, depending on the Coral Sea gyre and local currents influencing the broader Coral Sea and Great Barrier Reef regions, some of the larvae may settle off Australia's north-east coast and, similarly, some of the larvae spawned by the East Coast *P. ornatus* component may be advected into Torres Strait due to the predominant northerly direction of the current (Plagányi et al. 2018, Plagányi et al. 2019). The complexity of the oceanographic processes in combination with diverse life histories makes predictions of changes in recruitment success as a function of large-scale oceanographic changes difficult. Using 23 years of continuous survey and climate data, Plaganyi et al. (2019) found no clear relationship between population size and the predictions of the CONNIE3 oceanographic model. However, the BRAN model used is a global model with a daily time step so it does not adequately capture the complex dynamics of the tides in the Torres Strait (http://www.bom.gov.au/australia/tides/about/p4b-torres-strait.shtml) which may influence larval advection in this area. CONNIE3 uses archived currents from oceanographic models and particle tracking techniques to resolve spatial displacement of particles and estimate connectivity statistics from user-specified source regions (or to user-specified sink regions). A range of physical and biological behaviours can be specified including vertical migration, horizontal propulsion or swimming (user-specified random or constant velocity). But the model used cannot be considered reliable in terms of predictions of the exact final distribution of larvae in Torres Strait itself because the model does not resolve tides. Finer resolution oceanographic models are therefore needed to establish relationships between oceanographic processes and recruitment, as a basis for projected changes due to future changes in currents and tides.

Growth in all life history stages (larval, juvenile and adults) have been assessed (Norman-Lopez et al. 2013) as being at high risk due principally to a likely increase in sea temperatures. This effect was assessed as being mostly positive based on experimental studies demonstrating the enhancement of growth by warmer sea surface temperatures up to 30^{o}C (Dennis et al. 1997, Skewes et al. 1997a). Medium risks contained both positive and negative effects. Positive effects were associated with an increase in larval growth due to projected increases in primary production in the Coral Sea (Brown et al. 2010), and faster adult growth and bigger lobsters resulting in an increase in adult reproduction. Negative effects were associated with increased larval and juvenile mortality related to higher sea surface temperatures and detrimental effects on the juvenile lobsters' seagrass habitats. Norman-Lopez et al. (2013) also highlighted that climatic changes to rock lobster catches will have a direct effect on the employment and income (wages and profits) of Islanders (TIB) and non-Islander fishers (TVH), and in turn have a flow on effect to other sectors through changes in demand from these two fishing groups.

More recently, TRL projections to 2050 were run using the same decadal climate projections as the project 'Decadal scale projection of changes in Australian fisheries stocks under climate change.' The projections are available from the CSIRO decadal forecasting project (Matear and Zhang), with international models accessed from the CMIP5 archive. The March 2017 TRL stock assessment model was refitted by linking with climate data available from 1992, and model results suggest strong support for the hypotheses that growth and survival of lobsters are affected by changes in SST (Plagányi et al. 2018). The parameters of the latter functional form were estimated in the model, and used to forward project the lobster spawning biomass to 2050. The model estimated small changes only in lobster mortality over the temperature range 25-29°C, but a fairly steep increase in mortality as SST increased above the likely optimum SST of 29°C. Overall, in the short to medium-term, the TRL spawning biomass is predicted to remain roughly at current levels, with large inter-annual fluctuations as observed in the past, but a decrease is predicted in the longer term (Plagányi et al. 2018). The model fit improved substantially when introducing the hypothesized relationships between SST and growth and mortality, suggesting that changes in SST may already have been influencing TRL dynamics over the recent past, and also that the hypothesized relationships are consistent with available data to date. The model estimated a fairly steep increase in mortality as SST increased above the likely optimum SST of 29°C, although the model relationship was estimated using data up to a maximum of 32°C whereas future SST is predicted to increase to approximately 34°C by the end of the century, and hence is outside the range of current observations (meaning extrapolations are less certain).

However ongoing work will continue to refine these projections. These modelling results incorporate first order effects only, and more work is needed to account for more complex impacts of climate change shifting temperature beyond the thermal envelope for TRL, including moult frequency and increment, timing of larval release and potential mismatch with optimal food conditions and circulation patterns.

Torres Strait waters are expected to increase in acidity in future, with acidification proportional to emissions growth (CSIRO-BOM 2015). Although the exact effects on TRL are not known at present, ocean acidification is considered an important threat to marine species, including crustaceans (Keppel et al. 2012, Green et al. 2014). Negative impacts on lobsters and other crustaceans are increasingly being documented (Whiteley 2011, Agnalt et al. 2013, Bednaršek et al. 2020). A recent study (Bednaršek et al. 2020) demonstrated conclusively using an *in situ* study that increasing ocean acidity is impacting the shells of crab larvae, making them more vulnerable to predation as well as weakening support structures for muscles and possibly leading to loss of important sensory and behavioural functions.

Biophysical understanding is essential for planning responses to climate change but this is not sufficient as the full range of opportunities and threats that will confront fisheries are not limited to biophysical changes at the production phase of fisheries (Hobday et al. 2015). Consideration of the impacts of climate change along seafood supply chains, the steps a product takes from capture to consumer, is thus vital to ensuring the ongoing supply of seafood (Hobday et al. 2015). A quantitative metric for comparing key features and critical elements in wild fisheries and aquaculture supply chains under a changing climate was developed by Plagányi et al. (2014), and applied to case studies including TRL. The Supply Chain Index (SCI) identifies critical elements as those elements with large throughput rates, as well as greater connectivity. Identification of key elements along the supply chain may assist in informing adaptation strategies to reduce anticipated future risks posed by climate change. The SCI identified airports, processors and Chinese consumers as the key elements in lobster supply chains that merit attention to enhance stability and potentially enable growth. For TRL, the SCI identified the Chinese and U.S. markets as key elements, suggesting that the key mechanism for stabilising this supply chain is to reduce uncertainty in supplying these markets. This study underscored that maintaining and strengthening relationships with international markets may thus be key to underpinning the success of this supply chain.

7.1.5 Opportunities

Some environmental factors (eg. temperature) and habitats (eg. hard substrate) have obvious influences on lobster growth and survival and for this reason concurrent qualitative seabed habitat monitoring has been conducted during all lobster population surveys completed since 1989. Data from these surveys have provided insights into the major influencing factors; such as the 1991-1993 seagrass dieback event which impacted the lobster population in north-west Torres Strait (Dennis et al. 2013). However, these data are only collected once or twice a year and the seasonal dynamics of any environmental change are not measured. Since 1994 the habitat monitoring protocol was refined to include a standard set of abiotic and biotic categories so that inter-annual comparisons were consistent.

As an example, fishers operating on the deep Kircaldie fishing grounds have reported the strong influence of shell beds on lobster abundance through aggregation. Hence, the incorporation of influential environmental variables has potential implications for improved management of the TRL stock and improved forecasting of stock abundance for fishers. But the Dennis et al. (2013) and Plaganyi et al. (2018) studies found no strong relationships between the environmental variables recorded and lobster abundance, although percent consolidated rubble and seagrass cover were weakly correlated and more dramatic increases or declines in these variables would impact the lobster population. Likewise, more dramatic increases in water temperature, as forecast due to climate change may influence lobster growth and survival (see for example Norman-Lopez et al. (2013)) and there is evidence from recent anomalously high temperatures that this can impact lobster natural survival rates, capture, and handling mortalities (particularly because of the reduction in available oxygen as water temperatures increase) (Plagányi et al. 2018, Plagányi et al. 2019).

Based on results to date, none of the environmental variables recorded in the survey could be used as covariates in the integrated fishery model to significantly improve the precision of the lobster stock forecasts. This result is perhaps not surprising given that although variable, the densities of recruiting (1+) and fished (2+) lobsters have not trended up or down over long periods during 1989 to at least 2017. Further, the Torres Strait fishery is managed at quite conservative levels thereby eliminating the possibility of cascading effects (as documented in many temperate fisheries due to the lobster/urchin/kelp inter-dependence). Further, in contrast to the relatively simple trophic inter-actions documented in the temperate lobster fisheries it is likely that a multitude of complex environmental factors influence the Torres Strait tropical rock lobster population. The diet of *P. ornatus* for example is broad and opportunistic and lobsters would be capable of compensating for a decline in one component by selecting another. Nevertheless, the observed influence of seasonal shell beds (at least in attracting and aggregating lobsters) and the cause of their seasonal abundance deserve further study. In the past few years anomalously high temperatures have had impacts on the stock and ongoing monitoring will be valuable for future forecasting of impacts on the lobster population.

Changing environmental drivers may also have substantial impacts on the availability of stocks to fishers (and indeed may bias survey results too), such that improved understanding of these complex relationships could assist in improving the stock assessments and methods used to support the sustainable management.

7.2 Prawns

7.2.1 Description

Brown tiger, blue-tailed endeavour and red-spot king prawns are abundant in the Torres Strait region (2009-2018 average annual catch for each species was 338, 98 and 7 t, respectively; average 1960 days fished) (Turnbull and Cocking 2019). However, the ratio of species in the catch and hours fished have changed significantly since the 1990s and early 2000s (1991-2003 average annual catch of the three species was 668, 1044 and 70t, respectively; average 9,699 days fished). The prawns are fished in the inter-reef lagoon, east of the Warrior Reefs in the eastern region of Torres Strait; but west of the myriad of reefs and coral cays and terrigenous islands further east (Watson and Turnbull 1993). Their juvenile phase migrate from the shallow reef-top habitats associated with the Warrior Reefs; both from west and east of the reefs to deeper waters where they are fished (Watson and Turnbull 1993). The nursery source of juvenile king prawns is less well known. The CPUE of endeavour prawns declined significantly over 2005-18, while that of tiger prawns has remained steady, and increased markedly from the 1990s (Turnbull and Cocking 2019).

The Torres Strait Prawn Fishery is an industrial fishery undertaken from mechanised trawlers (~15-20 m length) with significant freezer capacity. They are self-contained for weeks of operation at sea and are serviced by a mothership from Cairns, Queensland. The Torres Strait Protected Zone Joint Authority limits vessel licences to 61. Licences can only be granted to Australian citizens. Fishing capacity is defined by units, which equal boat-days available to be fished (9200 Units). The units are divided as 6,867 Australian Units and 2,333 Papua New Guinea Units.

A feature of all commercial penaeid prawns is ontogenetic habitat shift during their life history (Dall et al. 1990); the juvenile phase inhabits littoral substrates within a range of micro-habitats, the adult phase inhabits shallow coastal water ~10-50 m deep. In Torres Strait, commercial prawn juveniles inhabit shallow reef-top seagrass communities (Blyth et al. 1990, Turnbull and Mellors 1990). The dependence of their juvenile-phase on littoral seagrass habitats renders the prawns vulnerable to Climate Change; particularly as their seagrass community habitats are vulnerable to direct and indirect climate impacts (Duarte 2002, Poloczanska et al. 2007) (see also Chapter 6.1).

Tiger and endeavour prawns are dependent on the refuge structure of seagrass shoots and leaves, which provide them shelter from predators, food, and an ameliorated physical environment (Kenyon et al. 1995, Haywood et al. 1998, Loneragan et al. 1998). Juvenile tiger prawns benefit from large, broad-leaved seagrasses which provide camouflage structures on which to hide and avoid silhouette and capture (Kenyon et al. 1995). The prawn's small, post-settlement stage does not bury to avoid predation; small juveniles are pigmented for camouflage against seagrass leaves (large juveniles and adults do bury)(Wassenberg and Hill 1994, Kenyon et al. 1995). Large juvenile tiger and endeavour prawns and the adult phase bury to avoid predation (Park and Loneragan 1999). In 1999 in Exmouth Gulf, Western Australia, cyclonic disturbance removed the majority of the shallow-inshore seagrass community and created a natural experiment to show the dependence of the tiger prawn population on their inshore seagrass nursery habitats. The loss of the seagrass nurseries deprived the benthic juveniles of critical refuge and forage habitat. Fishery catch declined markedly in 2000 (82 tonnes, down from 450 tonnes in 1999) as a consequence of failure of the juvenile phase due to inshore habitat loss, despite a strong spawning index and likely abundant pelagic larvae the previous year (Loneragan et al. 2013). Over the next three years, the shallow, inshore seagrass community re-established. As the habitat components recolonised the disturbed sediments, the juvenile tiger prawn critical seagrass habitat, the juvenile prawn population, the adult population's recruitment index, and the tiger prawn fishery catch (~200 to 600 tonnes, 2001 to 2006) re-established to pre-cyclonic levels, demonstrating a clear dependency of tiger prawns on seagrass habitat.

Juvenile king prawns inhabit bare substrates and seagrass communities; particularly short, thin-leaved seagrasses, and their distribution preference among bare vs vegetated habitats varies during the day verses the night (Young 1978, Tanner and Deakin 2001, Ochwada-Doyle et al. 2011). Small juvenile king prawns are transparent with speckles, camouflage to be 'invisible' and mimic sand grains on un-vegetated substrates. They bury as small juveniles to avoid predators (Tanner and Deakin 2001) and so vegetated habitats are not critical to them. Although a preference for bare or sparsely vegetated habitats is not consistent in all localities. In Moreton Bay, Skilleter et al. (2005) found eastern king prawns more abundant on dense seagrass than sparse, and sparse seagrass close to mangroves; so microhabitat interactions that affect local density distributions can occur. King prawns can use both bare substrates and (possibly sparse) seagrass habitats and the natural cyclone-induced experiment in Exmouth Gulf (described by Loneragan et al. 2013) did not reduce their local catch immediately after cyclonic disturbances (see Kangas et al. (2015)). Despite inshore seagrass nursery habitats being removed, king prawn catch and hence their population did not decline, demonstrating that their juvenile phase was not critically dependent on vegetated littoral nursery habitat.

In Torres Strait, juvenile tiger and endeavour prawns were found among the seagrass community on the reef-tops of the Warrior Reefs and the York Island reef (Turnbull and Mellors 1990, Turnbull and Watson 1990). Fewer tiger prawns were collected from the sparse seagrass at Yorke Island than the dense seagrasses at Warrior Reef (see Turnbull and Mellors 1990), a carrying-capacity relationship between sparse and dense seagrass identified elsewhere in Australia's tropical coasts (Loneragan et al. 1998).

Information on the habitats of juvenile king prawns is more difficult to determine in Torres Strait. However, Turnbull and Watson (1990) conducted comparisons of beam trawls catch efficiency on both the Warrior Reefs and Yorke Island seagrass communities. Catches from the dense seagrass habitats at Warrior Reefs were comprised of tiger, endeavour and greasyback prawns. In contrast, catches at Yorke Island were comprised of tiger, endeavour and red-spot king prawns. The presence of king prawns at Yorke Island matches the presence of bare substrate or sparse seagrass habitats on the Atoll's reef-top (their Site 111), benthic habitats as reported by Turnbull and Mellors (1990).

7.2.2 Trends and current status

Since 2010, the annual landings of prawns from the Torres Strait fishery have been mostly ≤500 t and comprised of a majority (70-80%) tiger prawns (Turnbull and Cocking 2019). Over the same period, fishing effort has ranged from about 1,000 to 3,000 boat-days a year. By both of these measures, the Torres Strait fishery has recently operated at much reduced levels compared to the 1990–2010 period. From 1990 to 2010, prawn landings were often in the range of 1,500 – 2,000t and the proportion of tiger prawns was 40-50%; the remainder of the catch dominated by endeavour prawns. From 1990 to 2000, annual fishing effort reached 10,000 to 12,000 boat days and was regularly > 6,000 boat days. Fishing effort declined steadily from 2000 to 2010. Since 2010, landings of king prawn were negligible compared to the period 1990-2000. The Torres Strait Prawn Fishery is managed by Total Allowable Effort (TAE), though the effort levels set for 2016-2018 (9200 boat days) were roughly three times actual effort (https://www.pzja.gov.au/the-fisheries/torres-strait-prawn-fishery). The fishery operates under a Management Plan (2009) and a Harvest Strategy (2011) (available from the Torres Strait Protected Zone Joint Authority website; see https://www.pzja.gov.au).

7.2.3 Value

The Torres Strait Prawn Fishery was valued at $4.6 million in 2017-18 (278 t) (Patterson et al. 2018).

7.2.4 Issues

If Torres Strait seagrass communities are impacted by climate change, then the dependence of the juvenile stage of Torres Strait commercial prawns on littoral seagrass habitats exposes them to critical habitat loss. A summary of climate change impacts on prawns is presented in Table 3. Temperature extremes, both air temperature and SST, are likely to affect shallow littoral habitats in Torres Strait by 2030. A surface air temperature increase between 0.5 and 1.5^{o}C, and a sea surface temperature (SST) increase by 1.0^{o}C under emission scenario RCP8.5 are predicted (CSIRO-BOM 2015). By the end of the century, SST increases are predicted in the range of 2.2 to 3.6°C under a high emissions scenario (RCP8.5).

Seagrass growth and survival is influenced by temperature, light, nutrient (N and P), salinity, and substrate availability. Thermal optimum temperature for seagrass ranges from 15 to 33^{o}C (Collier et al. 2011) and SST in Torres Strait reached 30-32 ^{o}C in 2019. By 2090, SST may exceed the upper thermal tolerance of seagrass communities. Extreme temperatures affect photosynthesis, nutrient uptake, flowering and germination in seagrasses (Duarte 2002, Poloczanska et al. 2007). Moreover, regional air-temperature heatwaves and marine heatwaves will elevate shallow sea temperatures for short periods (Frolicher et al. 2018) and cause seagrass community to decline.

In addition, extreme rainfall events are predicted to increase in frequency in the Australian tropics (see Chapter 5.2.4). Decreases in salinity due to large local flood events have been associated with a decline in seagrasses. Hence, the exposure of local reef-top seagrass communities to freshwater pulsed runoff is likely and seagrass community decline is a likely consequence (Carruthers et al. 2002). By 2100, global sea levels are predicted to increase by 1.1m (IPCC 2019a) with subsequent impacts on the average depths of coral reefs that support the seagrass communities; and limiting the light penetration to the then deeper seagrass communities. In addition, cyclones are expected to increase in intensity, which have the capacity to uproot and destroy seagrass communities (Poiner et al. 1993), and hence the juvenile habitats of tiger and endeavour prawns.

The bare-substrate habitats of juvenile king prawns might expand in extent due to the loss of seagrass extent. Greater areas of bare substrate may benefit the juvenile king prawn population in Torres Strait. Cyclonic impact on the prawn community in Exmouth Gulf Western Australia provides a natural 'experiment' to illustrate these benefits (Loneragan et al. 2013). In March 1999 the category 5 Cyclone 'Vance' bisected Exmouth Gulf and removed seagrass habitats that were prolific on the eastern shallows of the Gulf. Prior to 1999, the tiger prawn:king prawn ratio in Exmouth Gulf was 50:50. In 1999, the tiger prawn population remained strong as the 1998/99 juvenile recruitment and inshore growth had occurred prior to cyclonic impact. However, the March 1999 cyclone disturbed the littoral habitats of Exmouth Gulf and by the 1999/2000 juvenile recruitment time window (October to March), their critical seagrass habitats were non-existent (Loneragan et al. 2013). The 2000 and 2001 commercial prawn catches were dominated by king prawns (Kangas et al. 2015) as they had taken advantage of the extensive bare substrates exposed by cyclonic impact (tiger prawn:king prawn ratio was roughly 20:80 in 2000). Over subsequent years, the seagrass habitats re-established in extent, and as they did the population of tiger prawns re-established. By 2005, the tiger prawn:king prawn proportions of the community had returned to similar proportions to what it was in 1995. Hence, if littoral seagrass extent in Torres Strait was to decline, king prawns may benefit and be reflected as increased catches taken over those years.

In addition to the impact of marine heatwaves on the seagrass habitats of commercial prawns, marine heatwaves may impact the postlarval and juvenile phase of the prawns directly. The temperature of shallow sub-littoral waters may exceed the thermal tolerance of pelagic prawn larvae and postlarvae, impeding their development. As the prawns develop to their benthic juvenile phase, they immigrate to shallow nursery habitats and settle from the plankton. Among shallow reef-top seagrass habitats, their exposure to local temperature spikes would continue. Both marine and atmospheric heatwaves are expected to increase in frequency and duration (Coumou and Robinson 2013, Frolicher et al. 2018); the temperature of shallow-water recruitment habitats of juvenile prawns will spike as air temperature spikes. Shallow water temperatures above 40°C would exceed the thermal tolerance of juvenile prawns (Obrien 1994). Torres Strait reef-top waters and shallow inter-reef waters are candidates for localised elevated SST and prawn physiological stress. In 2015 and 2016, shallow water temperatures above 40°C were recorded within *Enhalus acoroides* seagrass beds within the Embley River estuary, Cape York; relatively close by Torres Strait (Skye McKenna, Michael Rasheed; Port of Weipa long-term seagrass monitoring program - 2017, pers. comm.)

A second facet of climate change that may directly impact on the prawn community of Torres Strait would be physiological stress on the larval and juvenile stage of their life histories due to ocean acidity associated with increasing levels of dissolved CO_2. Planktonic prawn larvae feed on phytoplankton and zooplankton and the calcification of the calcareous skeletons of plankton will be impaired interrupting planktonic prawn larval growth under increasingly acidic oceans (Poloczanska et al. 2007). In tank experiments, reduced growth of the larvae of the shrimp *Pandalus borealis* has been measured (Bechmann et al. 2011). In addition, ocean acidification may affect the development of the exoskeleton of juvenile commercial prawns. To date, the characterisation of possible impacts on a prawn's chitinous exoskeleton remains under investigation. Carapace dissolution of crustaceans have been recorded in the West coast of the United States (Bednaršek et al. 2020). However, the exoskeleton of shrimp is dominated by chitin with calcium carbonate impregnation of the chitinous matrix (Taylor et al. 2015). Experimentation reducing seawater pH has shown that calcification increases within the exoskeleton of caridean shrimp in the short term (21 days), but with no effect on moult or growth (Taylor et al. 2015). Body translucency is reduced, which may affect the shrimp's ability to remain cryptic in natural habitat. Changes in circulation in Torres Strait may affect prawn larvae dispersion (Johnson et al. 2018).

Table 3. Observed and expected effects of climate change on prawns.

FISHERY	PHYSICAL DRIVER	CLIMATE CHANGE EFFECT	ECOLOGICAL EFFECT	INDIRECT EFFECTS	FISHERY EFFECT	NOTES	SOURCE
Tiger and endeavour prawns	Sea Temperature	Increase in SST	Extreme temperatures affect photosynthesis, nutrient uptake, flowering and germination in seagrasses	Habitat loss for seagrass-dependent prawns such as tiger and endeavour prawns. Possible increase in habitat for King prawns as they are less dependent on vegetation as juvenile habitat.	Reduction in catch: prawn mortality due to habitat loss/ loss of structured habitat protection from predation; loss of foraging habitat. Tiger and endeavour prawns are a majority of the Torres Strait catch. King prawn catch may be sustained.	Thermal optimum temperature – for seagrass range from 15 to 33°C (Collier et al. 2011)	(Duarte 2002, Poloczanska et al. 2007) Expert opinion http\\www.climatechangeinaustralia.gov.au
Tiger and endeavour prawns	Temperature – marine heat waves (MHW)	High temperature water mass (+2.5°C) moves over Torres Strait	Extreme temperatures affect photosynthesis, nutrient uptake, flowering and germination in seagrasses Seagrass loss – water temperature above seagrass upper thermal tolerance; loss of dynamic ecosystem	Habitat loss for seagrass-dependent prawns such as tiger and endeavour prawns.	Reduction in fishery catch: prawn mortality due to habitat loss/ loss of structured habitat protection from predation; loss of foraging habitat. Catch may be modified depending on the seasonality of MHW impact and regeneration of seagrass.	Marine heatwave impacts evident in Australia.	(Carruthers et al. 2002)
Tiger and endeavour prawns	Air Temperature	Increase in air temperature; exposure of	Extreme temperatures in shallow littoral and tidally-	Habitat loss for seagrass-dependent prawns such as	Reduction in catch: prawn mortality due to habitat loss/ loss	Thermal optimum temperature – for seagrass range from 15 to 33°C	(Duarte 2002, Poloczans

		shallow littoral waters to localised increased temperature and insolation.	exposed seagrass habitats caused elevated air temperature and solar radiation - affects photosynthesis, nutrient uptake, flowering and germination in seagrasses; seagrass mortality	tiger and endeavour prawns. Prawn mortality due to habitat loss.	of structured habitat protection from predation; loss of foraging habitat	(Collier et al. 2011)	ka et al. 2007) Expert opinion http\\www.climatechangeinaustralia.gov.au
King prawns	Sea and air temperature	Increase in sea surface temperature.	Extreme temperatures affect photosynthesis, nutrient uptake, flowering and germination in seagrasses	Possible increase in habitat for King prawns as they are less dependent on vegetation as juvenile habitat.	Sustained king prawn catch perhaps an increase in cath. However, king prawns comprise a small proportion of the catch, so population increase due to habitat would have to be large to be material for fishery catch.	Based on habitat suitability models for Northern Australia	(Carruthers et al. 2002).
Tiger prawns	Ocean acidity	Increase in Ocean acidity due to increased carbon dioxide in solution	Interrupted calcification of phytoplankton and zooplankton – the food of prawn larvae food	Reduction in the quanta of food resources for prawn larvae	Reduction in prawn catch: prawn larval mortality – reduction in postlarval recruitment to juvenile nursery habitats	Based on global oceanographic predictions	(Duarte 2002, Poloczanska et al. 2007) Expert opinion
Tiger prawns	Extreme rainfall events	Decrease in salinity and sedimentation due to large flood events (possibly from Fly River in PNG; Increase in sedimentation and turbidity due to local flood events causing erosion and sediment transport/deposition	Decline in seagrasses abundance and extent due to turbidity; local scale juvenile prawn population loss	Increased turbidity reduces light penetration and photosynthesis. Turbidity impacts seagrass epifloral and fauna.	Reduction in local prawn catch: local juvenile prawn population depletion	Based on climate impact projections for Northern Australia	(Carruthers et al. 2002) http\\www.climatechangeinaustralia.gov.au Expert opinion
Tiger prawns	Sea level rise	Inundation and erosion of coasts increasing sediment transport and deposition; deeper waters over	Deeper reef-top habitats; increase in turbidity; reduction in light penetration and hence the ability of seagrass to photosynthesise.	Habitat loss for seagrass-dependent prawns such as tiger and endeavour prawns.	Reduction in catch: prawn mortality due to habitat loss/ loss of structured habitat protection from predation; loss	Based on climate models and habitat impact models for Northern Australia	(Duarte 2002, Poloczanska et al. 2007) Expert opinion

		reefs and littoral habitats			of foraging habitat.		http\\www.climatechangeinaustralia.gov.au
Tiger prawns	Increase in the frequency of intense cyclones	Inundation and coastal erosion due to cyclone storm surge, Removal of seagrass habitat due to mechanical erosion during cyclonic activity;	Loss of seagrass habitat due to mechanical wave impacts; increase in smothering and turbidity which reduces light penetration and hence photosynthesis.	Habitat loss for seagrass-dependent prawns such as tiger and endeavour prawns.	Reduction in tiger prawn catch; Prawn mortality due to habitat loss/ loss of structured habitat protection from predation; loss of foraging habitat.	Based on climate models for Northern Australia	(Carruthers et al. 2002) http\\www.climatechangeinaustralia.gov.au

7.2.5 Opportunities

As seagrasses photosynthesize, an increase in atmospheric CO_2 may increase community productivity and depth limits. Increased seagrass community productivity may benefit juvenile tiger and endeavour prawns as their habitat potentially could support higher abundances of meiofauna and macrofauna (Poloczanska et al. 2007). However, seagrass communities would be subject to many other stressors associated with climate change (see Chapter 6.1 and also Carruthers et al. (2002)).

If juvenile prawn seagrass nursery habitats declined under a warmer climate, the greater areas of bare shallow substrates that resulted may benefit the juvenile king prawn population in Torres Strait. Greater habitat extent may enhance the abundance of king prawns in the fishery. However, all shallow-water habitats would be subject to extreme events such as marine heatwaves, cyclonic impacts, and extreme rainfall/runoff events.

7.3 Finfish

7.3.1 Description

There are two main finfish fisheries that operate in the eastern Torres Strait: the Torres Strait Reef Line Fishery (TSRLF) and the Torres Strait Spanish Mackerel Fishery (TSSMF) with two commercial sectors participating in the fishery: the Traditional Inhabitant Boat (TIB) and non-TIB sectors (Williams et al. 2020). Coral trout (*Plectropomus* spp.) are the main target species for commercial fishers in the TSRLF. The four species of coral trout harvested in the TSRLF (*Plectropomus leopardus*, *P. maculatus*, *P. areolatus* and *P. laevis*) are currently managed as a single species in Torres Strait, as catch records reported by fishers do not require the catch of individual coral trout species to be recorded. A large number of other reef fish species (see Welch and Johnson (2013) and Williams et al. (2008) are also harvested in the TSRLF. Spanish mackerel (*Scomberomorus commerson*) is the primary target species in the TSSMF fishery, although other mackerel species are occasionally captured. Commercial fishing occurs mostly on the north-eastern side of Torres Strait with a large area to the west currently closed (Williams et al. 2020) (Figure 4).

Fishing methods mostly involves trolling from small boats tendered to larger vessels in the case of Spanish mackerel. Hook-and-line is the predominate method to target species in the TSRLF with common coral trout making up more than 90% of the retained commercial catches (by weight) for both TIB and non-TIB sectors (Williams et al. 2020).

Fishing effort (and catches) has decreased from peaks in the early 2000s due to diverse factors such as the voluntary surrender of Transferable Vessel Holder (TVH) licences and structural adjustments in the fishery (Williams et al. 2020).

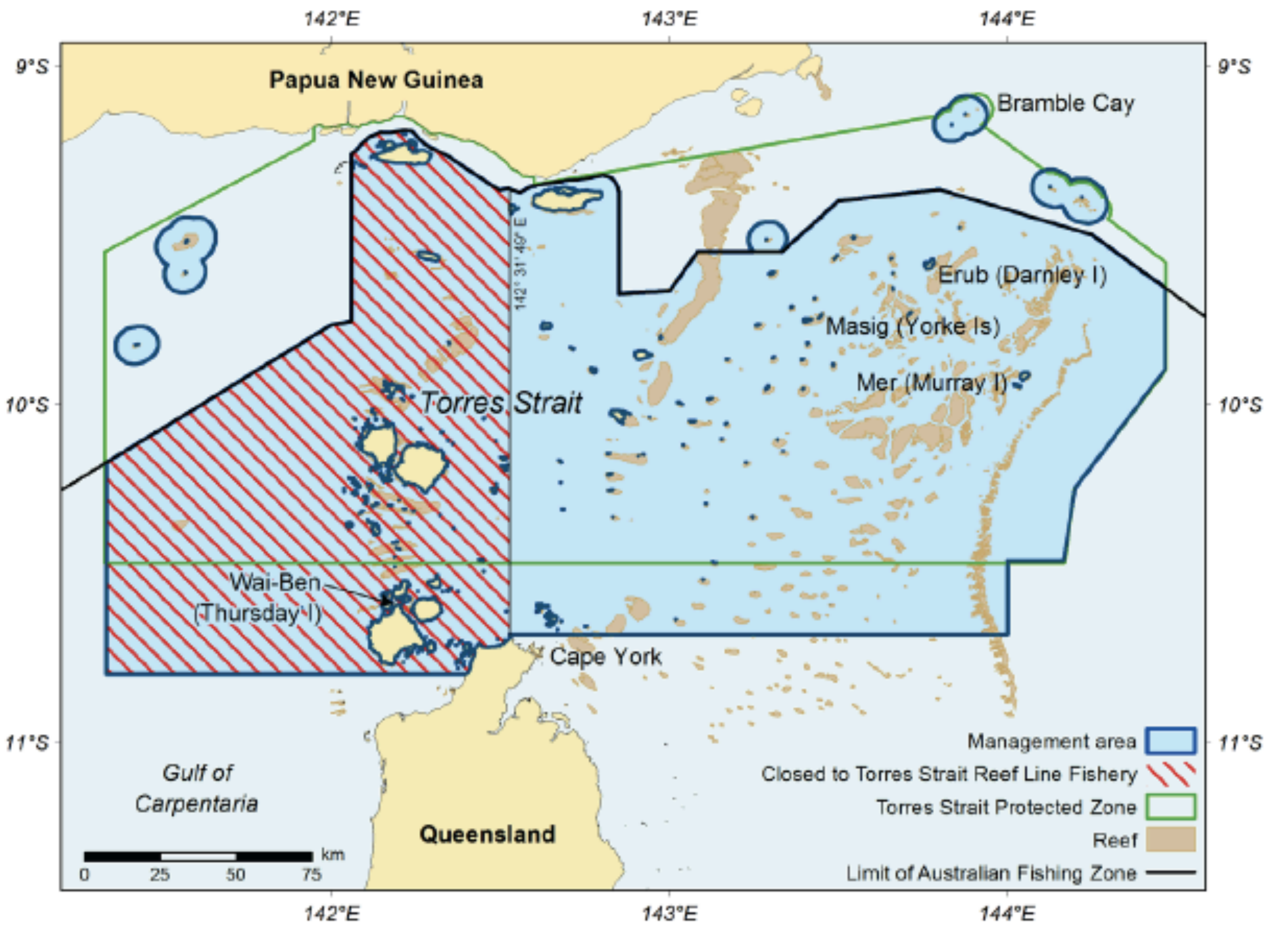

Figure 4. Area of the Torres Strait Finfish Fishery (from: Williams et al. 2020).

The following summary of climate related impacts on the Torres Strait fisheries is based on information from NESP Earth Systems and Climate Change Hub (2018), considering the following assumptions:

1. The Spanish mackerel population in Torres Strait is independent of other populations of Spanish mackerel in Northern Australia, the Gulf of Carpentaria and the East coast of Australia, and potential impacts of climate change are summarised for the Torres Strait population only.
2. Since we are unable to separate the catches of individual coral trout species (as they are not reported in fisheries logbooks), the impact on all coral trout species is assumed to be consistent among species – i.e. the assumption is that all coral trout species will be

impacted approximately the same as common coral trout. This is a high-risk approach, as the other species may be impacted differently, however there is limited information on the other species noting that Williams et al. (2008) offer information on distributions of each species which can potentially be used to identify some of the potential impacts, and

3. All other species of reef fish will be impacted in a similar way. The exception to this is rabbitfish, which form a major part of the food fish for Islanders. Where possible, we will provide reference material on future climate impacts that are specific to that type of fish.

7.3.2 Trends and current status

Spanish mackerel

Spanish mackerel is mostly fished by commercial non-indigenous fishers on the eastern side of Torres Strait (Bramble Cay), where catches are formed mostly by aged 2 to 4 years (Begg et al. 2006). It is assumed that the Spanish mackerel biological stock in Torres Strait is separate from Spanish mackerel in the eastern coast of Queensland and further west across northern Australia. The quota for Spanish mackerel was recently reduced to about 80 tonnes annually, down from 125 tonnes, due to the stock assessment indicating falling biomass levels, driven by a declining CPUE over the 8 years prior to 2018-19. Stock assessments determined that the fishery is classified as 'not overfished' but the Torres Strait Finfish Resource Assessment group recommended biological catch for 2020-21 season to be further reduced to either 56 t (F_{48}) or 71 t(F_{40}) due to model projections falling below limit reference points (Williams et al. 2020).

Coral trout (and food fish)

The peak of commercial catches for TSFRLF was in the 2003-04 fishing season at 132t, before falling to 50t in the 2007-08 season. Although the quotas were set at about 140t in the last 10 years, catches remained below 50t since then and in the 2018-19 fishing season it was 17.3t (Williams et al. 2020).

Catch reporting became mandatory in December 2017. TIB catches are likely to have been under-reported before–because catch-and-effort data reporting was not mandatory for this sector– then and have increased in recent years. Despite the need to closely monitor catch levels, recent research has shown the stock is classified as 'not overfished' and 'not subjected to overfishing' (Williams et al. 2020).

7.3.3 Value

In the 2018-19 fishing season catches for both coral trout and Spanish mackerel declined (by 35,9% and 12.2%, respectively) from catches in 2017-18, resulting in the lowest gross value of production since the 2012-13 fishing season, consistent with falls in catch and effort (Williams et al. 2020). Individual fishery value is not available but total value of the Torres Strait Finfish fishery (2018) was around $1M in the 2017-18 fishing season (Patterson et al. 2018), declining to $0.9M in the 2018-19 fishing season (Williams et al. 2020).

7.3.4 Issues

Spanish Mackerel

The population of Spanish mackerel in Torres Strait is highly vulnerable to climate change. Increases in water temperature could result in a net southward movement of the stock, which would limit access to the stock for Indigenous fishers who cannot move south to follow the stock. Spawning of Spanish mackerel is strongly influenced by sea surface temperatures, with optimal spawning temperatures < 30°C happening mostly during the wet season (Creighton et al. 2013). South migration of Spanish mackerel in response to increases in water temperatures have been suggested since 2011 (unpublished data cited in Creighton et al. 2013). Evidence of a southward range extension due to increasing water temperature has already been documented for Spanish mackerel in Western Australia (Caputi et al. 2015).

In the last 8 years there has been a significant decline in the standardised catch rate (catch per unit of effort – CPUE) from the commercial fleet in Torres Strait (Williams et al. 2020) which may be linked to a long period of drought in PNG (Tony Vass pers comm. and statements and Finfish RAG meeting). Projections of rainfall are highly variable (see Chapter 5.2.3) and fisheries models need to consider the risk of both increase and decrease in rainfall in the region. Although some downscaled rainfall modelled outputs are available (Katzfey and Rochester 2012), data (flow from Fly River and Rainfall) are generally not available to adequately investigate effects of rainfall and flow on Spanish mackerel (R. Buckworth pers. observation).

Data are currently being collated and a statistical analysis undertaken within a new project (2020 project – Buckworth and O'Neil *pers comm*.) to evaluate potential impacts of environmental variables on Spanish mackerel catch rates. Rainfall and river flow data are not of high quality and there is limited information on prey biomass (baitfish, sardines etc). Recruitment of Spanish mackerel on the Queensland East coast appears to be linked to SST with cooler years positively influencing recruitment, although the causal mechanism for this relationship is unclear (Welch et al. 2014).

The Spanish mackerel stock in the Torres Straits is unique in other regards, as well, in that the collection of age data from commercial fishing harvests in some years since the late 1990s has shown that the 'fishable' biomass of Spanish mackerel in Torres Strait is mostly dependent on only a few year classes (2-5 years), in contrast to the fishery on the Queensland east coast which is largely supported by single strong year classes that occasionally propagate through the population (O'Neill et al. 2018).

Coral trout (and food fish)

Tobin et al. (2010) provide detail on the potential impacts of climate change on coral trout. They provide evidence of declines in CPUE associated with cyclones and resulting changes in SST – an impact that is less likely in Torres Strait because cyclones are rare and not expected to increase in frequency (see chapter 5.2.4). Based on a recent study, it is postulated that heatwaves are likely to decrease biomass and increase catch rates independent of changes in habitat (Brown et al. 2020). Indirect climate change impacts on coral trout include an increase in abundance of prey species (e.g. damselfish) following coral bleaching events due to the dead coral providing additional algae substrate which damselfish eat and decline in coral reefs that provide settlement habitats for *P.*

maculatus (Wen et al. 2013, Wismer et al. 2019). However, in the long-term, species of damselfish are expected to be negatively impacted by warmer waters (Pankhurst and Munday 2011). Such ecological impacts via increased growth and prey dynamics are contradictory. Increasing temperatures lead to faster growth rates of coral trout; however, increased temperatures is also expected to cause direct negative impacts on their prey (Johansen et al. 2015).

Samoilys (1997) found that coral trout spawning aggregations and spawning does not occur below a temperature threshold of 24°C. However, the study did not establish an upper spawning temperature (measuring a maximum of 28°C). Large increases in temperature could decrease spawning potential or change the time of spawning (which may not be in phase with currents for eggs and larvae and out-of-phase with primary productivity)(Pratchett et al. 2013). Other negative impacts on coral trout result from acidification–via an increase in metabolic demand, especially of early larval development, and a decline in coral reef habitats–and temperature, where coral trout is not able to cope with high physical activity at temperatures above 30°C (Munday et al. 2008). Also important to consider are the indirect impacts of climate change on behavioural attributes of the fishes (e.g. activity, feeding rates or escape responses), which will affect catchability. For example, if catchability increases a fishery can maintain CPUE even as biomass declines which can result potentially in a collapse as high catch rates cannot indefinitely be maintained (Brown et al. 2020 and references therein).

7.3.5 Opportunities

As a general point, references to previous scientifically reviewed studies on Spanish mackerel are from overseas work (Hare et al. 2016, Cisneros-Mata et al. 2019); whereas for coral trout (due to its dominance as an iconic species on the Great Barrier Reef) all of our references to previous scientifically reviewed studies on coral trout are from Australia. This is important as it appears the work on Spanish mackerel does not provide a good indication of the possible impacts, and if anything, local research in Australia could provide more in-depth knowledge to the real issues.

Spanish Mackerel

Not all predictions of climate change impacts on Spanish mackerel are likely to be negative. Some learnings from responses of other species of Spanish mackerel may provide useful insights on their potential responses to changes in climate. In a study on fish stocks in the Northeast US continental shelf and using *S. maculatus* as an example although we acknowledge it is a different species, Hare et al. (2016) suggest that while Spanish mackerel 'climate exposure' metric is Very High, their biological sensitivity is Low. They rate Spanish mackerel as a species with High species distribution change and therefore on the basis of this and the fact that they can move and fishers could follow them, a positive directional impact on their productivity and implied fishery catches. However, this is not necessarily the case for the stock in the Torres Straits and considerable uncertainty exists as to likely impacts. In terms of regional studies Nguyen and Nguyena (2017) (using data from Vietnam) correlate sea surface temperature (SST), moon phase, and fishing season against observed Spanish mackerel CPUE. The SST is related to ENSO/La Niña changes during the same time period and the authors admit they have no explanation for the biological linked environmental variables. In summary, Nguyen and Nguyena (2017) found a negative relationship between SST and CPUE indicating that if SST increases, Spanish mackerel biomass will decrease.

Townhill et al. (2019) quote unpublished reports (Creighton et al. 2013) that state Spanish mackerel is resilient to climate change impacts (which is possible if it is a relative metric).

Coral trout

For coral trout, changes in temperatures (including heat waves) pose a serious threat to the fishery. Declining biomass is expected along with increases in catch rates (Brown et al. 2020). The impacts from increased growth and prey dynamics are contradictory. Increasing temperatures lead to faster growth rates of coral trout; however increased temperatures impact negatively on their prey via direct links on these species and indirect links on habitats via coral bleaching. To complicate matters, expected decline in coral reefs will also affect settlement and, although overall impacts will likely be negative to the fishery, it is not known what the outcome will be in these circumstances. Although cyclones occur less frequently in the Torres Strait, where coral bleaching is more common, one could postulate a strong negative impact, yet fishing pressure in the Torres Strait on coral trout is low. There is also deep cooler water to the east. Therefore, a better understanding of impacts of temperature on coral trout growth, and its indirect effects on coral trout abundance and distribution due to changes in habitat will offer useful opportunities in Torres Strait.

Future research

Future research should be focused on the following:

1. For Spanish mackerel – data on rainfall, and river flow in PNG, data on prey abundance, data on cohort strength in Spanish mackerel over a long time period
2. For Coral trout – species-specific catch information and abundance estimates for each species. Data on the status of reefs and changes in the Torres Strait and changes in coral trout prey species over time

Note for both species, the biological-environmental links (that could capture the complex effects of climate change) lead to analyses that will be two stage, first stage – environmental drivers on prey of these predators and then second stage – links between prey abundance and Spanish mackerel and coral trout abundance.

7.4 Bêche-de-mer

7.4.1 Description

In Torres Strait, sea cucumber processed into *bêche-de-mer* (BDM) brings important socio-economic benefits to Torres Strait Islanders (Plaganyi et al. 2013a). Despite being a smaller fishery when compared to other high-value species such as the tropical rock lobster, the BDM fishery is wholly traditionally owned and contributes to regional economic development, improves quality of life and autonomy of Islanders, especially on the Eastern Islands (Skewes et al. 2002).

Sea cucumbers are sessile gonochoric (separate sexes) broadcast spawners (release sperms and eggs in mass events; usually once a year). Therefore, they need to be in close proximity to mates for successful fertilization of gametes; In low-density populations (e.g. a few individuals per ha), they may fail to get close enough to conspecifics in breeding periods, resulting in asynchronous spawning (Purcell et al. 2013). Most of the Torres Strait sea cucumbers spawn during warmer (summer) months, with some (e.g. Black teatfish and Lollyfish) also spawning during colder months (Murphy et al. 2019a). There is increasing evidence showing that sea cucumbers improve the health and resilience of coral reefs, soft-bottom and deep-water habitats (Purcell et al. 2013). They play important roles in ecosystems, most notably due to bioturbation involving ingestion, excretion and burrowing within sediments, thereby cleaning sand and keeping organic matter in check. Other important roles include nutrient cycling, oxygenation, alkalizing water which has a positive effect on coral production, and acting as hosts for a number of other species and as prey for several species such as sea stars and fish (Lee et al. 2018, Murphy et al. 2019b). The conversion of organic detritus into animal tissue and nitrogenous wastes, which can be taken up by algae and seagrasses increasing their productivity, thus producing more available food for herbivores, is highly significant for coral reefs where nutrients may be a limiting factor. Not surprisingly, declines in sea cucumber populations may reduce primary production with cascading effects to food webs and sediment infauna via the reduction of the aerobic layer of sediments (Purcell et al. 2013).

They are easy to harvest and aggregate to reproduce (Marquet et al. 2018). Such characteristics, combined with scattered landing places and wide reach of buyers make the fishery difficult to manage and maintain sustainable yields (Hair et al. 2016a). Overfishing of sea cucumber often results in reduction in their density and biomass (Uthicke and Benzie 2001), which negatively affect reproductive success, with cascading effects on the function and productivity of ecosystems (Lee et al. 2018). In Torres Strait, overfishing led to management responses including fishery closures and minimum catch sizes (Skewes et al. 2006, Murphy et al. 2014, PZJA no date). In addition to overfishing, the fishery is also threatened by climate and environmental change, which pose risks to its future (Lee et al. 2018).

Collected animals are processed to *bêche-de-mer* (ready for market) in a range of ways that may include gutting, salting, boiling and drying. The value and demand for sessile marine resources such as sea cucumber is rising (Purcell et al. 2013) resulting in the general over-exploitation and even high extinction risk for some sea cucumber populations globally (Purcell et al. 2013, Purcell et al. 2014, Purcell et al. 2018), even in seemingly well managed fisheries such as in the Great Barrier Reef Marine Park (Eriksson and Byrne 2013, Plagányi et al. 2015, Plaganyi et al. 2015, Purcell et al. 2015).

Torres Strait has two Hand Collectable Fisheries – trochus and *bêche-de-mer* which have both historically been characterised by boom and bust cycles as the result of resource depletion or price fluctuations. The trochus (*Trochus niloticus*) population in Torres Strait appears to be at least stable at present compared to historical data. A survey in 2009 showed densities were similar to 1995 survey data and healthy populations elsewhere (Murphy et al. 2010).

Historically, Sandfish (*Holothuria scabra*) on Warrior Reef provided the bulk of the early catches for the Torres Strait *bêche-de-mer* fishery (TSBDMF), which peaked at over 1,200 t (wet gutted weight) in 1995. A survey in 1998 (Skewes et al. 2000) found that the population was severely depleted and the sandfish fishery was closed. Subsequent surveys found a small recovery in the population, especially of the breeding cohort, but the current status is unknown (Murphy et al. 2011) and has remained closed. After the closure of sandfish in 1998, the fishery mostly targeted Black teatfish (*H. whitmaei*), Deepwater redfish (*Actinopyga echinites*), Surf redfish (*A. mauritiana*), Blackfish (mostly *A. miliaris*) and White teatfish (*Holothuria fuscogilva*). A stock survey in March 2002 found that Black teatfish and Surf redfish were probably overexploited (Skewes et al. 2003), and a prohibition on the harvest of these species was introduced in January 2003. Further surveys in 2009 found that the density of Black teatfish had recovered to near natural (unfished) densities (Skewes et al. 2010) and it was recommended that this species be reopened to fishing, but with a modest TAC of 25t and community-based harvest strategies to manage the spatial effort of this species (Skewes et al. 2010). Trial openings of the Black teatfish fishery with a maximum catch of 15 tonnes were conducted in 2014 and 2015. However, on both occasions the catch limit was exceeded and the fishery was closed again.

Given concerns regarding the effectiveness of catch monitoring systems, considerable effort has been invested in recent years in establishing a more reliable catch reporting system. As a result, the Torres Strait Fish Receiver System was implemented for the Torres Strait on 1 December 2017. A new harvest strategy for the Torres Strait Bêche-de-mer (sea cucumber) Fishery (TSBDMF) was implemented form 1 January 2020, known as the Torres Strait Bêche-de-mer Harvest Strategy (TSBDMHS) and is a set of pre-agreed rules that provides clear and practical guidance for sustainably managing the fishery, including what data are needed and whether the fishery can be expanded (Plaganyi et al. 2019b). It was put together based on scientific evidence from CSIRO, Australia's national science agency, and in consultation with the Hand Collectables Working Group (HCWG), AFMA, TSRA, Malu Lamar and other stakeholders (https://www.pzja.gov.au/the-fisheries/torres-strait-beche-de-mer-fishery).

7.4.2 Trends and current status

The Eastern part of Torres Strait has been historically associated with the fishery as the Western side of Torres Strait, although included in the fishery, is documented as having naturally low abundance of sea cucumbers (Figure 5) (Skewes et al. 2006, Patterson et al. 2018). Most of the catch is typically taken from the Great North East Channel, Don Cay, Darnley Island, Cumberland Channel and Great Barrier Reef regions (Patterson et al. 2018).

Twenty-three commercial sea cucumber species have been recorded in Torres Strait. There has been a demonstrated change in species fished over the last twenty years (Long et al. 1996, Skewes et al. 2000, Skewes et al. 2004, Skewes et al. 2010), with high value species harvested more regularly than medium and low value species, putting them at risk of overfishing.

In recent years there has been a shift to harvesting medium and low value species due to high value species being closed to fishing or limited TAC. The development of new processing techniques has also seen increased catches of Curryfish and more Greenfish taken.

Current catch records show Curryfish as the most caught species, followed by Prickly redfish, Lollyfish and Blackfish. This is a noticeable change in targeted species since 2018, where Leopardfish and White teatfish were the two most commonly caught species after Curryfish and Prickly redfish.

Having a formal harvest strategy (TSBDMHS) is a key building block for the future of the TSBDMF. It provides certainty to fishers, communities, scientists and managers about how the fishery will be managed. It outlines what data are needed and how the information will be used to adjust total allowable catches. A tiered (or step-wise) approach is used for how fishery data can be used to manage the fishery to reduce the risk to a resource and potentially support higher TACs (Plaganyi et al. 2019b). The HS also specifies the requirements for monitoring, with agreement that a fishery will be closed if no data are provided by fishers and fish receivers. Mixed species/basket catches are managed through the monitoring of as many individual target species as possible. The HS includes rules for re-opening a fishery/species that has been closed. For the Sandfish species that was previously overfished, there are guidelines for supporting species recovery as well as how surveys (either full scale scientific surveys or smaller experimental surveys with local participation) can be used to inform whether the fishery could be re-opened.

The HS also included the introduction of a number of new individual TAC's for species that had been previously managed in the 80 tonne catch 'basket', these included Hairy blackfish, Deepwater redfish, Greenfish and Curryfish (*Stichopus herrmanni* and *Stichopus vastus*). Curryfish and Prickly redfish are of present management concern in Torres Strait, with anecdotal evidence of local depletion reported at fishery meetings.

The implementation of more elaborate management strategies is of timely importance with teatfish species currently being considered for listing under the Convention on International Trade of Endangered Species, due to international exploitation (past and present) for the species (Conand 2018, CITES 2019). Any future international trade would be subject to strict guidelines through export permit authorisation and a non-detriment finding of the source fishery demonstrating measures for species sustainability (Korwin et al. 2019).

Two extensive sea cucumber surveys have been conducted in 2019 and 2020 and will be used to provide an updated assessment of trends and current status of a number of key fished species in Torres Strait.

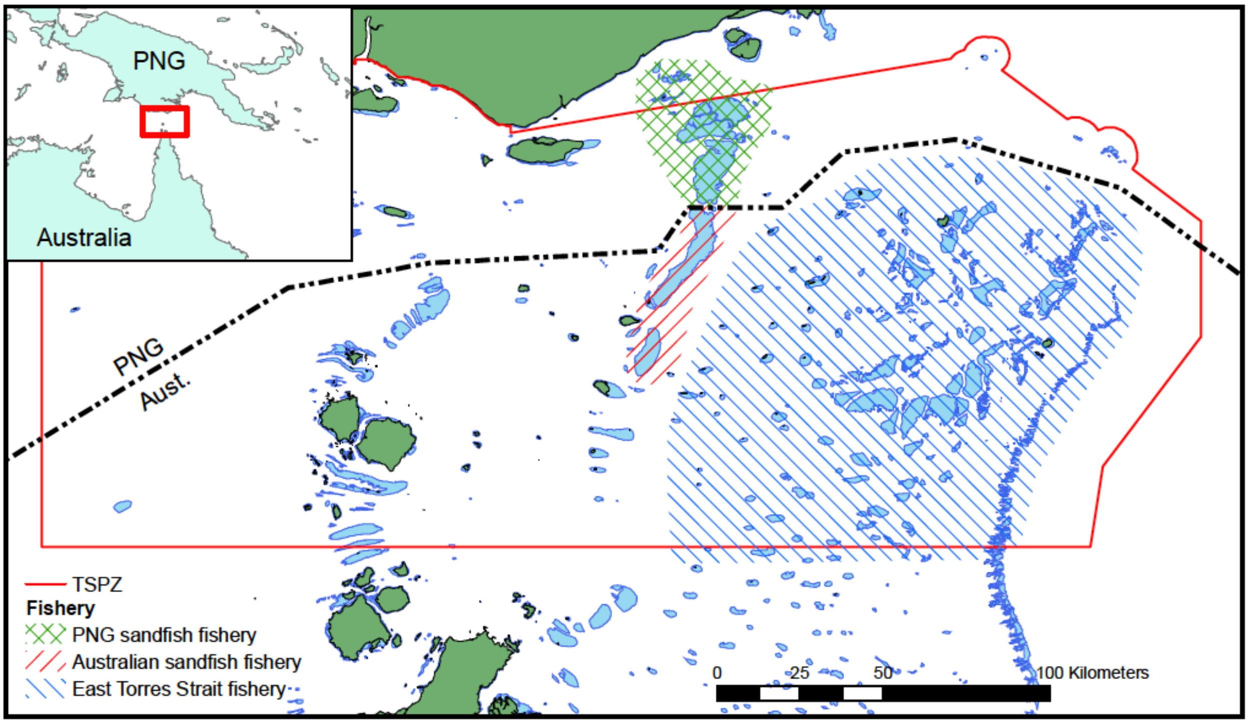

Figure 5. Map of Torres Strait showing approximate locations of sea cucumber fisheries (from (Skewes et al. 2006)

7.4.3 Value

There are no available estimates of net economic returns or gross value of production for the TSBDMF and the value of the catch is not available (Patterson et al. 2018). However, following the recent implementation of the Torres Strait Fish Receiver System as well as new TSBDMHS, these estimates may become available in future.

Most of the product landed in Torres Strait is exported to China, with particularly high retail prices in Hong Kong (Purcell et al. 2018). Prices were also found to be higher for larger animals, particularly for the three high-value species, *Holothuria fuscogilva* (White teatfish), *H. lessoni* (Golden sandfish) and *H. scabra* (Sandfish) (Purcell et al. 2018). Curryfish have only been fished more recently in Torres Strait due to earlier challenges in processing, but catches of Curryfish have been increasing (Plaganyi et al. 2019b) and this species now has a relatively high market value (Purcell et al. 2018).

7.4.4 Issues

Much of the sea cucumber fishing occurs on coral reefs and lagoons, which are under particular threat from global impacts such as climate change and ocean acidification (Purcell et al. 2013). Their calcareous skeletal structures are directly affected by seawater CO_2 concentrations and resulting ocean acidification (Dupont et al. 2010, Yuan et al. 2015). Sea cucumbers are considered to have high vulnerability to climate change (Johnson and Welch 2016, Cochrane et al. 2019), which means that ongoing improvements to harvest strategies will need to ensure that they are climate-smart (Plaganyi et al. 2013a, Punt et al. 2013). Recent studies have shown that considerable uncertainty exists for the potential impacts on sea cucumbers for most combinations of physical and biological variables (Plagányi et al. 2013). Climate change impacts may have both negative and positive effects on sea cucumbers, when they were assessed on the various life history stages of sea cucumber in combination (see Table 4 below), the net effect was slightly more negative for most species (Plagányi et al. 2013). Negative effects were associated with increased larval and juvenile mortality related to higher sea surface temperatures and detrimental effects on the juvenile Sandfish seagrass habitats. Sea level rise was assessed as being mostly positive for shallow water species (e.g. Sandfish, Black teatfish). Climate change is expected to affect distribution and phenology (likely changes in timing of spawning), and to a lesser extent in abundance of Sandfish (Fulton et al. 2018).

Table 4. Summary modified from (Plagányi et al. 2013) on potential changes due to high and medium risks from climate impacts on different life stages of sea cucumber populations in Torres Strait. Values obtained from the literature and expert opinion.

RISK	LIFE STAGE	LIFE HISTORY COMPONENT	SPECIES	EXPLANATION
High	Larvae	Growth	All	Development and growth of invertebrate larvae are generally temperature sensitive. Higher SST will speed growth up to physiological tolerances. Faster growth will mean faster development and larvae ready to metamorphose into settling juveniles quicker. This will likely increase larval supply back to settling habitats.

High	Juvenile/ Adult	Growth	All	Warmer SST generally mean faster growth up to a physiological tolerance. Very little information on the upper limits to growth in the literature, however these species are found in equatorial tropical waters.
High	Larvae	Mortality	All	Higher SST could increase mortality rates due to physiological thresholds, though interactions with other factors (i.e. higher phytoplankton) could ameliorate this impact to some extent.
High	Juvenile/ Adult	Mortality	All	Higher SST, physiological thresholds, disease and parasites may result in higher mortality, though predation pressure will be reduced due to faster growth.
High	Adult	Reproduction	All	Faster growth and bigger sea cucumbers will mean an increased fecundity due to size fecundity relationship. Higher SST could also result in an earlier and longer reproductive season.
Medium	Larvae	Growth/ mortality	All	Projected increases in phytoplankton density in the Coral Sea may influence the Torres Strait and result in faster growth and faster development of sea cucumber larvae. This in turn could increase larval supply.
Medium	Juvenile	Habitat: seagrass	Sandfish	Seagrass habitats may be negatively impacted by increased SST (mostly shallow) and sea level rise (driven by light and species niches) (Connolly, 2009). Settling juvenile sandfish rely on seagrass for habitat.
Medium	Juvenile/ Adult	Carrying capacity	Sandfish, Black teatfish, Surf redfish.	Shallow reef tops may become more available for sea cucumber species that use that habitat (Sandfish, BlackTeat Fish, Surf redfish).

7.4.5 Opportunities

There is a need for new management paradigms and instruments to safeguard reproductive capacity of sea cucumber stocks (Purcell et al. 2013)

It is increasingly important to develop models to link climatic effects over a range of life history components and critical habitats for fisheries (e.g. seagrasses, coral reefs), and quantify the resultant impact on fisheries productivity using alternative emission scenarios (Plaganyi et al. 2013a). This can help identify which kinds of management strategies, monitoring and adaptive feedback are likely to perform best in managing under future climate change. The TSBDMF is a multispecies fishery and the different species have very different distributions, depth preferences and life histories. They will thus be affected differently by climate change drivers, and it's possible that these may have a much smaller impact on deeper water species such as White teatfish.

Management interventions and aquaculture techniques can be used to increase yields of sea cucumber. The foci of management interventions are on minimum sizes, spatial and temporal closures and may also include artificial aggregation of adults to increase the chances of reproductive success. Induced spawning in hatcheries and rearing have become relatively simple (Mazlan and Hashim 2015) and may also be employed to improve wild stocks.

The relative easiness of management initiatives and aquaculture techniques mean that there is potential to establish small or community-based enterprises to cost-effectively enhance stocks in overfished areas (Aalbersberg et al. 2005, Hair et al. 2016b, Han et al. 2016). However, high costs, market access, species choice, inadequate capacity and planning, and poor stakeholder engagement, communication and consultation are some of the barriers reported for small-scale community-based initiatives (Toral-Granda et al. 2008, Hair et al. 2016b). Lack of appropriate monitoring programs to measure effectiveness of initiatives of management and aquaculture techniques for stock enhancement is also common (but see Hair et al. 2016b).

7.5 Turtles

7.5.1 Description

The Torres Strait Turtle Fishery is operated by local Torres Strait residents as an artisanal fishery (Johnson and Welch 2016) that has supplied a large proportion of the daily food intake for Torres Strait islanders for 1000s of years (Hagihara et al. 2016). Turtles are hunted for domestic consumption only. Green Turtles make up ~98% of the catch, with Hawksbill Turtles (~1%) also taken (Harris et al. 1994). The islands of Torres Strait are insignificant nesting locations for both of these species (Limpus et al. 1989). Green Turtles nest in the Great Barrier Reef region (Commonwealth of Australia 2017). However, remote islands in north-west Torres Strait are major nesting sites for the flatback turtle (Limpus et al. 1989), though only their eggs are harvested. The threat of Climate Change is rated as 'very high' for Green Turtles in the northern Great Barrier Reef region (Commonwealth of Australia 2017) and Torres Strait is noted as a major foraging habitat for the stock.

In the 1990s, about 5,000 person-days were spent hunting each of turtle and dugong each year. This effort was much less than the ~30,000 person days spent handlining for fish. Other species such as tropical crayfish (*Panulirus ornatus*) were hunted for commercial sale (~9,000 person days y^{-1}). The majority of the turtle catch in Torres Strait is taken between September and February annually (Harris et al. 1994).

7.5.2 Trends and current status

In the 1990s, the number of turtles harvested in Torres Strait was $2{,}504 \pm 358.y^{-1}$ with a bimodal size distribution (with peaks at 45 and 105 cm carapace length) (Harris et al. 1994). Turtles were the second highest catch by percent composition (26%), only exceeded by dugong (28%) and much higher than finfish, crustaceans and molluscs (18%, 16%, 11%, respectively). The proportion of artisanal catch made up of turtle varies regionally in Torres Strait. In the eastern islands, over 50% of the daily catch is comprised of turtle, while in the central and western Island, turtles comprise about 25% or less of the daily catch. More contemporary data on the fishery taken by species-group composition of the annual resource harvest in Torres Strait are not available, though estimates of a harvest of about $3{,}000 \pm 1{,}000$ turtles.y^{-1} remain reasonable (Hagihara et al. 2016).

7.5.3 Value

Turtle and Dugong fisheries are customary subsistence fisheries whereby only indigenous inhabitants of Torres Strait are allowed access to harvest. Turtles are important to a traditional way of life and provide a major source of protein in the diet of Torres Strait peoples.

7.5.4 Issues

Turtles are particularly vulnerable to the impacts of Climate Change as they are dependent on both the marine and terrestrial environments. A phase of their life history includes terrestrial nesting. Terrestrial sea turtle nests are particularly vulnerable to sea level rise causing erosion, inundation and higher groundwater levels (Fuentes et al. 2010). Elevated temperature is also critical; they and their niche are subject to both air temperature and sea surface temperature increases (both of which are predicted as ambient conditions in Torres Strait through 2050 to 2100). Highly dependent on terrestrial environmental conditions, the temperature of nests is critical to incubation success, sex-structure of the population and hatchling fitness (Booth and Evans 2011, Cavallo et al. 2015, Rivas et al. 2019, Staines et al. 2019). In addition, their nests are subject to coastal and terrestrial large-scale processes such as coastal erosion and extensive rainfall events.

Optimally, turtle nests range in temperature from about 27-30°C over the duration of incubation (about 60 days). However, nest temperature depends on variables such as shaded vs non-shaded location, rainfall incidence and duration, depth of egg burial, and surface vegetation vs bare sand. For example, tree shade can reduce the temperature of nests by 2°C compared to un-shaded nest locations (Booth and Evans 2011, Rivas et al. 2019, Staines et al. 2019). Under current environmental conditions, unshaded turtle nests can reach a sustained 32°C and might reach 34°C for several days. Crucially, the lethal temperature for turtle embryo survival is ~34-36°C (Staines et al. 2019), though reduced incubation success occurs at lower temperatures. Consequently, an ambient temperature rise of 2°C may cause nest temperature to rise to lethal levels; or near-lethal levels that dramatically reduce incubation success and hatchling fitness (Staines et al. 2019).

Nest temperatures ~31°C (compared to 28°C) reduce the incubation period (by ~15%), the percent incubation success (by ~16%), cause the feminisation of the population; and reduce the carapace length of hatchlings (by ~4%), and their crawl speed, self-righting success and swimming speed/thrust (Booth and Evans 2011, Cavallo et al. 2015, Rivas et al. 2019, Staines et al. 2019). Turtles reproduce from October/November to February/March annually in Australia; the hottest season of the year, the late-dry and wet seasons. Climate prediction for tropical Australia suggests that by 2070 and 2100 mean annual temperature, mean 'early-wet' season and 'late-wet' season ambient air temperatures will increase by 3°C, possibly increasing turtle nest temperatures by a significant amount (buried at ~45-50 cm depth). In addition, worldwide heatwave frequency and duration are predicted to increase three- to five-fold by 2100 (Coumou and Robinson 2013), causing prolonged temperature spikes that may impact incubation success, sex-ratios and hatchling fitness.

Green turtles (*Chelonia mydas*), for example, develop into females if the temperature of the nest is higher than 29°C. Recent surveys have found 65-69% of turtles hatching from beaches in the southern Great Barrier Reef female, but 99% of those hatching from northern beaches are female. It seems that the northern rookeries have been producing primarily females for more than two decades, and that complete 'feminisation' of the population may occur in the very near future, with disastrous consequences (Hughes et al. 2019).

Monsinjon et al. (2019) modelled the impacts of climate change (RCP4.5 and 8.5) on key indicators of stable turtle populations across seven nest sites worldwide (using indicators such as incubation success and hatchling fitness). Their model outcomes showed that future climate impacts that would destabilise turtle populations would be crucial at six of the seven nesting sites; from feminisation at RCP4.5 to much reduced incubation success at RCP8.5. The model outcomes implied that a temporal shift in the annual breeding cycle (earlier and cooler) would be required to sustain populations, and questioned the adaptability of turtle populations.

A major indirect impact of rising temperature on turtle populations is the impacts on their food sources, both herbivory and carnivory. In particular, herbivorous turtles (e.g. the Green Turtle) feeds on the extensive seagrass communities that exist in Torres Strait. Herbivorous turtles make up >95% of the turtle harvest as a food resource by Torres Strait human communities and they are dependent on reef-top seagrasses. For example, on the Orman Reefs in Torres Strait, Green Turtles consume both seagrasses (especially *Thalassia hemprichii* and *Enhalus acoroides*) and algae (mainly *Hypnea* spp., *Laurencia* spp. and *Caulerpa* spp.) (Andre et al. 2005).

Higher temperatures will impact turtles indirectly via changes in seagrass abundance given they are close to their temperature tolerance limit (see details in Chapter 6.1). As their food resources reduce, so will the local populations of turtles, either by mortality or movement to more productive seagrass communities (as has been documented for dugongs (see Marsh et al. (2004)).

As well, Torres Strait seagrass communities may suffer sedimentation and deposition impacts due to pulsed nutrient and sediment loads from Papua New Guinea's Fly River associated with extreme rainfall events (Suppiah et al. 2010, Johnson and Welch 2016).

Carnivorous turtles feeding on crustaceans and molluscs will be impacted as warming Sea Surface Temperatures inflict coral bleaching of the reefs of Torres Strait (see Hoegh-Guldberg 1999, Bainbridge et al. 2015, Hughes et al. 2017). Bleached reefs interrupt fundamental nutrient cycles and food webs in coral reef ecosystems and reduce the species richness and abundance of many benthic and demersal fauna, including crustaceans and molluscs (Hoegh-Guldberg 1999). Coral bleaching is a relatively short-term process; it can occur if reefs are exposed to temperature > 30^{o}C for 24-48 hours, increasing in intensity as duration of exposure to above-ambient temperature increases (Hoegh-Guldberg 1999, Hughes et al. 2017). Marine heat waves are predicted to increase in tropical Australia (Frolicher et al. 2018) and short-term air temperature heatwaves are a culprit to induce spikes in littoral waters over 3-5 days. As a consequence, the frequency and extent of coral bleaching is expected to increase across the Australian tropics with broad ecosystem consequences. The abundance of the reef-dependent crustacean and mollusc prey of carnivorous turtles will reduce. As for herbivorous turtles, carnivores will move to locations where reefs are less impacted and their key diet species are more abundant.

Sea turtle populations will also be impacted by sporadic environmental phenomena, the effects of which are less defined both temporally and spatially. Extreme rainfall events are predicted to increase in frequency to 2100 and beyond. In addition, the intensity of tropical cyclones is predicted to increase. These stochastic events can impact both the nests and the adult phase of turtle populations; particularly when they overlay a predicted to increase in sea level by 1.1 m worldwide by 2100 (see Chapter 5.2.5).

Heavy rainfall lowers the temperature of turtle nests and may saturate the sands surrounding the eggs (Staines et al. 2019). Too low temperatures and the drowning of nests are lethal to embryonic development (Rivas et al. 2019). The storm surge associated with cyclones, overlapping with seas level rise may inundate turtle nests and drown the incubating eggs (Fuentes et al. 2010). Moreover, the storm surge associated with intense tropical cyclones strand turtles (and dugong) on nearby shores, particularly when nearby coasts are extensive salt flats only a metre or two above sea level (Limpus and Reed 1985, Marsh 1989). In the Northern Territory coast in the vicinity of the McArthur River estuary, Cyclone Kathy (1984) beached an estimated 1,000 turtles and 500 remained stranded and disorientated up to 9 km inland on the low supratidal mudflats, a week after the cyclone. They would have died without human assistance back to coastal waters. All of the stranded turtles were green turtles and >90% were large females, presumably feeding of the extensive seagrass beds in the littoral habitats along the coastline when Cyclone Kathy struck (Limpus and Reed 1985). Green turtles are vulnerable to both cyclonic-stranding and hunting by indigenous peoples as they make up mostly 100% of shallow-water seagrass-feeding turtles in both Torres Strait and the Gulf of Carpentaria (Limpus and Reed 1985, Harris et al. 1994). Green Turtles also make up 73% of coastal stranding that occurs daily along the Queensland coast (Meager and Limpus 2012). Therefore, the turtle species that is key to support a Torres Strait customary food source is the same species that is most vulnerable to stranding. Note however, that the area of mudflats available for stranding as a percentage of costal habitats is not as great in Torres Strait as it is in the Gulf of Carpentaria; probably lessening the chance of stranding in Torres Strait habitats.

Table 5. Observed and expected effects of climate change on turtles.

PHYSICAL DRIVER	CLIMATE CHANGE EFFECT	ECOLOGICAL EFFECT	INDIRECT EFFECTS	FISHERY EFFECT	NOTES	SOURCE(S)
Air Temperature	Increase in air temperature	Extreme temperatures affect sex ratio of hatchlings; reduced hatching success; feminisation of population; individual size and locomotion capacity	Seasonal reproductive shift	Changed population structure: seasonal behavioural changes	Sex ratio of population may change; optimal hatching success 25 to 35ºC long generation time limits adaptability; tropical ecosystems already at upper thermal tolerance	Duarte (2002), Poloczanska et al. (2007) Collier et al. (2011) Expert opinion http\\www.climatechangeinaustralia.gov.au Monsinjon et al. (2019) Babcock et al. (2018)
Sea Temperature	Increase in sea tempertures	Mollusc/ crustacean population impacts due to niche decline; especially food	Coral bleaching; loss of dynamic reef ecosystem	Reduction in loggerhead turtle population and catch; starvation and turtle relocation	Expert opinion – ecosystem effects	Carruthers et al. (2002); . http\\www.climatechangeinaustralia.gov.au
Sea Temperature	Increase in SST	Extreme temperatures affect photosynthesis, nutrient uptake, flowering and germination in seagrasses	Spikes in air temperature impact seagrass habitat in shallow littoral waters	Reduction in turtle catch: increase in Turtle mortality due to starvation / Turtle relocation	Thermal optimum temperature – for seagrass range from 15 to 32-33ºC	Duarte (2002), Poloczanska et al. (2007) http\\www.climatechangeinaustralia.gov.au Expert opinion Collier et al. (2011)
Salinity	Decrease in salinity due to large flood events	Decrease in salinity due to large flood events have	large scale turtle relocation and	Reduction in catch: turtle mortality due to starvation /	Based on habitat suitability models for Northern Australia	Carruthers et al. (2002) GoC cyclone Sandy.

PHYSICAL DRIVER	CLIMATE CHANGE EFFECT	ECOLOGICAL EFFECT	INDIRECT EFFECTS	FISHERY EFFECT	NOTES	SOURCE(S)
	(possibly from PNG)	been associated with a decline in seagrasses	mortality due to lack of food	turtle relocation		http\\www.climatechangeinaustralia.gov.au
Temperature	Increase in SST; Increase in the number / intensity of marine heat wave (MHW)	Sea temperature over migration routes Sea temperature above thermal tolerance	na	Seasonal behavioural changes Reduction in catch: Turtle mortality not likely as sea temperature within thermal tolerances MHW-mortality unknown.	Green Turtles don't nest in Torres Strait. They migrate there to forage; they nest in Great Barrier Reef waters	Duarte (2002), Poloczanska et al. (2007) Collier et al. (2011)
Extreme rainfall events	Increase in sedimentation and turbidity due to regional and local flood events causing erosion and sediment transport/deposition	possible increase in turtle mortality due to limited visual detection of large predators. Local scale turtle relocation	Decline in seagrasses abundance and extent due to turbidity – less fod for turtles	Reduction in local catch: Turtle relocation	Based on climate impact projections for Northern Australia	Carruthers et al. (2002) Expert opinion http\\www.climatechangeinaustralia.gov.au
Extreme temperature (heatwave) events	Increase in frequency of series of very hot days. (days over 35°C, Expected to increase threefold in Cairns).	Poor incubation success (terrestrial nests) due to heat stress	Thermal stress on just-emerged hatchlings before they reach seawater	Reduction in catch: Turtle hatchling mortality; poor locomotion by hatchlings, reduced access to the sea; lower individual weight	Extreme heat days estimated under RCP4.5 to ~2090 (website). ~34°C nest temperature lethal threshold for early stage embryos (Collier et al. 2011)	Duarte (2002), Poloczanska et al. (2007) Expert opinion http\\www.climatechangeinaustralia.gov.au
Sea level rise and frequency of intense cyclones	Combined inundation or erosion of nests due to sea level rise and cyclone-associated storm surge;	Poor incubation or mortality of embryos due to temperature drop associated with sea water inundation or anoxia due to semi-permanent inundation; erosion/ exposure of eggs in nests-100% mortality	Stranding of adult turtles due to storm surge and wave action during intense cyclones.	Reduction in catch: turtle hatchling mortality resulting in long-term population decline; adult mortality due to beaching	Based on climate models and habitat impact models for Northern Australia; stranding during cyclonic impact in the Gulf of Carpentaria.	Carruthers et al. (2002) http\\www.climatechangeinaustralia.gov.au

7.5.5 Opportunities

A caveat of the possibility of stochastic weather events impacting turtle populations is that turtles have survived for > 100 million years; over which temperature increases and ice-ages have come and gone. During times of ecosystem stress on Earth, turtles must have adapted to change in the locations of environmental conditions that support nests, either by locating nesting activity to more facilitative latitudes, or by changing the timing of nesting activities seasonally to benefit from favourable temperatures (Poloczanska et al. 2007). However, in the 2000s, spatial and temporal caveats exist on their ability to adapt. From now until the 2100s and ongoing, the rate of temperature change will be much greater than over past biome-wide fluxes; and today, urbanisation and coastal infrastructure, coastal modification and human use has rendered much of their historically-used natural habitat unavailable for undisturbed nesting activity.

7.6 Dugongs

7.6.1 Description

Torres Strait contains the largest Dugong population in the world. Dugongs have been hunted by Islanders since at least 4,000 years ago (Crouch 2015). They are considered the most significant and highest ranked marine food in the traditional subsistence economy (Carter et al. 2014). Dugongs are known as 'cultivation grazers' (Preen 1995). An adult dugong eats about 7 per cent of their body weight in seagrass per day (Department of Environment and Heritage Protection 2016). They feed in a way that promotes growth of *Halophila ovalis*; their preferred seagrass species. Pulling out the seagrass aerates the sea floor and increases the amount of organic matter in the area, thereby encouraging regrowth of the seagrass (Department of Environment and Heritage Protection 2016). Dugongs in Torres Strait were found to feed exclusively on seagrasses (mainly *Thalassia hemprichii*, *Cymodocea* spp. and *Syringodium isoetifolium*), suggesting slight differences in diet to other areas, based on abundance and palatability of seagrass species (Andre et al. 2005).

7.6.2 Trends and current status

Data on dugong population estimates from aerial surveys in Torres Strait are scarce and the absolute population size is unknown (Marsh et al. 2015), but estimates suggest the dugong population in 2013 was ca. 16,000 and stable with a seagrass area of 30,560km^2 (Sobtzick et al. 2014). Data on dugong harvest is sparse but the fishery is sustainable (although it was considered unsustainable in the past) (Marsh et al. 2015).

The area of dugong habitat that supports very high densities of dugongs in Torres Strait is large (5,268 km^2) and hunting is largely restricted to a very low percentage of that habitat (5%) due to the input control on the fishery and socio-economic reasons (Marsh et al. 2015).

7.6.3 Value

Dugong fisheries are customary subsistence fisheries whereby only indigenous inhabitants of Torres Strait are allowed access to harvest. Dugongs are considered the most significant and highest ranked marine food in TS traditional subsistence economy (Carter et al. 2014). The cultural services associated with hunting have been reported by Torres Strait traditional owners to be more important than provisioning services (Delisle et al. 2018).

7.6.4 Issues

Seagrasses provide critical habitats and are a critical food resource for dugongs (Carter et al. 2014) that feed almost exclusively on shallow water seagrasses, particularly on pioneer species from genera such as *Halophila* and *Halodule* (Wooldridge 2017; Preen, 1995). This means that dugongs are highly vulnerable to changes in seagrass abundance.

It is hard to predict the exact response of dugongs to changes in seagrass abundance because a combination of factors, such as age, sex, physical condition, matrilineally transmitted learned behavior can all contribute to apparently highly individualistic movement patterns (Marsh et al., 2011; Wooldridge 2017).

Effects of climate change on dugongs found in the literature were mostly indirect, showing changes in location, abundance and biomass of dugongs associated with changes in abundance and distribution of seagrasses (Table 6). Dugongs themselves are also sensitive to changes in water temperature and known to undertake meso-scale thermoregulatory movements in response to changes in temperature (Sheppard et al. 2006). Direct effects include stranding associated with extreme weather events (e.g., cyclones and flooding) (Marsh 1989, Fuentes et al. 2016). Boat strikes is a localised direct threat to dugongs (Marsh and Sobtzick 2019)

Table 6. Observed and expected effects of climate change on dugongs.

PHYSICAL DRIVER	CLIMATE CHANGE EFFECT	ECOLOGICAL EFFECT	FISHERY EFFECT	NOTES	REFERENCE(S)
Temperature	Increase in SST	Extreme temperatures affect photosynthesis, nutrient uptake, flowering and germination in seagrasses Dugongs are sensitive to changes in water temperature and known to undertake meso-scale thermoregulatory movements in response to changes in temperature	Reduction in catch: Dugong mortality due to starvation / Dugong relocation	Thermal optimum temperature –for seagrass range from 15 to 33ºC (Collier et al. 2011)	Duarte (2002), Poloczanska et al. (2007) Sheppard et al. (2006)
Salinity	Decrease in salinity due to large flood events	Decrease in salinity due to large flood events have been associated with a decline in seagrasses which led to large scale dugong relocation and mortality	Reduction in catch: Dugong mortality due to starvation / Dugong relocation	Based on habitat suitability models for Northern Australia	Carruthers et al. (2002)
Water clarity	Increase in extreme events	Reduced abundance of seagrass is associated with deteriorating water clarity due to: (a) floods and (b) longer-term impact of terrestrial fine sediment exports due to poor land practices.	Reduction in catch: Dugong mortality due to starvation / Dugong relocation	Burdekin region (GBR)	Wooldridge (2017)

Water clarity		Mean daily irradiance (I_d) above 5 and 8.4 mol $m^{-2} d^{-1}$ was associated with gains in seagrass. Percent of days below 3 mol $m^{-2} d^{-1}$, correlated with change in seagrass cover with 16–18% of days below 3 mol $m^{-2} d^{-1}$ being associated with more than 50% seagrass loss. Number of hours of light saturated irradiance (H_{sat}) correlated well with change in seagrass abundance; where H_{sat} of 4 associated with increases in seagrass abundance, and < 4 H_{sat} with more than 50% loss	Reduction in catch: Dugong mortality due to starvation / Dugong relocation	Experimental work in the GBR	Collier et al. (2011)
Extreme events (cyclone & flooding)	Stranding	Extreme weather events (e.g., cyclones and flooding) have been associated with mass stranding of dugongs	Reduction in catches		Fuentes et al. (2016)
Temperature	Increase in temperature	Conditions such as warm sea temperatures and low rainfall (promoting seagrass growth) may be facilitating explorative ranging south by dugongs.	Reduction in catches due to relocation of dugongs to cooler waters	New South Wales	Allen et al. (2004)

7.6.5 Opportunities

Understanding the indirect impacts of habitat degradation and food availability is important to manage dugong populations under climate change. Seagrasses are highly dynamic, subjected to seasonal changes in Torres Strait. Climate, localised impacts and harvest act synergistically, affecting seagrass communities and dugong populations in Torres Strait. Understanding these processes and behavioural responses thresholds (e.g. migration) will support the management of this important traditional fishery.

Seabed habitat has been monitored annually along transects by CSIRO divers undertaking TRL surveys since 1989, and although snapshots only, these data complement aerial survey data and provide valuable insights into abundance and trends in seagrass in Torres Strait. For example, Plaganyi et al. (2016) reported that seagrass declined to 2001 (from 1994) but increased post 2001. By species, the overall trend in seagrass cover for the repeated sites was not as evident, although the dominant species *Halophila spinulosa* showed a similar increasing trend post 2001. Seagrass composition also changed between years with *H. spinulosa* dominant in most years, but *S. isoetifolium* and *T. hemprichii* also dominant in three of the 19 years.

8 Conclusion of Part 2

This report identified a range of localised and climate change impacts potentially affecting the key fisheries selected for consideration. Anthropogenic impacts in Torres Strait are minimal, but exist in specific locations. Local impacts include sediment runoff and metal pollution from the Fly River (PNG), localised oil contamination, mangrove cutting, alteration of hydrology, nutrient and sediment runoff, chemical contamination, and over-harvest of marine living resources.

Climate change is already affecting Torres Strait fisheries and culture. Expected impacts from climate change include higher seas, warmer atmospheric and ocean temperatures, more acidic waters, changes in ocean circulation, and more intense rainfall events. Although minimal, simultaneous local impacts (e.g. untreated sewage, chemical, sediment and nutrients runoff, oil pollution, overfishing) act together with climate change impacts, such as sea-level rise, ocean warming, acidification, leading to interactive, complex and amplified impacts for species and ecosystems.

These pressures manifest directly in the form of changes in abundance, growth, reproductive capacity, distribution and phenology (changes in cyclic and seasonal phenomena such as reproduction and migrations)), and indirectly through changes in foodwebs and habitats. Invertebrates (TRL, prawns, BDM) are likely to be more impacted by climate change than vertebrates (Finfish, turtles and dugongs), although responses are species specific (Fulton et al. 2018). For example, TRL has wide ranging life history circulation pattern which gives it some flexibility to “move” whereas BDM are more sedentary with more localised recruitment.

Climate change will likely cause mostly negative direct effects on the fisheries investigated in this report, but some effects may also be positive. If climate-related environmental changes go beyond certain limits or ranges for species, they will simply move or have their abundance reduced (Pecl et al. 2014, Fulton et al. 2018). For example, changes in ocean currents and circulation in Torres Strait will likely affect larval transport and distribution of TRL, BDM, prawns and finfish. High water temperature can cause mortality, affect growth (relatively small warming may increase growth rates of sea cucumber and TRL), reproduction and its timing, and negatively affect supporting habitats (coral reefs, seagrasses) of finfish, invertebrates, dugongs and turtles. Elevated air temperatures can also reduce incubation success, shift timing of annual breeding cycle and increase ‘feminisation’ of Green turtle populations. Higher seas and extreme weather events can uproot mangrove trees and cause erosion and increase in turbidity, with consequent reduction in light penetration and salinity and an increase in sediment deposition, negatively affecting seagrasses and coral reefs. Some organisms, such as sea cucumbers may benefit from higher seas, but others like turtles and dugongs can be negatively effects via changes in abundance of preferred food (e.g. seagrass) and also via the inundation of nesting sites (turtles) and stranding (turtles and dugongs) associated with extreme weather events.

Although recent studies have shown that ocean acidification does not alter reef fish behaviour (Clark et al. 2020a, Clark et al. 2020b), there is strong evidence that it is already affecting carapaces of crustaceans in other parts of the world (Bednaršek et al. 2020). This can have potential ramifications for TRL and prawns, and, to a lesser extent, sea cucumbers.

Table 7. Main drivers causing changes in Torres Strait ecosystems and fisheries.

CLIMATE CHANGE IMPACT	DRIVER	ECOSYSTEMS	FISHERY
Change in ocean circulation	Currents	Seagrass, Mangroves, Coral Reefs	TRL, Prawns, Finfish (CT), BDM

CLIMATE CHANGE IMPACT	DRIVER	ECOSYSTEMS	FISHERY
Increase in intensity of extreme rainfall events	Turbidity	Seagrass, Coral Reefs	Indirect fishery effect via changes in seagrass and coral reefs (Dugongs, prawns, Turtles, TRL, BDM, Finfish)
Increase in air and sea temperature	Temperature	Seagrass, Coral Reefs	Prawns, Finfish (SM, CT), Turtles, BDM, TRL
Sea level rise	Tides / water level	Seagrass, Mangroves, Coral Reefs	TRL, BDM
Increase in intensity of extreme rainfall events	Light	Seagrass, Coral Reefs	Indirect fishery effect via changes in seagrass and coral reefs (Dugongs, prawns, Turtles, TRL, BDM, Finfish)
Increase in intensity of extreme rainfall events	Nutrients (N & P)	Seagrass, Coral Reefs, Mangroves	Finfish (SM, CT)
Increase in intensity of extreme rainfall events	Salinity	Seagrass, Mangroves, Coral Reefs	Indirect fishery effect via changes in seagrass and coral reefs (Dugongs, prawns, Turtles, TRL, BDM, Finfish)
Increase in intensity of extreme rainfall events	Sedimentation	Seagrass, Coral Reefs	Indirect fishery effect via changes in seagrass and coral reefs (Dugongs, prawns, Turtles, TRL, BDM, Finfish)
Ocean acidification	pH	Coral Reefs	TRL, Prawns, Finfish (SM, CT), BDM
Increase in sea temperature	Oxygen		TRL
Changes in ENSO / La Niña patterns	Exposure to the air	Seagrass, Coral Reefs	Turtles
-	(Over)grazing	Seagrass	
Increase in intensity of extreme rainfall events	Extreme events (e.g. rainfall, cyclones)	Seagrass, Coral Reefs, Mangroves	Finfish (CT), Turtles, Dugongs
Increase in intensity of extreme rainfall events	Waves / tidal surges	Seagrass, Mangrove	Dugongs and Turtles
-	Moon phase		TRL
Anthropogenic impact	Overfishing		BDM
Potentially associated with increase in temperatures	Diseases & parasites		Finfish, Prawns, BDM

Part 3: Scoping a future data framework project

Part 3 scopes a future project that would provide an over-arching data framework (e.g. from global atmospheric and oceanographic models, down-scaled to the broader TS region as appropriate) needed as a foundation for future work. Subsequent projects could ultimately use modelling approaches to quantitatively evaluate the effects of future climate change scenarios on the selected fisheries, and explore alternative adaptation options. More specifically, Part 3 presents the modelling requirements to simulate impacts of climate and non-climate drivers on the key fisheries to guide the development of a future data framework project. Based on the review provided in Part 2, Chapter 9 presents simulation requirements and identifies data gaps. Chapter 10 presents the proposed modelling and supporting data framework, followed by preliminary costs presented in Chapter 11. Finally, Chapter 12 provides the main conclusions and recommendations from the project.

9 Requirements for modelling and data framework

9.1 Modelling questions

The data framework will be specified in a way that meets the input data needs of various future fishery-specific and ecological modelling, addressing issues associated with changes in local and climate drivers and modelling needs presented in Part 2. In this Chapter, we first provide the key question that the future models need to address, the simulation requirements to address the research questions (Chapter 9.2), and an assessment of the minimum requirements versus available data (Chapter 9.3).

The data and modelling framework will primarily be designed to answer the following question: *What are the potential consequences associated with changes in local conditions, including climate variability and change, on the selected Torres Strait Fisheries, ecosystems and dependent communities?*

The objectives of the modelling exercise are to simulate future climate scenarios and assess the impacts of these on fisheries and associated habitats and species through quantitative evaluation. The modelling framework will support the exploration of responses and strategies to manage the selected Torres Strait fisheries, such as the evaluation of:

1. Interactions between different fisheries and broader ecosystem functioning;
2. Impacts of climate change scenarios on the abundance and distribution of selected species;
3. Impacts of current and future catchment conditions and management scenarios on fisheries;
4. Impacts of incidents (e.g. oil spills, ships run aground) on fisheries;

5. Combined scenarios of 1-4 to develop strategies that are robust across impacts and fisheries;
6. Evaluation of alternative adaptation options

9.2 Simulation requirements

Based on the summary of threats to Torres Strait provided in Part 2 and questions and objectives identified in Chapter 9.1, the modelling framework is expected to simulate the following processes:

1. *Catchment runoff:* The model should be able to represent catchment runoff (river flows, sediment and nutrients) to test scenarios associated with: a) changes in rainfall (annual average and changes in frequency/intensity of extreme rainfall events), and b) changes in land-use and practices. Ideally the model should incorporate runoff from main river systems entering the Gulf of Papua, especially turbidity and optionally mine tailings from the Fly River system. Sediments (and associated decline in light penetration), nutrients and pollutants from catchments can affect habitats (seagrasses, mangroves and coral reefs) directly with flow-on effects on targeted species, their prey and predators.
2. *Hydrodynamics and transport*: Understanding oceanographic processes such as currents, waves, sea level, tides and tidal surges, and how these affect turbidity, sediment plumes, suspension / resuspension and deposition of sediments, and larvae dispersal would be important to evaluate individual and synergistic impacts from localised impacts (e.g. changes in land-use and practices, oil spills) and climate change on habitats and fisheries. For a more holistic representation of catchment and coastal/oceanic connections, such models can use point-source outputs from the catchment model, such as flows, and loads of sediment, nutrients and other pollutants.
3. *Physio-chemical water quality constituents*: Variables, such as pH, dissolved oxygen, water and air temperature, total suspended solids, and salinity would be useful to include in the model to assist in the prediction of their direct and indirect impacts on key species and habitats.
4. *Biogeochemistry*: It may be advantageous if a model is capable of simulating the reactive transport and transformation of common parameters such as nitrogen, phosphorus, oxygen, carbon and inorganic suspended solids. Another desirable feature would be to simulate sediment-water column interactions for these parameters and assimilation of nutrients by primary producers. Simulating parameters such as bacteria, pathogens, algae and zooplankton is also desirable.
5. *Fisheries dynamics*: Simulation of fisheries processes (e.g. catch, effort, gear) and the interactions between ecosystems, species and fisheries is essential to understand direct and indirect effects of localised and climate change impacts.
6. *Ecological relations*: Simulation of higher order functions, such as interactions between targeted species and their predators and prey, and indirect impacts of changes in habitats on targeted species (e.g. coral bleaching and impacts on fishery or prey, impacts of climate change on nursery function of mangroves) are highly desirable. Simulation of mega-fauna trophodynamics, such as the dynamics between dugong, turtles and seagrass is important in

understanding impacts of localised and climate change impacts on habitats and flow-on effects in food chain and fisheries.

The various processes to be represented in the modelling framework are shown in Figure 6. This includes catchment processes, environmental effects (hydrodynamics, transport of sediments and nutrients, physical and biogeochemical processes), fisheries and interacting species and habitat dynamics, and trophodynamics.

We have outlined a suite of desirable model features that will facilitate in-depth understanding of the Torres Strait marine ecosystem. We note, however, that this is an ambitious list that may not be possible with all model frameworks, given limited available information and the level of detail that could be included depends on available funding for model construction. The model should also consider the specific high priority questions that need addressing, and hence whereas some of the features we overview may be essential, others are not or may simply be stretch objectives that could be built on at a later stage.

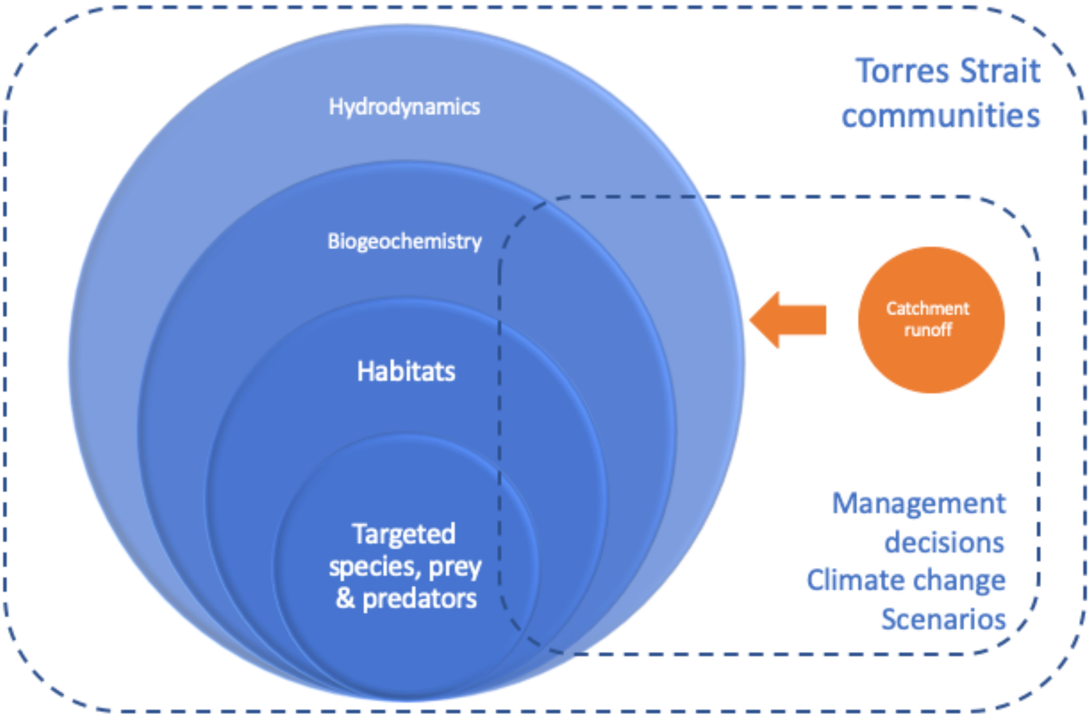

Figure 6. Torres Strait conceptual modelling framework.

9.3 Assessment of data requirements

9.3.1 Data requirements

Biological / Fisheries data

Fishery-dependent data such as catch and effort (and preferably also fishery-independent survey data), are required to simulate populations of the target species, on which potential impacts of localised and climate change scenarios can be assessed. Having a good understanding of biomass of the fishery is important. In general, long-term data is sparse and restricted to certain species but there has been substantial improvements in recent times. Data collection of catches of all commercially fished species in Torres Strait communities has been mandated since 1 December 2017 using the Torres Strait Fish Receiver System and provides valuable information to communities and scientists. Additional voluntary information on changes in fishing behaviour and effort by community sectors would provide important data that can be incorporated in models to communicate information back to communities on status of fisheries, seafood consumption, catches / consumption trends over time. This would support local adaptation efforts and decisions, including the use of traditional knowledge to fishing practices, as well as the identification of socio-economic development needs, which will benefit traditional owners, non-traditional recreational sector and resource managers in Torres Strait (Bedford et al. 2020). The availability of fisheries and related biological data for each of the fisheries investigated in this report is presented in Table 8. The information provided in Table 8 refers only to presence/absence, not on the quantity or quality of data or its limitations. These are provided in Appendix A.

Table 8. Availability of essential data for each of the selected fisheries investigated in this report (TRL: Tropical Rock Lobster, FFISH: Finfish; BDM: Bêche-de-mer). Note that 'availability' may indicate fairly limited data. Details include period of data, references, spatial extent, with more specific information presented in Appendix A.

	TRL	PRAWNS	FFISH	BDM	TURTLES	DUGONGS
Catch location	Y	Y	Y	Y	N	N
Harvest numbers	Y	Y	Y	Y	N	N
Target species identification	Y	Y	Y	Y	N	N
Gear type	Y	Y	Y	Y	Y	Y
Age / Size frequency of catches	Y	N	Y	N	N	N
Species distribution	Y	Y?	Y	Y	N	N
Recruitment survey	Y	N	N	N	N	N
Population size	Y	N	N	Y	N	Y
Growth	Y	Y	Y	N	N*	N**
Reproduction	Y	Y	N	Y	N	Y
Maturity	Y	Y	Y	Y	N	Y

*Data exists for Green turtles in the Southern GBR (Chaloupka et al. 2008).

**Growth rates have been estimated from other sources in the literature (Hagihara et al. 2016).

Habitat data

Distribution and abundance data about habitats supporting the fisheries investigated can be used to assess direct impacts of climate-related events on habitats (e.g. marine heat waves; Duke et al. (2017), Babcock et al. (2019)) and potential flow-on effects (e.g. changes in abundance and distribution) on the fisheries (Plaganyi et al. 2019c). The availability of habitat data for Torres Strait is presented in Table 9. The information provided in Table 9 refers only to presence/absence, not on the quantity or quality of data or its limitations. These are provided in Appendix A.

Table 9. Availability of essential data for habitats supporting selected fisheries investigated in this report. Note that 'availability' may indicate fairly limited data. Details include period of data, references, spatial extent, with more specific information is presented in Appendix A.

	MANGROVES	SEAGRASSES	CORAL REEFS
Location	Y	Y	Y
Area	Y	Y	Y
Species	Y	Y	Y

Physio-chemical data

The following processes (identified in Chapter 8, Table 7) are desirable to incorporate in the modelling framework to evaluate potential impacts of climate change on system functioning and flow-on effects on habitats and species. The availability of physio-chemical data in Torres Strait is shown in Table 10. The information provided in Table 10 refers only to presence/absence, not the quantity or quality of data or its limitations. These are provided in Appendix A. In a general sense, there is limited data showing spatial differences in physical characteristics (e.g. depths and tides), which are important to understand Torres Strait dynamics.

Table 10. Availability of essential physio-chemical data to simulate localised and climate change impacts on fisheries of the Torres Strait region. Details including period of data, references, spatial scale and more specific information are presented in Appendix A.

	DATA AVAILABILITY IN TORRES STRAIT
Currents	Models, Observations
Turbidity	Models, Observations
Temperature	Models, Observations
Tides / water level	Models, Observations
Light	Models, Observations
Nutrients (N & P)	Models, Observations
Salinity	Models, Observations
Sedimentation	Models, Observations
pH	Models, Observations
Oxygen	Models, Observations
Exposure to the air	Related to water level
(Over)grazing	Observations
Extreme events (e.g. rainfall, cyclones)	Observations
Waves / tidal surges	Models, Observations
Moon phase	Modelled
Overfishing	Models, Observations
Diseases & parasites	Limited Observations?

The review of datasets available for Torres Strait revealed significant information covering Torres Strait fisheries, marine species, habitats, geology and physiochemical water quality parameters (Appendix A). However, datasets are sparse both in space and time and, with few exceptions (e.g.

Torres Strait Rock Lobster survey, recent Logbooks and catch disposal records) data have been collected opportunistically mostly due to financial and logistical limitations. A large-scale monitoring program for Torres Strait would support the identification of long-term trends and improve understanding about local and regional processes affecting habitats, species and fisheries (Pitcher et al. 2004), including the impacts of climate change on these. Modelling projects would also provide important insights into where to collect oceanographic data.

Most of the understanding about physical and biogeochemical cycles and processes (e.g. currents, tides, primary productivity, nutrients) in Torres Strait have been derived from remote sensing and hydrodynamic models developed in the 2000s (Hemer et al. 2004, Saint-Cast and Condie 2006, Saint-Cast 2008) and in the early 2010s (Wolanski et al. 2013), each with pros and cons relatively well-known (see Chapter 10.1.2). Limited physical long-term observational data are available and were mostly collected in the 1990s (Wolanski et al. 2013). These models would also benefit from a coherent monitoring program for data collection to reduce uncertainties, validate and improve such models (Pitcher et al. 2004, Margvelashvili et al. 2008, Wolanski et al. 2013).

Habitat, fisheries and ecological data are also sparse, but recent mapping of mangroves, seagrasses and coral reefs (Chapter 6) combined with survey data on substrate and species (Murphy et al. 2020, Plagányi et al. 2020b) offer valuable information about the location and health status of such habitats, which can support the development of models to explore impacts and adaptation options. It takes a long time to gather the financial means to run surveys, and collect adequate time series of data but we do have sufficient data to start modelling to investigate potential climate change impacts on fisheries. In what follows, we proposed a modelling and data framework to answer the research question presented in Chapter 9.1.

10 Proposed modelling and data framework

10.1 Modelling framework

The conceptual modelling framework presented in Figure 7 shows an example of how the different processes could be represented and their impacts on habitats and species, including on different life stages. We present below a summary of common modelling approaches that can be used in the framework based on simulation requirements presented in Chapter 9.2 and data availability for Torres Strait presented in Chapter 9.3. Important to note is that a number of modelling initiatives are already in place in Torres Strait and it would be worth considering capitalising on these efforts. We note also that a modular approach to modelling whereby different detailed components are coupled together rather than developing an entirely new model, may also be a productive method to address integrated modelling needs.

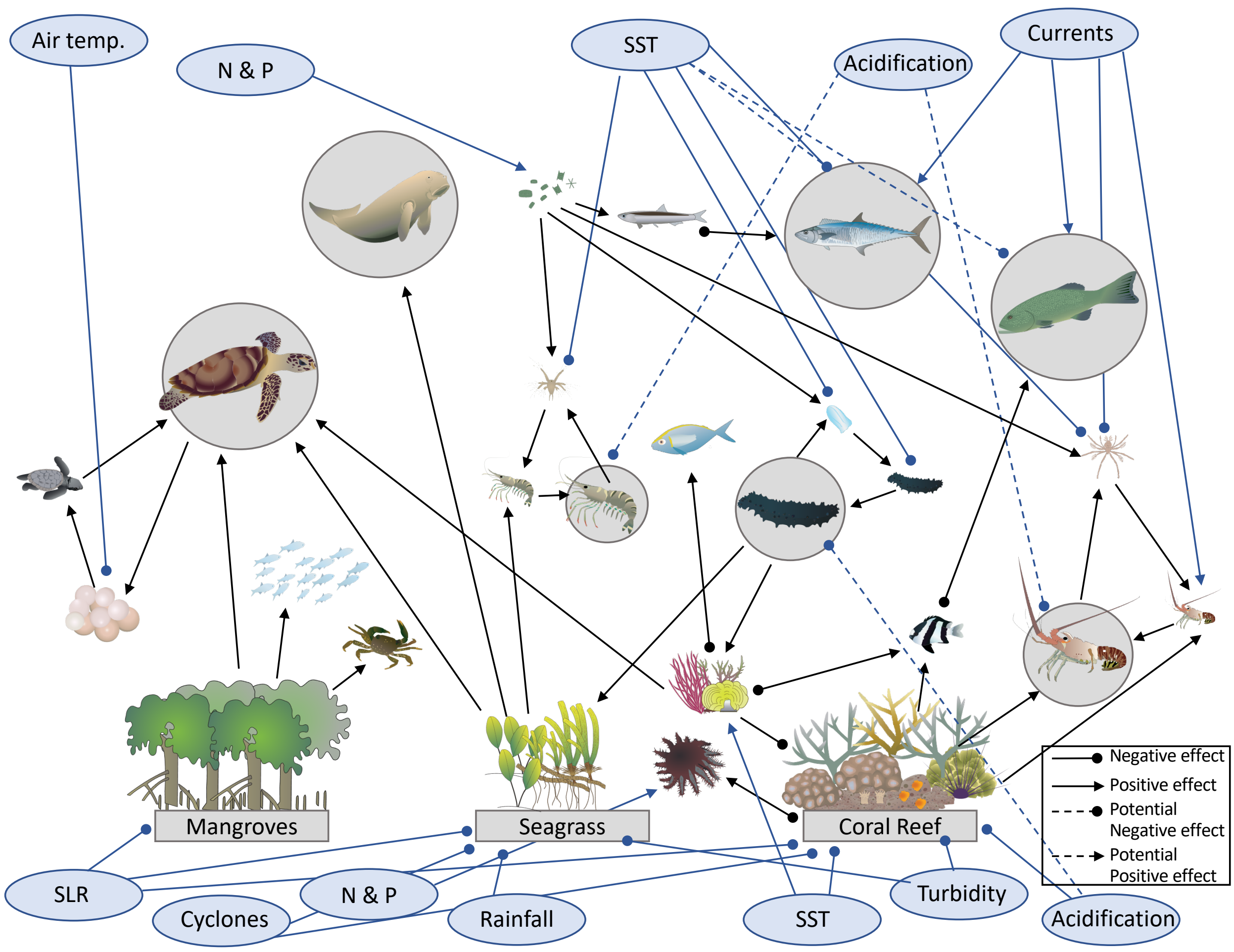

Figure 7. Torres Strait conceptual model framework. Symbols obtained from the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/). Blue lines: direct physio-chemical impacts; black lines: indirect biological / ecological impacts.

10.1.1 Catchment runoff

Catchment models generate outputs of freshwater flows and catchment runoff (nutrients, sediments and other pollutants) using data on soil characteristics, land-use and rainfall as inputs. In terms of impacts on some northern regions of Torres Strait, it is important to evaluate climate change and local impacts on Torres Strait fisheries in the simulation of catchment runoff from the rivers entering the Gulf of Papua (Fly, Purari and Kikori Rivers, and two smaller rivers: the Aramia and Era Rivers; especially mine tailings pollution from the Fly River) (Li et al. 2017), including the impacts of changes in rainfall due to climate change on catchment runoff. There are concerns that plumes from main rivers entering the Gulf of Papua may enter Torres Strait waters (Li et al. 2017), which can potentially impact fisheries resources and critical habitats in Torres Strait (Wolanski et al. 2013, NESP Earth Systems and Climate Change Hub 2018). A recent water quality study by Waterhouse et al. (2018) found trace metal enrichment originating from PNG rivers around the islands of Boigu and Saibai, but the trace metal analysis did not indicate that there was widespread deposition of mine-derived sediments in Torres Strait. Waterhouse et al. (2018) divided Torres Strait into six zones for which the potential risk of influence of Fly River waters varied form very likely to low risk (Appendix B).

10.1.2 Hydrodynamics and transport

A three-dimensional (3-D) fine-resolution hydrodynamic model coupled with a sediment transport model can potentially capture much of spatial and temporal variability of currents, waves, tides and sea level, as well as the sediment, light penetration and pollution characteristics on the shelf. Hydrodynamic models have previously been implemented in the Torres Strait region in the early 2000s and 2010s, using datasets from the 1990s. These models have a number of limitations and effort to address such limitations or re-run these models under different scenarios is likely to be similar to developing a new regional model (N. Margvelashvili pers. communication, June 2020). For example, Saint-Cast and Condie (2006), and Saint-Cast (2008) developed a regional circulation model for Torres Strait based on an 8-year hindcast period (i.e. 01/03/1997–31/12/2004) using realistic forcing fields, including winds, waves, tides, and large-scale regional circulation. Their model is an update from a model developed by Hemer et al. (2004). The model uses a curvilinear grid of approximately 4km resolution. This resolution may not reliably solve hydrodynamic processes in topographically complex areas such as Torres Strait (Wolanski et al. 2017) and would require nesting approaches to improve model resolution. Model outputs include 3-D distributions of velocity, temperature, salinity, and mixing coefficients, as well as two-dimensional fields such as sea level and bottom friction. Wolanski et al. (2013, 2017) developed a depth- averaged 2-D oceanographic hydrodynamic model on an unstructured mesh for Torres Strait. The unstructured mesh allows the spatial resolution to be made locally higher in shallow areas and near coastlines, where small-scale flow features are important, and lower in deeper areas, where the flow is more uniform. However, their modelling approach does not resolve vertical flow structure, which constrains its ability to simulate 3-D processes, thereby resulting in less realistic outputs.

More recently, CSIRO developed a modified Ocean Forecasting Australia Model version 3 (OFAM-v3), a near-global (does not include Arctic region) oceanographic model run under standard IPCC emissions scenarios to project future ocean states around Australia (Zhang et al. 2017, Fulton et al. 2018). These scenarios are taken from global ocean-atmosphere models (CMIP5 climate models), which set the context for the finer scale OFAM-v3 model, which focuses on the Australian region in more detail. The OFAM-v3 model was originally developed for upper-ocean short-range operational forecasting (e.g. ocean forecasts of the type found at the www.bom.gov.au website) and was adapted for climate change studies (Oke et al. 2013). The downscaling simulations run with OFAM-v3 provide monthly surface high-resolution (10km, 0.1^{o}) outputs that can resolve important oceanographic features (e.g. eddies) and how these may change under future climate change. Outputs for two scenarios are available for regions across Australia, including Torres Strait: a) a control scenario without emissions (control) and 2) a high emission scenario (RCP8.5) (Fulton et al. 2018). There were differences between observations in Torres Strait and outputs from downscaled models (Plaganyi et al. 2018b), which suggests the need to develop a regional hydrodynamic model to capture local dynamics (see Chapters 10.1.3, 10.1.4 and Figure 8).

Uncertainty in model predictions in previously deployed hydrodynamic models was high due to lack of adequate data in Torres Strait to specify initial and boundary conditions, as well as poor knowledge of the empirical parameters (Margvelashvili et al. 2008, Saint-Cast 2008, Wolanski et al. 2017). There is a strong need for a monitoring program with extensive spatial and temporal coverage to improve hydrodynamic modelling efforts in the region (Saint-Cast 2008).

Given recent improvements in hydrodynamic modelling capability, it is recommended that a dedicated regional model be constructed for Torres Strait. This will also help resolve differences in observations and predictions from ecosystem models developed for the region (Fulton et al. 2018, Plaganyi et al. 2018b). The effort to re-run previously developed models will likely be similar to deploying an up-to-date state-of-the-art modelling platform such as eReefs, a comprehensive interoperable information platform that has been developed for the Great Barrier Reef (GBR) region (Steven et al. 2019). eReefs is a CSIRO modelling platform that runs hydrodynamic models, sediments and biogeochemistry of the GBR shelf in near real time, routinely producing 3D hydrodynamic fields of the GBR environment on a 4km x 4km grid and building up an archive of such data. It is possible to extend boundaries of eReefs to cover the Torres Strait region and increase model resolution in eReefs by nesting high resolution models (10s to 100s of meters) inside eReefs, through the relocatable coastal ocean model (RECOM) (Steven et al. 2019) in a subset of the regional grid encompassing Torres Strait.

10.1.3 Physio-chemical water quality constituents

Modelling physio-chemical water constituents is important to investigate impacts of future climate (e.g. temperature, pH, salinity, light penetration) on critical habitats supporting the fisheries (Chapter 6), targeted species (Chapter 7) and their predators and prey in Torres Strait (see Chapters 10.1.5 and 10.1.6). Previously deployed hydrodynamic models implemented in Torres Strait have incorporated basic physio-chemical parameters. For example, Saint-Cast (2008) 3-D model simulates temperature and salinity and OFAM-v3 (see description in Chapter 10.1.2) model simulates temperature and salinity for base case and different climate change scenarios. Plaganyi et al. (2018b) analysed observations from Thursday Island, MODIS remotely sensed SST and full time series of CIMP5 outputs. They found that the modelled results exceeded the maximum temperature from observations and MODIS SST each year (Figure 8). Again, these differences between observations and model outputs highlight the paucity of data for the area and difficulties in downscaling oceanic models to a unique strait. This also underscores the need to prioritise data collection of physical variables through a monitoring program to improve modelling efforts in Torres Strait. A range of global and regional observations and model outputs for physio-chemical water quality and specific products are available through special licence arrangements or free of charge that can be used to build new or update existing physio-chemical models (Table 10 , Appendix A).

10.1.4 Biogeochemistry

Biogeochemical models coupled with hydrodynamics are important to understand the links between oceans, land and atmosphere. Such models are important to assess local and climate change impacts on biological and chemical cycles and flow-on impacts on food chains and fisheries in Torres Strait. A biogeochemical model that represents nutrient flows and plankton components of the ocean food web (primary producers such as phytoplankton, some bacteria and zooplankton consumers) was coupled with OFAM-v3 to produce patterns of primary productivity, nutrient cycling and carbon fluxes consistent with observations across Australia (outputs were extracted for Torres Strait). The OFAM-v3 outputs provide downscaled climate change projections for all common ocean state variables including currents, temperature (^{o}C), phytoplankton (mmol Nm^{-3})

and primary productivity (mmol C $m^{-2}day^{-1}$). These outputs were then used as input to ecosystem and fisheries models used to assess impacts of climate change on fisheries across Australia, including Torres Strait (Fulton et al. 2018).

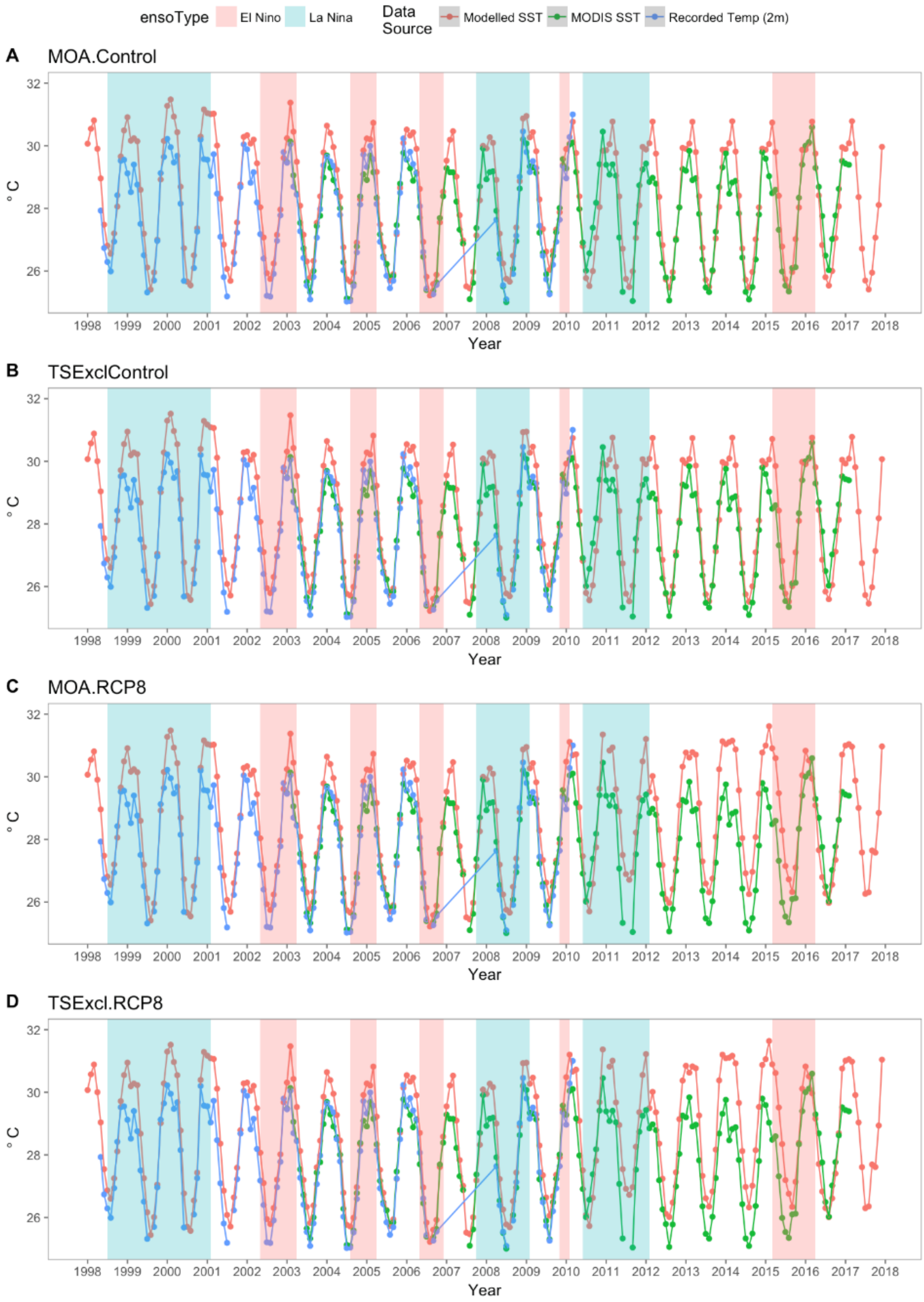

Figure 8. Plots of water temperature (modelled SST, remotely sensed (MODIS) SST and actual water temperature at 2 m depth at Thursday Island). The modelled SST is shown for the Torres Strait model output area (MOA) and the MOA minus the exclusion zone (TSExcl) under two future climate scenarios: no change (Control) and RCP8.5 (RCP8). Major ENSO events are overlaid (Figure from (Plaganyi et al. 2018b).

Sediment transport models have been developed to understand source and fate of sediments, processes maintaining naturally high turbidity in some parts of Torres Strait and the behaviour of sediment plumes from the Gulf of Papua into Torres Strait (Hemer et al. 2004, Margvelashvili et al. 2008, Saint-Cast 2008, Wolanski et al. 2013, Li et al. 2017, Wolanski et al. 2017).

10.1.5 Fisheries dynamics

The dynamics of fish stocks and how they are impacted by fishing can be simulated using models. For key fisheries across the world these are routinely performed as stock assessments. Three main groups of models are used in stock assessments – biomass dynamic models, age-structured models and size-based models (Hilborn 1992). These models, and their derivations, range in complexity and require key biological information on the species modelled, as well as indices of abundance such as catch and effort data generated from the fishery, and where possible, fishery independent survey data. In the Torres Strait region, stock assessment models have been developed for TRL (Plaganyi et al. 2013b, Plaganyi et al. 2018a, Plaganyi et al. 2019a); BDM (Plagányi et al. 2011b, Plaganyi et al. 2013a); Prawns (O'Neill and Turnbull 2006, Turnbull et al. 2009) and Fin Fish (Holden and Leigh 2019, O'Neill 2019).

It is usually difficult to correlate environmental variables with fish stock abundance, particularly for highly variable species such as prawns and TRL, and consequently many stock assessments do not explicitly incorporate environmental variables to help with the prediction of stock abundance. In Torres Strait, this has been the case for the TRL reference case stock assessment model, but there are model versions presented as sensitivities that explicitly incorporate an environmental driver (Plaganyi et al. 2013b)(see section 7.1.5). For the BDM fishery, Plaganyi et al. (2013a) used a set of operating models that incorporated environmental drivers in a Management Strategy Evaluation approach (Rademeyer et al. 2007, Punt et al. 2016) to evaluate the performance of alternative fisheries management strategies under varying climate scenarios.

When considering broader ecosystem impacts on fisheries, ecosystem models of varying complexity, depending on the questions being asked and data available, can be used to simulate changes in the environment, including from climate and flow-on effects to fisheries and vice-versa.

Fishery ecosystem models range from those that are simple in structure and complexity, representing only a simplified part of the system (e.g. one or two species), to those that have high complexity and capture many components of the system (e.g. whole of ecosystem models; see Chapter 10.1.6) (Collie et al. 2016). The former are usually fitted to fishery data (e.g. stock assessment models) and thus used for tactical (i.e. day-to-day) decision making, while the latter, which are not always fitted to data, often display large parameter uncertainty and are used more for strategic purposes (Collie et al. 2016). Models of intermediate complexity for ecosystem assessments (MICE; Plagányi et al. 2011a) fall somewhere in the middle. MICE aim to simulate key components of the system and thus only the most important species are represented e.g. the fished species and those that most closely interact with it. Where possible, these components are fitted to data, allowing these models to also be used for tactical decision-making purposes, with the benefit of considering other components such as habitats in the ecosystem.

Stock assessment models are a useful start for capturing the dynamics of key resources in the TS region, which can then be used to “ground-truth” larger whole of system models or can be added to by including other components of interest or for which there are data available, for example using a MICE model.

10.1.6 Ecological relations

Simple qualitative network-based representations of ecosystems, including ecological relations and system drivers, are a useful start to conceptualise the system and highlight key components and stressors (Plagányi et al. 2011a, Melbourne-Thomas et al. 2013, Metcalf et al. 2014, Dambacher et al. 2015, Fulton et al. 2019). Conceptual and qualitative models therefore provide better insight into ecosystem form and function before moving to more complex models. Information for these simple network models can be (and is) sourced from literature and engagement with stakeholders such as fishers, researchers and other sources of local ecological knowledge. These qualitative network models can then be developed into quantitative models, whose form and complexity will depend on their purpose and data available.

Ecosystem models commonly applied to marine systems include complex whole of system models such as Ecopath with Ecosim (EwE)(Christensen and Walters 2004) and Atlantis (Fulton et al. 2011a), and models of intermediate complexity such as MICE (Plagányi et al. 2011a). Socio-ecological models are increasingly being developed to account for the human dimension (Fulton et al. 2011b, Plagányi et al. 2014, van Putten et al. 2018, Hornborg et al. 2019).

EwE is a mass-balanced model, typically representing the entire ecosystem from detritus through to top-predators using built-in trophic relationships that track the flow of energy through the system. The model is forced by primary productivity and typically doesn’t include links to environmental variables. Various sources of data are required for each species/trophic group and are usually gathered from research in the region of interest, or if not available, from similar systems elsewhere. EwE models have been created for many marine ecosystems around the world (e.g. Colleter et al. 2015). EwE models therefore have many advantages such as being relatively quick and easy to implement, but they also have a number of disadvantages such as those outlined in Plaganyi and Butterworth (2004).

Similar to EwE, Atlantis represents the whole system, but at a finer resolution including age and size components. Atlantis is a dynamic system model that attempts to represent both bottom-up (physical) and top-down (biological) forces interacting in an ecosystem (Fulton et al. 2011a). It is forced by environmental variables such as temperature, salinity and physical oceanographic variables. Anthropogenic activities can also be included in the system. Atlantis has a range of successful applications to support strategic decisions around the world and is highly regarded by modellers as one of the best approaches for addressing very broad ecosystem issues (Plagányi et al. 2011a). Atlantis models have the advantage of including a very large amount of complexity and components of the ecosystem. The disadvantage though is that there is considerable uncertainty associated with several components and hence these models are more suited for addressing strategic insights than tactical applications. These models are also relatively expensive with a long development time typically needed. An Atlantis model has been developed for the Coral Sea to look into fisheries management and climate change impacts (Hutton et al. 2017). A Torres Strait Atlantis model would need to be adapted/fine-tuned for just the Torres Strait region, which is quite distinct from the rest of the east Australian coast (Wolanski et al. 1988).

Unlike whole of system models, MICE only focus on representing key components in a system. Both trophic and non-trophic relationships can be modelled and are custom added as necessary (i.e. not already built-in as with EwE trophic relationships). MICE can include both temporal and spatial resolution, and if data are available, they can link environmental variables (e.g. temperature) to a species, e.g. through linking to recruitment or survival. MICE rely on stakeholder input to help capture key processes and links within the ecosystem and importantly they rely on fitting to data and thus can better account for uncertainty than many whole-of-system models, an important requirement in fisheries and ecosystem management. A limitation of this approach is that it does not consider all components in an ecosystem, but as a result these models are more question focussed, quicker to develop than Atlantis models, and they provide more rigorous predictions which can be used in ecosystem assessments (rather than broad strategic insights only).

MICE have been developed for a range of ecosystems, including coral reefs south of Torres Strait on the GBR to assess effectiveness of various measures in controlling Crown-of-Thorns Starfish (COTS) outbreaks (Morello et al. 2014). A spatial MICE is also currently being developed for the Gulf of Carpentaria to the west of Torres Strait, looking at impacts of reduced riverine water flow on prawns and other key species and associated fisheries (Plagányi et al. 2020a).

Morello et al. (2014) used a MICE to model trophic interactions between COTS and two types of coral on a reef in the GBR. By fitting to data, they were able to quantify COTS prey-switching between two types of coral prey. Parameters from this model were then used to help model trophic interactions in a larger metacommunity model, i.e. scaled to the whole GBR (Condie et al. 2018). This is an example of how models can be combined at different scales to address questions pertaining to local through to more regional scales. Some simple MICE (seagrass-dugongs and TRL) have been developed in Torres Strait, covering the areas to the west and east of Torres Strait (Fulton et al. 2018)

Modelling approaches can produce different outputs for similar fisheries (e.g. Atlantis model predicts that lobster populations will increase with climate change (Fulton et al. 2018), while MICE predicts a decline (Plaganyi et al. 2018b). Such discrepancies can be resolved by constructing a specific regional ecosystem model to assess climate change impacts on Torres Strait fisheries.

A more suitable strategy to develop ecosystem models for Torres Strait would be to develop some sort of hybrid MICE-Atlantis approach drawing on features from both approaches. There are existing examples of MICE that have successfully been coupled with general circulation models (Tulloch et al. 2019). Approaches such as these and other system-level hybrid models, which bring together the strengths of various modelling approaches, can represent each component of the system in a way that best captures that system and the data available (Fulton et al. 2019). The Torres Strait region will likely need a mix of modelling approaches that feed into one another. For example, it could start with conceptual / qualitative model of the ecosystem representing key fished species and other components of the ecosystem which are important for / linked to them, including drivers and stressors. Different model structures can be tested using qualitative network or other models to inform the development of a MICE or more complex ecosystem model(s).

A more pragmatic and cost-effective approach would be to develop a regional hydrodynamic model that simulates basic physical and biogeochemical processes coupled to fisheries, ecological or ecosystem models. Given there are already assessment models developed for some of the key species (e.g. TRL, BDM, prawns), a useful starting point would be to combine these in an integrated spatial MICE for the Torres Strait region. Modelling key species using MICE can include uncertainties and provide valuable information on their ecological status and integrating this information with stock assessments. Outputs/parameters from MICE can be fed into a more complex ecosystem model or help to ground-truth a larger more complex model. The modelling approach should be iterative with models developed and refined with improved understanding about the system.

Traditionally most marine ecosystem models have focused on physical and ecological components but it is increasingly recognised that the human dimension is important too (Fulton et al. 2011b). This is particularly the case in Torres Strait because of the close relationship with and custodianship of traditional owners towards their marine environment, as well as dependency on marine resources. Socio-ecological models are still in the early stages of development (Thebaud et al. 2017), but to the extent feasible, it would be advantageous to integrate social and cultural considerations into any ecosystem modelling approach. It may also be possible to draw on previous work as part of the Torres Strait lobster MSE project which integrated economics considerations, as well as coupling a Bayesian Belief Network (BBN) approach (van Putten et al. 2013b) with ecological and economic components (Pascoe et al. 2013), thereby integrating aspects of the social dimension to support operationalising a triple bottom line approach (Plaganyi et al. 2013b, Van Putten et al. 2013a).

10.2 Data framework

In order to support future modelling work to explore impacts of climate change in Torres Strait fisheries we propose the development of a data framework that identifies how the physio-chemical and ecological data should be managed and delivered to support the development of models. Consideration of confidentiality of some data (e.g. fisheries data) will be required. The assumption used to describe the future data framework project is that datasets will be managed on CSIRO IT infrastructure, utilising relational database systems and enterprise file servers. Datasets will be described using geonetwork (www.marlin.csiro.au) and these descriptions can be made public to allow third parties (non-CSIRO) to access data depending on level of permission granted (i.e. licence restrictions). Datasets can be shared using Open Geospatial Consortium (OGC) standards where appropriate, by using a standards-compliant webserver (geoserver) linked to the collated data. This framework is scalable, robust and compliant with open data/metadata standards, allowing a flexible data delivery method. The detailed specification of how the physical data should be managed and delivered is therefore the key output of the project, and is specified below and Figure 9.

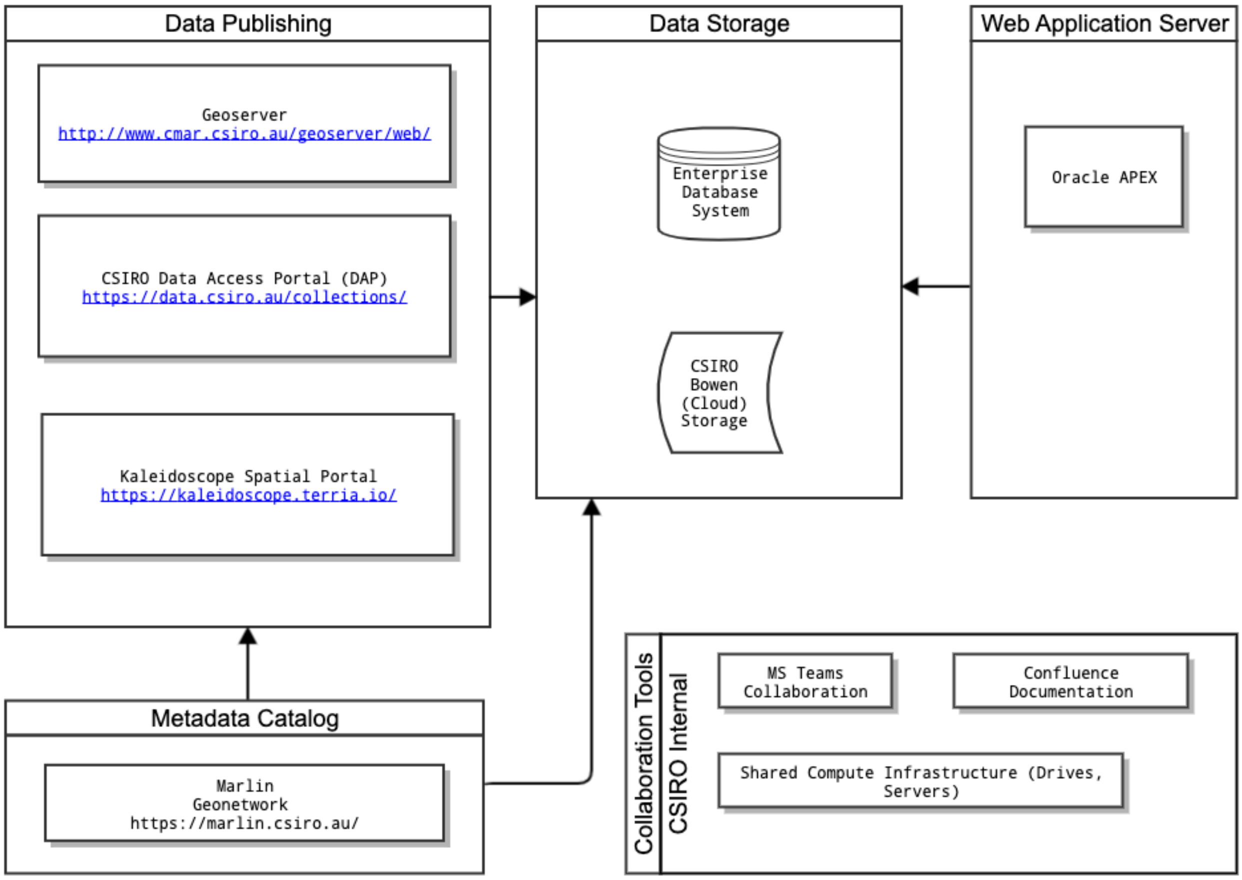

Figure 9. Data and modelling connections.

10.2.1 Data storage

Datasets are managed on CSIRO infrastructure where possible, making use of relational database systems, enterprise file systems and CSIRO's Bowen Cloud infrastructure (cloud-based storage systems). This ensures that data services are available to scientists, secure and provide a scalable platform to meet the expected data growth demands. The Bowen Research Cloud is an internal cloud resource that provides cloud storage for projects and virtual compute resources for data processing. The storage capability caters for datasets up to multiple terabytes. The Oracle database run by CSIRO Oceans & Atmosphere Business Unit is used to store structured information in a relational database system, and can provide an environment to manage information on the range of targeted datasets.

10.2.2 Data access / web services

To facilitate access to data across different analysis tools and platforms, data services will be configured to provide access to the various datasets. The open source Geoserver software will be used where the data is predominantly spatial in nature, and Geoserver supports the Open Geospatial Consortium (OGC) Web Feature Service (WFS) and Web Mapping (WMS) specifications. WFS and WMS provide a standard mechanism to exchange vector and image data respectively over http(s). Provision of fine-grained access to the data allows additional services - particularly spatial mapping or "spatial portals" - to be developed utilising standard data ingestion methods, leading to additional data visualisation tools.

10.2.3 Metadata (marlin)

The CSIRO marlin metadatabase is based on open standards, and provides a mechanism to store information on datasets in a standard way, and share this information with other web applications. It is based on Geonetwork (https://geonetwork-opensource.org/), an open source metadata system, and stores information using the Marine Community Profile, which is a profile of the latest ISO standard for encoding Geographic metadata information (ISO 19115-1:2014). This enables information to be exchanged readily with other services that are based on these open standards - in particular the Australian Ocean Data Network (AODN; https://portal.aodn.org.au/).

10.2.4 Visualisation (spatial portal / Kaleidoscope)

Datasets that are actively stored and managed within this project will be connected to allow visualisation and provide access to a broad range of users. CSIRO's Ocean & Atmosphere and Data61 business units are partnering to develop a spatial portal - Kaleidoscope - that is based on TerriaJS. This software is open source, and backs other portals such as Australia's National Maps data initiative (https://nationalmap.gov.au). This software uses open protocols and open data formats to access data, and provides a web-based platform for spatial data visualisation and analytics. This portal will provide capacity, as an ongoing service, to host, display and distribute spatial data from our centralised repositories, to support the ongoing requirements of data users.

A web-based database will be developed to track details on the datasets and model outputs that were identified in the initial stages of this project. Datasets will be managed on CSIRO infrastructure where possible, including relational database systems, enterprise file systems and CSIRO's Bowen Cloud infrastructure. This ensures that data services will be available to scientists, will be backed up, and will be secure.

10.2.5 Spatial scale

The boundaries for regional hydrodynamic model should include all important fishery areas in Torres Strait (https://www.pzja.gov.au/the-fisheries). We propose to use such regional scale coarser grid using boundaries defined in Plaganyi et al. (2018b)(Figure 10):

A. Top left coordinates: 9^{o} 08’ 24.83” S / 141^{o} 01’ 0.00” E

B. Bottom Right coordinates: 11^{o} 10’ 0.00” S / 144^{o} 28’ 0.00” E

The quadrants defined in the Tropical Rock lobster survey (Plagányi et al. 2020b/ Figure 11) are the primary spatial units (or areas) for ecological modelling and finer-scale (RECOM) hydrodynamics because of North/South differences in lobster growth rates, different fisheries in West and East, different oceanographic processes influencing the Eastern part of the Torres Strait (e.g. cooler upwelling intrusions into the area prevented bleaching), and northern region more influenced by runoff from PNG rivers and then also captures differences in underlying strata and habitat types. We would consider extending the eastern border of the Tropical Rock lobster survey quadrants or adding an additional spatial unit further to the east to include fisheries in the eastern Torres Strait, depending on how finely resolved the underlying oceanography is.

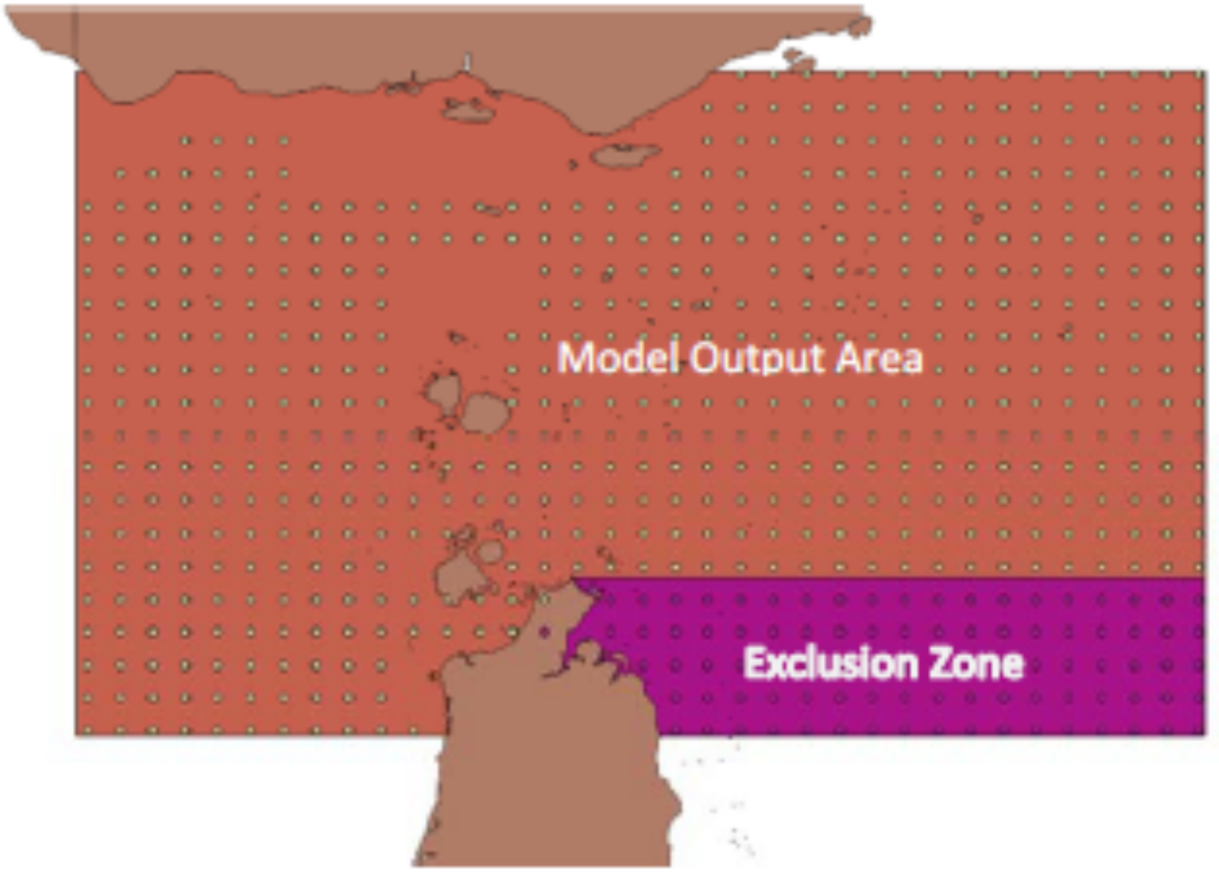

Figure 10. Proposed modelling region defined by: A) Top left coordinates: 9° 08' 24.83" S / 141° 01' 0.00" E, and B) Bottom Right coordinates: 11° 10' 0.00" S / 144° 28' 0.00" E.

For finer spatial scale within each quadrant if wanting to capture more localised oceanographic drivers and ecological processes, or if wanting to model the impacts on fisheries in the eastern side of Torres Strait, ecological modellers can opt to use the Management Strategy Evaluation sub-areas as previously implemented by Plagányi et al. (2020b) (Figure 12). These sub-divisions align broadly with fishery data and habitat characteristics although are not perfectly aligned with community spatial locations. Such subdivisions can facilitate the development of even finer-scale (e.g. RECOM) hydrodynamic models to support the evaluation of specific questions around particular ecosystems or fisheries.

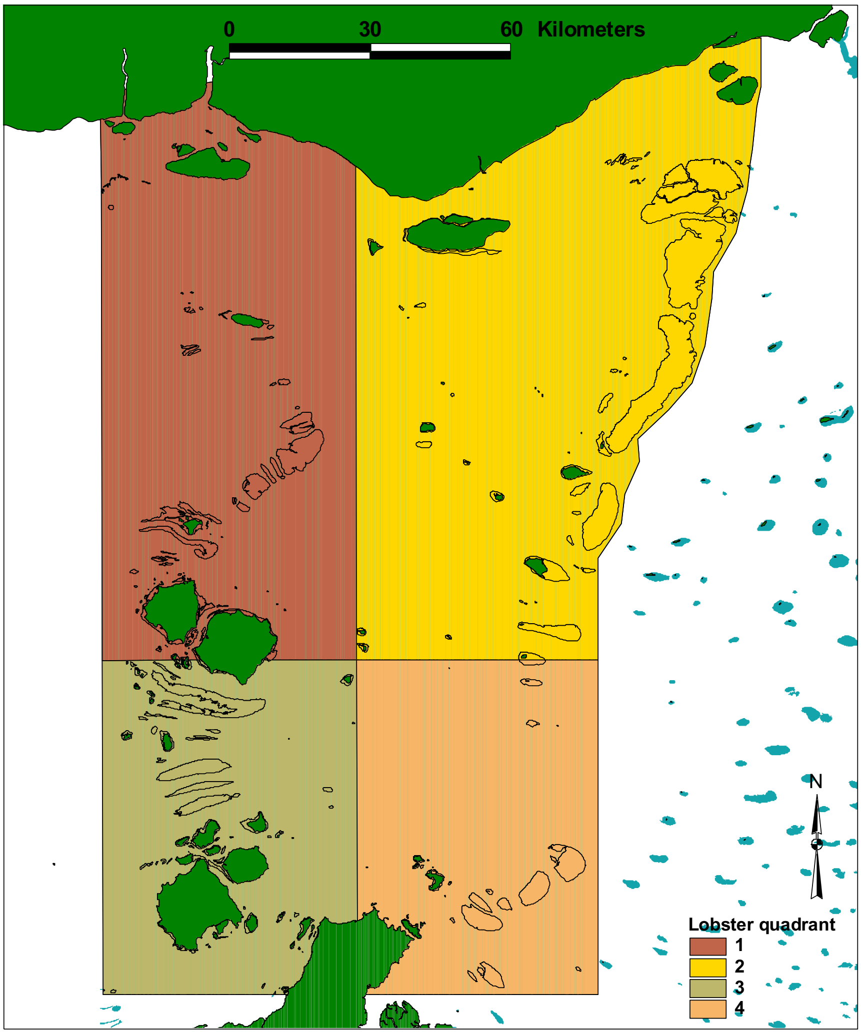

Figure 11. The area of the Torres Strait lobster survey split into four quadrants centered on 10.21 degrees S and 142.5 degrees E (from Plagányi et al. 2020b).

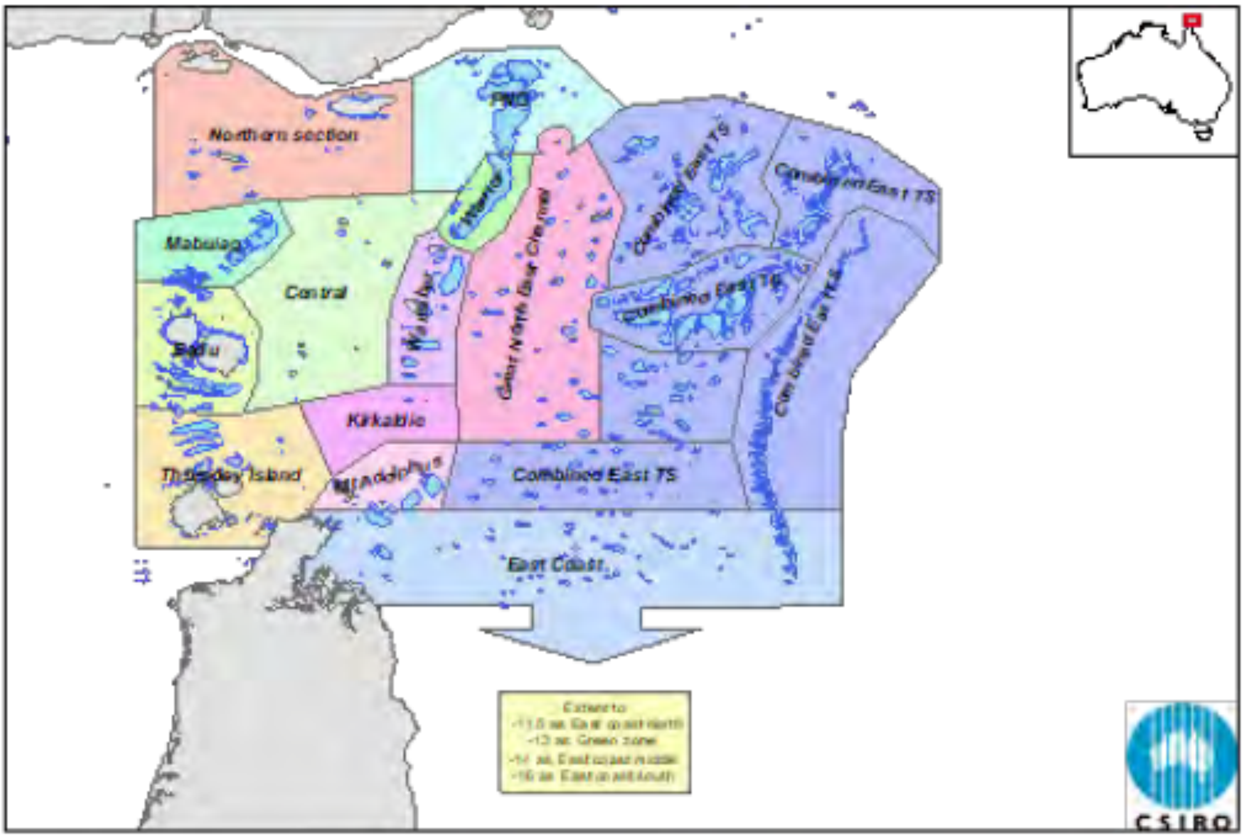

Figure 12. Proposed modelling sub-areas (source: Plaganyi et al. 2018b).

Modelling approaches were developed for TRL, BDM and dugongs in the past, considering environmental (including climate change drivers) and these can be improved as more data is now available since these models were developed. It takes a long time to organise surveys and collect adequate time series of data but as discussed in Chapter 9, sufficient data are available to start modelling. Efforts to improve data collection should be done in parallel so model refinements can be done when data from such monitoring program becomes available.

In summary, starting the modelling exercise sooner rather than later would provide a framework to utilise existing datasets and investigate potential climate change impacts on the fisheries and there are sufficient data available to start modelling. Our recommended approach would be to build the models in a stepwise fashion, adding new data and complexity as these become available or necessary. This also allows time to start obtaining feedback from stakeholders on preliminary model results, which allows time to communicate the usefulness of models as well as how to draw on local knowledge to further refine models.

The data framework described is needed to support the proposed modelling exercise to investigate impacts of climate change on the selected fisheries, but will also support other future research efforts in the region. Many ecosystem models involve coupling together different components and this is also how we envisage development of an ecosystem model proceeding – hence the starting point is to extend and link the current biological models of key species (e.g. TRL, BDM, dugongs), add current known environmental drivers (e.g. SST), gradually add other species (e.g. seagrass, finfish, turtles) and link with prelim hydrodynamic models or model outputs to start adding complexity associated with the oceanographic setting. A fully integrated couple hydrodynamic model usually takes a few years and is an expensive process so we recommend starting small and gradually expanding.

11 Preliminary costs of future project/s

1) The cost of a future project that will produce the over-arching data framework at the appropriate spatial scales, as required to address future climate variability and change scenarios for Torres Strait fisheries (i.e. deliver on Chapter 10.2) is approximately 0.4-0.5 FTE for 1 year or rough estimate of A$130k
2) We also strongly recommend a parallel project to initiate development of an integrated MICE-ATLANTIS modelling framework based on existing data to consolidate knowledge, fill gaps and support planning and adaptation in Torres Strait. Consideration should be given to drawing on existing assessment models available for some of the key species (e.g. TRL, BDM and dugongs). This would require approximately 0.5-0.7 FTE over each of 2 years, or rough estimate of $460k.
3) Developing a regional hydrodynamic modelling platform, such as eReefs, to provide link with ecological models would require approximately 0.3-0.5FTE over each of 2 years, or rough estimate of $350k

12 Conclusions and recommendations

12.1Conclusions

The first objective of this report was to detail findings from a literature review on the main climate change drivers in Torres Strait affecting tropical rock lobster, bêche-de-mer, finfish, prawns, turtles and dugongs, including a review on local and climate change threats to habitats and species (Parts 1 and 2).

- Anthropogenic impacts (other than climate change) in Torres Strait are relatively minor, but exist in specific locations. Torres Strait is, however, relatively highly vulnerable to shipping accidents, with this being recognised by TSRA (Carter et al. 2013) and oil spill risk may be important to consider in an ecosystem modelling framework.
- Local impacts include sediment runoff and metal pollution from the Fly River (PNG), localised oil contamination, mangrove cutting, alteration of hydrology, nutrient and sediment runoff, and chemical contamination.
- Fishing is an additional anthropogenic impact source. Most marine living resources have been managed sustainably but there are examples of past overharvesting (most notably Sandfish and Black teatfish) and this needs to be considered.
- Climate change is already affecting Torres Strait fisheries and culture. Impacts from climate change include higher sea levels and associated coastal erosion, warmer atmospheric and

ocean temperatures, more acidic waters, changes in ocean circulation, and more intense rainfall events.

- Although relatively minor, simultaneous local impacts (e.g. untreated sewage, chemical, sediment and nutrients runoff, oil pollution, overfishing) can act together with climate change impacts, such as sea-level rise, ocean warming and acidification, leading to interactive, complex and amplified impacts for species and ecosystems.
- These pressures manifest directly in the form of changes in abundance, growth, reproductive capacity, distribution and phenology (changes in cyclic and seasonal phenomena such as reproduction and migrations), and indirectly through changes in habitats.
- Invertebrates (Tropical Rock Lobster, prawns, bêche-de-mer) are likely to be more impacted by climate change than vertebrates (Finfish, turtles and dugongs). This is *inter alia* because although highly productive, their life spans are short, which makes it difficult for them to move out of a certain area severely impacted over many years before significant losses at the population level happen (Fulton et al. 2018).
- Climate change is likely to cause mostly negative direct effects on the fisheries investigated in this report, but some effects may also be positive, especially in the short to medium-term. If climate-related environmental changes exceed certain limits or ranges for species, they will either move if possible or have their abundance reduced (Pecl et al. 2014, Fulton et al. 2018).
- High water temperature can cause mortality, affect growth (relatively small warming may increase growth rates of sea cucumber and lobsters), reproduction and its timing, and negatively affect supporting habitats (coral reefs, seagrasses) of Finfish, invertebrates, dugongs and turtles. Elevated air temperatures can also reduce incubation success, shift timing of annual breeding cycle and increase 'feminisation' of Green turtle populations.
- Higher seas and extreme weather events can uproot mangrove trees and cause erosion and increase in turbidity, with consequent reduction in light penetration and salinity and an increase in sediment deposition, negatively affecting seagrasses and coral reefs. Some organisms, such as sea cucumbers may benefit from higher seas, but others like turtles and dugongs may be negatively affected via changes in abundance of preferred food (e.g. seagrass) and also via the inundation of nesting sites (turtles) and stranding (turtles and dugongs) associated with extreme weather events.

The second objective of the report was to use findings from the literature review to provide a detailed specification and costings for a future project that will produce an over-arching data framework at the appropriate spatial scales, as required to address future climate variability and change scenarios for Torres Strait fisheries, including detailed information about data availability, and specifications on data storage, management and data accessibility issues (Part 3).

- The data and modelling framework will primarily be designed to answer the following question: *What are the potential consequences associated with changes in local conditions, including climate variability and change, on the selected Torres Strait Fisheries and ecosystems?*
- The objectives of the modelling exercise are to simulate future climate scenarios and assess the impacts of these on fisheries and associated habitats and species through

quantitative evaluation. It will support the exploration of responses and strategies to manage the selected Torres Strait fisheries, such as the evaluation of:

1) Interactions between different fisheries and broader ecosystem functioning, including consideration of communities that rely on these resources;

2) Impacts of climate change scenarios on the abundance and distribution of selected species;

3) Impacts of current and future catchment conditions and management scenarios on fisheries;

4) Impacts of incidents (e.g. oil spills, ships run aground) on fisheries;

5) Combined scenarios of 1-4 to develop strategies that are robust across impacts and fisheries; and

6) Evaluation of alternative adaptation options.

- In order to address objectives, some of the desirable features of the modelling framework include: 1) Catchment runoff; 2) Hydrodynamics and transport; 3) Physio-chemical water quality constituents; 4) Biogeochemistry, 5) Fisheries dynamics; and 6) Ecological and socio-ecological relationships.
- Data requirements to simulate these desirable features include: a) biological and fisheries data (catches, catch locations, target species, gear, age and size frequency of catches, species distribution, growth rates, reproduction and maturity, mortality and population size); b) location, area and species of supporting habitats (mangroves, seagrasses and mangroves); and c) physical and biogeochemical data (currents, turbidity, temperature (air and sea), tides and water level, light penetration, nutrients, salinity, sedimentation, pH, oxygen, grazing, extreme events, waves, moon phase, diseases and parasites).
- There is significant information covering Torres Strait fisheries, key marine species, habitats, geology and physiochemical water quality parameters. However, datasets are sparse both in space and time. A large-scale monitoring program for Torres Strait would support the identification of long-term trends and improve understanding about local and regional processes affecting habitats, species and fisheries (Pitcher et al. 2004), including the impacts of climate change on these (NESP Earth Systems and Climate Change Hub 2018).
- Most of the understanding about physical and biogeochemical cycles and processes (e.g. currents, tides, primary productivity, nutrients) in Torres Strait have been derived from remote sensing and hydrodynamic models developed in the 2000s and in the early 2010s, each with pros and cons relatively well-known. Limited physical long-term observational data is available as was collected mostly in the 1990s (Wolanski et al. 2013).
- Habitat, fisheries and ecological data are also sparse, but recent mapping of mangroves, seagrasses and coral reefs (Chapter 6) combined with survey data on substrate and species collected in large-scale sea cucumber and Tropical Rock Lobster surveys (Murphy et al. 2020, Plagányi et al. 2020b) offer valuable information about the location and health status of such habitats, which can support the development of models to explore impacts and adaptation options.
- A number of modelling initiatives are already in place in Torres Strait and it would be worth considering capitalising on these efforts.

- It is recommended that a dedicated regional hydrodynamic model, including physics and biogeochemistry be constructed for Torres Strait as the effort to re-run previously developed models will likely be similar to deploying an up-to-date state-of-the-art modelling platform such as eReefs, which has been developed for the Great Barrier Reef (GBR) region (Steven et al. 2019).

- A suitable strategy to develop ecosystem models for Torres Strait would be to develop some sort of hybrid MICE-Atlantis approach drawing on features from both approaches and coupled with a regional hydrodynamic model.
- The Torres Strait region will likely need to integrate a mix of modelling approaches that feed into one another, built in a stepwise fashion, such as the development of conceptual / qualitative model of the ecosystem, representing key fished species and other components of the ecosystem which are important for/linked to them, including drivers and stressors. Different model structures can be tested using qualitative network or other models to inform the development of a MICE or more complex ecosystem models.
- A cost-effective approach would be to couple a regional hydrodynamic model that simulates basic physical and biogeochemical processes with an ecological or socio-ecological model. Given there are already assessment models developed for some of the key species (e.g. Tropical Rock Lobster, bêche-de-mer, prawns), a useful starting point would be to combine these in an integrated spatial MICE for the Torres Strait region. This can form the basis of a more complex ecosystem model or help to ground-truth a larger more complex model.
- The proposed data framework identifies how the physio-chemical and ecological data could be managed and delivered to support the development of models. Datasets will be managed on CSIRO IT infrastructure, utilising relational database systems and enterprise file servers. Datasets will be described using geonetwork (www.marlin.csiro.au) and these descriptions can be made public to allow third parties (non-CSIRO) access data depending on level of permission granted (i.e. licence restrictions). Datasets can be shared using Open Geospatial Consortium (OGC) standards where appropriate, by using a standards-compliant webserver (geoserver) linked to the collated data. This framework is scalable, robust and compliant with open data/metadata standards, allowing a flexible data delivery method.

12.2 Key Recommendations

1. Prioritise physical data collection and further strengthen and expand a large-scale monitoring program for Torres Strait that would support the identification of long-term trends and improve understanding about local and regional processes affecting habitats, species and fisheries, and to support the development of models.
2. Staged approach in the development of an integrated ecosystem modelling framework to investigate the impacts of climate and local changes on fisheries in Torres Strait, via coupling together:

a. Development and implementation of data framework to support future modelling efforts in Torres Strait

b. Development of integrated ecological or socio-ecological models capable of integration with a regional hydrodynamic model:

   i. For example, combining existing data and models (Tropical Rock Lobster, bêche-de-mer, and dugongs) into an integrated spatial MICE, which will form the basis for a hybrid MICE-ATLANTIS ecosystem model;

   ii. Dedicated regional hydrodynamic model, including physics and biogeochemistry for Torres Strait, for example similar to eReefs.

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PZJA advisory committee	Position	Name
TRL RAG	Chairperson	Ian Knuckey
TRL RAG	Scientific member	Eva Plaganyi
FF RAG and FFWG	Chairperson and Sci Member	David Brewer
FF RAG and FF WG	Scientific member	Michael O'Neill
FF RAG	Scientific member	Rik Buckworth
FF RAG	Scientific member	Ashley Williams
FF WG	Permanent observer, scientific	Trevor Hutton
HCWG	Scientific member	Tim Skewes
HCWG	Scientific member	Steven Purcell
TSSAC	Chairperson	Ian Cartwright
TSSAC	Scientific member	Roland Pitcher
PrawnMAC	Scientific member	Clive Turnball
-	Climate and Coastal, TSRA	John Rainbird
-	AFMA	Selina Stoute
-	AFMA	Danait Ghebrezgabhier
-	AFMA	Georgia Langdon
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Appendix A Available data

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
1	Fisheries	Prawn	AFMA	Logbooks and catch disposal records	Observation al	1978	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005. Data is scattered until 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
2	Fisheries	Prawn - Tiger	AFMA	Logbooks and catch disposal records	Observation al	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
3	Fisheries	Prawn - Endeavour	AFMA	Logbooks and catch disposal records	Observation al	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
4	Fisheries	Prawn - King	AFMA	Logbooks and catch disposal records	Observation al	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
5	Fisheries	Prawn - Vessels	AFMA	Logbooks and catch disposal records	Observation al	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
6	Fisheries	By-Catch Flatback Turtle	AFMA	Logbooks and catch disposal records	Observational	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
7	Fisheries	By-Catch Green Turtle	AFMA	Logbooks and catch disposal records	Observational	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
8	Fisheries	By-Catch Hawksbill Turtle	AFMA	Logbooks and catch disposal records	Observational	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
9	Fisheries	By-Catch Loggerhead Turtle	AFMA	Logbooks and catch disposal records	Observational	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
10	Fisheries	By-Catch Pacific (Olive) Turtle	AFMA	Logbooks and catch disposal records	Observational	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
11	Fisheries	By-Catch Turtles	AFMA	Logbooks and catch disposal records	Observation al	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
12	Fisheries	By-Catch Sawfish	AFMA	Logbooks and catch disposal records	Observation al	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
13	Fisheries	By-Catch Seasnakes	AFMA	Logbooks and catch disposal records	Observation al	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
14	Fisheries	By-Catch Seahorses and Pipefish	AFMA	Logbooks and catch disposal records	Observation al	2015	2019	catch and effort information for the Torres Strait Prawn Fishery (TSPF) from the 2019 fishing season in comparison to previous years.The PZJA collect data for the TSPF through both operator completed daily fishing logbooks and an automatic Vessel Monitoring System (VMS) established in 2005.	on request to AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia.
15	Fisheries	Sea cucumbers	AFMA	Bêche-de-mer Fishery-dependent data (logbooks)	Observation al	2017	2020		on request to AFMA	https://www.afma.gov.au/fisheries-services/logbooks-and-catch-disposal

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
16	Fisheries	*Coral trout (Plectropomus spp.)*	partly in the paper	Population biology of coral trout species in eastern Torres Strait: Implications for fishery management	Modelled and Observational	2004	2005	Information on the catch composition of coral trout species was obtained during observer surveys on board Islander and nonindigenous. Authors used modelled growth curves for coral trout. commercial vessels operating in the ETS		Williams, A. J., L. M. Currey, G. A. Begg, C. D. Murchie and A. C. Ballagh (2008). "Population biology of coral trout species in eastern Torres Strait: Implications for fishery management." Continental Shelf Research 28(16): 2129-2142.
17	Fisheries	*Dugong dugon*	CSIRO NERP	Quantification of risk from shipping to large marine fauna across Australia. Dugong	Modelled	2013	2015	Broadscale and finescale dugong vessel strike risk maps (2013-15). Also for other species: humpback whale, green turtle, seagrass locations and generic species	unknown	https://www.marlin.csiro.au/geonetwork/srv/eng/search#!40e7e293-e5e2-4d46-9611-c2db22182b24
18	Fisheries	*Dugong dugon*	Not clear. Needs search	The Torres Strait Dugong Fishery	Modelled	1991	1993	Population estimates and yield. 1994 Torres Strait Dugong fishery report	unknown	http://www.cmar.csiro.au/datacentre/torres/AFMA1980_2003/DVDVer101/Reports/r494.pdf
19	Fisheries	*Dugong dugon*	Not clear. Needs search	1991 The Status of the Dugong in Torres Strait	Observational	1987	1988	Observed count. Population estimate	unknown	researchgate.net/publication/237260190_The_Status_of_the_Dugong_in_Torres_Strait
20	Fisheries	*Dugong dugon*	https://dugongs.tropicaldatahub.org/	JCU Dugong aerial survey database	Observational	1984	2013	Online database of aerial surveys	Near CC. Details at https://dugongs.tropicaldatahub.org/	https://research.jcu.edu.au/researchdata/default/detail/70987a255de5bba750bd671901009ac3/
21	Fisheries	*Dugong dugon*	Not clear. Needs search	Stock Assessment Report on Dugong in the Torres Strait 1994	Modelled	1994	1994	Stock assessment report. Population estimates and yield	Copyrighted	http://dugong.id.au/publications/TechnicalReports/Marsh%201995.%20Torres%20Strait%20Dugong%20Stock%20Assessment%20Report.%20T~1.pdf
22	Fisheries	*Dugong dugon*	In the paper	Temporal variability in the life history and reproductive biology of female dugongs in Torres Strait: The likely role of sea grass dieback	Observational	1978	1982	Indigenous catch from 2 islands. 35+ specimens	unknown	https://www.sciencedirect.com/science/article/pii/S0278434308001349#fig1
23	Habitat	*Seagrass*	In the paper	Spatial patterns of sub-tidal seagrasses and their tissue nutrients in the Torres Strait, northern Australia:	Observational			Forraging sites	unknown	https://www.sciencedirect.com/science/article/pii/S0278434308001441#fig3

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
				Implications for management						
24	Fisheries	*Dugong dugon*	In the paper	Aerial surveys and the potential biological removal technique indicate that the Torres Strait dugong fishery is unsustainable	Observational	1987	2001	Population estimates from aerial surveys	unknown	https://zslpublications.onlinelibrary.wiley.com/doi/epdf/10.1017/S1367943004001635
25	Fisheries	*Dugong dugon*	In the paper	Diving behaviour of dugongs, Dugong dugon	Observational			Diving behaviour. One site is in the GOC	unknown	http://apps.webofknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=F3cEpMRxEhS9IDR3OHk&page=4&doc=35&cacheurlFromRightClick=no
26	Fisheries	*Dugong dugon*	In the paper	Pathological findings in wild harvested dugongs Dugong dugon of central Torres Strait, Australia	Observational	2011	2011	Six dugongs hunted legally examined on Mabuiag Island in 2011	unknown	https://www.int-res.com/articles/dao2015/113/d113p089.pdf
27	Fisheries	*Dugong dugon*	Shapefile at: https://eatlas.org.au/pydio/public/0a6f55.php	Satellite Tracking of Sympatric Marine Megafauna Can Inform the Biological Basis for Species Co-Management	Observational	2009	2010	Tagging and tracking 6 dugongs at Mabuiag Isl.	unknown	https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0098944&type=printable
28	Fisheries	*Dugong dugon*	In the paper	Movements and distribution of dugongs (Dugong dugon) in a macro-tidal environment in northern Australia	Observational	2002	2002	Dugong sightings from aerial surveys in the TS 2002	unknown	https://www.publish.csiro.au/zo/pdf/ZO08033

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
29	Fisheries	*Dugong dugon*	On team share and in https://biocache.ala.org.au/occurrences/search?q=qid:1590003182716#tab_recordsView	ALA collection records search	Observational	1936	2007	Data search in ALA provides 26 records (in Excel file) from QM, AM, WAM, National Whale and Dolphin Sightings and Strandings Database, Australian Antarctic Data Centre, NT DENR, Fauna Atlas N.T.	CC-BY	On file
30	Fisheries	*Dugong dugon*	In the paper	Estimating Animal Abundance in Heterogeneous Environments: An Application to Aerial Surveys for Dugongs	Modelled		Uses previous surveys	Population estimates from aerial surveys	unknown	https://wildlife.onlinelibrary.wiley.com/doi/pdf/10.2193/0022-541X%282006%2970%5B255%3AEAAIHE%5D2.0.CO%3B2
31	Fisheries	*Dugong dugon*	In the paper	The Sustainability of the Indigenous Dugong Fishery in Torres Strait, Australia/Papua New Guinea		1987	1993	Sustainability of TS population. Based on previous studies	unknown	https://conbio.onlinelibrary.wiley.com/doi/epdf/10.1046/j.1523-1739.1997.95309.x
32	Fisheries	*Dugong dugon*	Needs search. Not easily found online. Data.gov does not provide it.	SPRAT Species Profile and Threats Database - Dugong	Australian distribution		From various sources		CC-BY	environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=28
33	Fisheries	*Dugong dugon*	eAtlas	Dugong relative density 1987-2011 (JCU, NERP-TE1.2)	Modelled	1987	2011	Modelled distibution density	CC-BY	https://eatlas.org.au/data/uuid/70e21d20-cc5e-4d1d-9d2b-7b08f4b061a2
34	Fisheries	*Dugong dugon*	eAtlas	Dugong relative density 1987-2013 (JCU, NERP-TE2.1)	Modelled	1987	2013	Modelled distibution density	CC-BY	https://eatlas.org.au/data/uuid/8a49e81b-0f88-43b4-8599-fc371da4063a

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
35	Fisheries	*Dugong dugon*	Table 1 is a good overview of the aerial surveys conducted on Dungon in the TS	Informing Species Conservation at Multiple Scales Using Data Collected for Marine Mammal Stock Assessments	Observational			Species conservation	unknown	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0017993#pone-0017993-g001
36	Fisheries	*Dugong dugon*	Fig. 8 in eAtlas, rest unknown	Aerial survey of Torres Strait to evaluate the efficacy of an enforced and possibly extended Dugong Sanctuary as one of the tools for managing the dugong fishery.	Modelled	2011	2011	Distribution modelling	unknown	https://data.marinemammals.gov.au/common/documents/grants/2010/Marsh_2.pdf
37	Fisheries	*Dugong dugon*	Figs. in the paper. Repository unknown	Condition, status and trends and projected futures of the dugong in the Northern Great Barrier Reef and Torres Strait; including identification and evaluation of the key threats and evaluation of available management options to improve its status	Observational			Temporal changes and desity. Some evidence that seagrass abundance affects reproductive rates in females.	copyrighted	http://rrrc.org.au/wp-content/uploads/2014/06/141-JCU-2007-Marsh-et-al-Dugong-status-and-trends.pdf
38	Fisheries	*Dugong dugon*		Analysis of Stomach Contents of Dugongs from Queensland	Observational	1968	1978	Stomach content, diet of 2 dugong from the TS	copyrighted	https://www.publish.csiro.au/wr/pdf/WR9820055

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39	Fisheries	*Dugong dugon*	Access is via registration and registration is not provided. Requires emailing JCU.	Dugong Tropical Data Hub. Dugong Aerial Survey Database. DOI: 10.4225/28/557F7B61ED8E1	Observational	1984	2013	Observations from aerial surveys	contact researchdata@jcu.edu	https://dugongs.tropicaldatahub.org/
40	Fisheries	*Dugong dugon*	Some in eAtlas, rest unknown	An assessment of the distribution and abundance of dugongs in the Northern Great Barrier Reef and Torres Strait	Observational	1985	2013	Distribution and abundance		http://www.nerptropical.edu.au/sites/default/files/publications/files/An%20assessment%20of%20the%20distribution%E2%80%A6%20Sobtzick%20et%20al%202014.pdf
41	Fisheries	*Dugong dugon*	Partly in the paper	Improving the estimates of abundance of dugongs and large immature and adult-sized green turtles in Western and Central Torres Strait	Observational	2006	2013	Distribution and abundance		http://www.tsra.gov.au/__data/assets/pdf_file/0007/13975/JCU-TSRA-2016-Improving-the-Estimates-of-Abundance-of-Dugongs-Green-Turtles-in-Western-and-Central-Torres-Strait.pdf
42	Fisheries	*Tropical Rock Lobster*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2019	CSIRO has been engaged, for the past 30 years, by AFMA to undertake annual diving surveys to determine the relative abundance of Tropical Rock Lobsters (TRL) (Panulirus ornatus). Divers complete a census of lobster along transects at pre-determined sampling sites, with a subset of lobster collected for additional measurements. Data collected: The number and age-class of lobsters observed, but not collected; The number of lobsters collected per age-class; The size (tail width in mm), sex and moult stage of the collected lobsters	Contact CSIRO	Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.

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43	Habitat	*Algae*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2019	Torres Strait		Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
44	Habitat	*Coral reefs*		Marine resources, biophysical processes, and environmental management of a tropical shelf seaway: Torres Strait, Australia-Introduction to the special issue				Torres Strait		Harris, P. T., A. J. Butler and R. G. Coles (2008). "Marine resources, biophysical processes, and environmental management of a tropical shelf seaway: Torres Strait, Australia-Introduction to the special issue." Continental Shelf Research 28(16): 2113-2116.
45	Habitat	*Coral reefs*	eAtlas: https://eatlas.org.au/ts/maps/torres-strat-islands-reefs-poster	Mapping the Torres Strait Reef and Island Features: Extending the GBR Features (GBRMPA) dataset. Report to the National Environmental Science Programme.	Observational		2015	historical landsat images		Lawrey, E. P. and M. Stewart (2016). Mapping the Torres Strait Reef and Island Features: Extending the GBR Features (GBRMPA) dataset. Report to the National Environmental Science Programme. Cairns, Reef and Rainforest Research Centre Limited.
46	Habitat	*Coral reefs*	CSIRO	Mapping and characterisation of the inter-reefal benthic assemblages of the Torres Strait	Observational	2004	2004	Torres Strait	unknown	Haywood, M. D. E., C. R. Pitcher, N. Ellis, T. J. Wassenberg, G. Smith, K. Forcey, I. McLeod, A. Carter, C. Strickland and R. Coles (2008). "Mapping and characterisation of the inter-reefal benthic assemblages of the Torres Strait." Continental Shelf Research 28(16): 2304-2316.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
47	Physiochemical	*Water depth*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Data from various surveys since 1989	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
48	Physiochemical	*Slope of the seabed*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

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49	Physiochemical	*Nitrate*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
50	Physiochemical	*Oxygen*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
51	Physiochemical	*Phosphate*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
52	Physiochemical	*Silicate*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

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53	Physiochemical	*Salinity*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
54	Physiochemical	*Water temperature*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

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55	Physiochemical	*Currents*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
56	Physiochemical	*Tides*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
57	Physiochemical	*Carbonate concentration*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
58	Physiochemical	*Bottm Sediments*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

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59	Physiochemical	*Chlorophyl a*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
60	Physiochemical	*Suspended sediments*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

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61	Ecological	*Benthic irradiance*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	2004	2004	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
62	Fisheries	*Prawn Trawling effort*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	1987	2002	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

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63	Habitat	*Epibenthos*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	1987	2002	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
64	Habitat	*Seagrass*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	1987	2002	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
65	Habitat	*Algae*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	1987	2002	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/
66	Ecological	*Seabed fishes*	CSIRO	Torres Strait seabed and water-column data collation, biophysical modeling and characterization	Models and Observations	1985	1986	Torres Strait	unknown	Pitcher, C. R., S. Condie, N. Ellis, I. McLeod, M. Haywood, S. R. Gordon, T. D. Skewes, J. Dunn, D. Dennis, E. Cotterell, M. Austin, W. Venables and T. Taranto (2004). Torres Strait seabed and water-column data collation, biophysical modeling and characterization. Final Report to the National Oceans Office. Cleveland: 117. https://parksaustralia.gov.au/marine/management/resources/scientific-publications/torres-strait-seabed-and-water-column-data-collation-bio-physical-modeling-and/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
67	Habitat	*Coral reefs*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2020	Torres Strait		Pitcher, C. R., T. D. Skewes, D. M. Dennis and J. H. Prescott (1992). "Distribution of Seagrasses, Substratum Types and Epibenthic Macrobiota in Torres Strait, with Notes on Pearl Oyster Abundance." Australian Journal of Marine and Freshwater Research 43(2): 409-419.
68	Fisheries	Rock Lbster (*Panulirus ornatus*)	CSIRO	Tropical Rock Lobster recent catches	Observational	1973	2019			Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
69	Fisheries	*Prawns*	AFMA	Trawl effort data - AFMA fisheries logbook	Observational				on request to AFMA	https://www.afma.gov.au/resources/catch-data
70	Fisheries	*Prawns: Brown tiger*	on paper	Migration and growth of two tropical penaeid shrimps within Torres Strait, northern Australia	Observational	1986	1988			Watson, R. A. and C. T. Turnbull (1993). "Migration and growth of two tropical penaeid shrimps within Torres Strait, northern Australia." Fisheries Research 17(3): 353-368.
71	Fisheries	*Prawns: Blue-tailed endeavour*	Queensland Department of Primary Industries	Settlement of juvenile Penaeus esculentus	Observational	1986	1988	Information on settlement, maturity, growth and reproduction for Torres Strait.		Turnbull, C. T. and J. E. Mellors (1990). Settlement of juvenile Penaeus esculentus (Haswell, 1879) on nursery grounds in Torres Strait. Torres Strait Prawn Project: A review of research 1986-88. J. E. Mellors. Brisbane, Fisheries Branch, Queensland Departmnet of Primary Industries, Information series Q190018.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
72	Fisheries	*Prawns: Red-spot king prawn*	Queensland Department of Primary Industries	Experimental beam trawls for sampling juvenile prawns	Observational	1986	1988			Turnbull, C. T. and R. A. Watson (1990). Experimental beam trawls for sampling juvenile prawns. Torres Strait Prawn Project: A review of research 1986-88, Information series Q190018. J. E. Mellors. Brisbane, Fisheries Branch, Queensland Departmnet of Primary Industries.
73	Fisheries	*Prawns*	AFMA	Torres Strait Prawn Fishery Data Summary 2015	Observational	2015	2015		Contact AFMA	Cocking, L. and C. Turnbull (2016). Torres Strait Prawn Fishery Data Summary 2015. Canberra, Australia.
74	Fisheries	*Prawns*	AFMA	Torres Strait Prawn Fishery Data Summary 2016	Observational	2016	2016		Contact AFMA	Cocking, L. and C. Turnbull (2017). Torres Strait Prawn Fishery Data Summary 2016. Canberra, Australia: 22.
75	Fisheries	*Prawns*	AFMA	Torres Strait Prawn Fishery Data Summary 2017	Observational	2017	2017		Contact AFMA	Turnbull, C. and L. Cocking (2018). Torres Strait Prawn Fishery Data Summary 2017. Canberra, Australia.
76	Fisheries	*Prawns*	AFMA	Torres Strait Prawn Fishery Data Summary 2018	Observational	2018	2018		Contact AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2018. Canberra, Australia.
77	Fisheries	*Prawns*	AFMA	Torres Strait Prawn Fishery Data Summary 2019	Observational	2019	2019		Contact AFMA	Turnbull, C. and L. Cocking (2019). Torres Strait Prawn Fishery Data Summary 2019. Canberra, Australia: 33p.
78	Fisheries	Sea cucumbers	PZJA website	Beche-de-mer catch watch reports	Observational	2019	2020		available through website	https://www.pzja.gov.au/fishery-catch-watch-reports
79	Fisheries	Sea cucumbers	CSIRO	Stock survey of sea cucumbers in East Torres Strait	Observational	2019	2020	Fishery independent survey across Torres Strait		Murphy, N., T. Skewes, E. Plaganyi, S. Edgar, K. Salee and C. Wildermuth (2020). Stock survey of sea cucumbers in East Torres Strait. Progress report. May 2020. . Brisbane, Australia.
80	Fisheries	Sea cucumbers	CSIRO	Stock survey of sea cucumbers in East Torres Strait	Observational	2009	2009	Fishery independent survey across Torres Strait		Skewes, T. D., N. E. Murphy, I. McLeod, E. Dovers, C. Burridge and W. Rochester (2010). Torres Strait Hand Collectables, 2009 survey: Sea cucumber - Final Report. Cleveland: 70p.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
81	Fisheries	Sea cucumbers	CSIRO	Survey and stock size estimates of the shallow reef (0-15 m deep) and shoal area (15–50 m deep) marine resources and habitat mapping within the Timor Sea MOU74 Box	Observational	1995	1996	Fishery independent survey		Skewes, T. D., D. M. Dennis, D. R. Jacobs, S. R. Gordon, T. J. Taranto, M. Haywood, C. R. Pitcher, G. P. Smith, D. Milton and I. R. Poiner (1999). Survey and stock size estimates of the shallow reef (0-15 m deep) and shoal area (15–50 m deep) marine resources and habitat mapping within the Timor Sea MOU74 Box. Cleveland, Australia: 71p.
82	Fisheries	Sea cucumbers	CSIRO	Stock survey and Sustainable Harvest Strategies for the Torres Strait Beche-de-Mer	Observational	2002	2002	Fishery independent survey across Torres Strait		Skewes, T., D. Dennis, A. Koutsoukos, M. Haywood, T. Wassenberg and M. Austin (2004). Stock survey and Sustainable Harvest Strategies for the Torres Strait Beche-de-Mer. Report prepared for the Australian Fisheries Management Authority and Queensland Fishery Service. Thursday Island, Queensland, CSIRO Marine and Atmospheric Research.
83	Fisheries	Sea cucumbers	CSIRO	Torres Strait Hand Collectables, 2009 survey: Sea cucumber	Observational	2005	2009	Fishery independent survey across Torres Strait. Only for years 2005 and 2009		Skewes, T. D., N. E. Murphy, I. McLeod, E. Dovers, C. Burridge and W. Rochester (2010). Torres Strait Hand Collectables, 2009 survey: Sea cucumber - Final Report. Cleveland: 70p.
86	Physiochemical	Sea Surface Temperature	UK Met Office		Modelled	1850	2020	Global dataset for land and sea surface temperature (HADCRUT4)	Free download	https://crudata.uea.ac.uk/cru/data/temperature/#datdow
87	Physiochemical	Sea Surface Temperature	UK Met Office		Modelled	1851	2020	Global dataset for sea surface temperature anomaly (HADST3)	Free download	https://www.metoffice.gov.uk/hadobs/hadsst3/data/download.html
88	Physiochemical	Sea Surface Temperature	Bureau of Meteorology		Modelled	1900	2020	Sea surface temp (SST) time series data is available for boxed region round Australia and six regions within this box. Relevant to Torres Strait are the Northern Tropics and Coral Sea regions.	Mean SST values for Northern Tropics and Coral Sea can be requested to BoM	http://www.bom.gov.au/climate/change/about/sst_timeseries.shtml

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
89	Physiochemical	Sea Surface Temperature	QLD DSITIA	QLD storm tides monitoring sites	Observational	2011	2020	Obervations every minute for Sea surface temp (SST) is available for the following stations: 1) Boigu Island monitoring site, 2) Ugar Island monitoring site, 3) Iama Island monitoring site, 4) Moa Island (St Pauls) monitoring site, 5) Moa Island (Kubin) monitoring site, and 6) Thursday Island monitoring site.	Data can be obtained by contacting Daryl Metters from the Queensland Department of Science Information Technology Innovation and the Arts (DSITIA)	1- Boigu Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/boigu): Installation 23 November 2013 2- Ugar Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/ugar): Installation 22 November 2013 3- Iama Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/iama): Installation 22 November 2013 4- Moa Island (St Pauls) monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/stpauls): Installation 23 November 2013, not currently recording 5- Moa Island (Kubin) monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/kubin): Installation 22 November 2013 6- Thursday Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/thursday-island): Installation 13 May 2011

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
90	Physiochemical	Sea Surface Temperature	Geosciences Australia		Modelled	1997	2004	outputs include three-dimensional distributions of velocity, temperature, salinity, and mixing coefficients, as well as two-dimensional fields such as sea level and bottom friction	Not known	Saint-Cast, F. (2008). "Multiple time-scale modelling of the circulation in Torres Strait-Australia." Continental Shelf Research 28(16): 2214-2240.
91	Physiochemical	Sea Surface Temperature	IMOS		Modelled		check	SST maps obtained from satellite data based on AVHRR instruments on a 2D grid with a cell size of 0.02deg. X 0.02deg., with each cell representing SST averaged over 14 days.	Free access	https://portal.aodn.org.au/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
92	Physiochemical	Sea Surface Temperature	CSIRO		Modelled	1992	2099	The modified Ocean Forecasting Australia Model version 3 (OFAM-v3) run under standard IPCC emissions scenarios to project future ocean states around Australia. These scenarios are taken from global ocean-atmosphere models (CMIP5 climate models, which set the context for the finer scale OFAMv3 model, which focuses on the Australian region in more detail. The OFAM-v3 model was originally developed for upper-ocean short-range operational forecasting (e.g. ocean forecasts of the type found at the bom.gov.au website) and was adapted for climate change studies. The downscaling simulations run with OFAM-v3 provide high-resolution (10km, 0.1º) outputs that can resolve important oceanographic features (e.g. eddies) and how these may change under future climate change. A biogeochemical model that represents nutrient flows and plankton components of the ocean food web (primary producers such as phytoplankton, some bacteria and zooplankton consumers) was coupled with OFAM-v3 to produce patterns of primary productivity, nutrient cycling and carbon fluxes that are consistent with observations. The OFAM3 outputs provide downscaled climate change projections for all common ocean state variables including currents, temperature (ºC), phytoplankton (mmol Nm-3) and primary productivity (mmol C m-2day-1). These outputs were then used as input to the ecosystem models.Data were modelled for the Torres Strait as defined by: A. Top left coordinates: 9o 08’ 24.83” S / 141o 01’ 0.00” E B. Bottom Right coordinates: 11o 10’ 0.00” S / 144o 28’ 0.00” E	on request to Richard Matear and Xuebin Zhang (CSIRO)	Fulton, E. A., A. J. Hobday, H. Pethybridge, J. Blanchard, C. Bulman, I. Butler, W. Cheung, L. X. C. Dutra, R. Gorton, T. Hutton, H. Lozano-Montes, R. Matear, G. Pecl, E. E. Plagányi, C. Villanueva and X. Zhang (2018). Decadal scale projection of changes in Australian fisheries stocks under climate change. Canberra. Plaganyi, E., M. Haywood, B. Gorton and S. Condie (2018). Environmental drivers of variability and climate projections for Torres Strait tropical lobster Panulirus ornatus. Brisbane: 156.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
93	Physiochemical	Nutrient	CSIRO		Modelled	1992	2099	The modified Ocean Forecasting Australia Model version 3 (OFAM-v3) run under standard IPCC emissions scenarios to project future ocean states around Australia. These scenarios are taken from global ocean-atmosphere models (CMIP5 climate models, which set the context for the finer scale OFAMv3 model, which focuses on the Australian region in more detail. The OFAM-v3 model was originally developed for upper-ocean short-range operational forecasting (e.g. ocean forecasts of the type found at the bom.gov.au website) and was adapted for climate change studies. The downscaling simulations run with OFAM-v3 provide high-resolution (10km, 0.1º) outputs that can resolve important oceanographic features (e.g. eddies) and how these may change under future climate change. A biogeochemical model that represents nutrient flows and plankton components of the ocean food web (primary producers such as phytoplankton, some bacteria and zooplankton consumers) was coupled with OFAM-v3 to produce patterns of primary productivity, nutrient cycling and carbon fluxes that are consistent with observations. The OFAM3 outputs provide downscaled climate change projections for all common ocean state variables including currents, temperature (ºC), phytoplankton (mmol Nm-3) and primary productivity (mmol C m-2day-1). These outputs were then used as input to the ecosystem models.Data were modelled for the Torres Strait as defined by: A. Top left coordinates: 9o 08' 24.83" S / 141o 01' 0.00" E B. Bottom Right coordinates: 11o 10' 0.00" S / 144o 28' 0.00" E	on request to Richard Matear and Xuebin Zhang (CSIRO)	Fulton, E. A., A. J. Hobday, H. Pethybridge, J. Blanchard, C. Bulman, I. Butler, W. Cheung, L. X. C. Dutra, R. Gorton, T. Hutton, H. Lozano-Montes, R. Matear, G. Pecl, E. E. Plagányi, C. Villanueva and X. Zhang (2018). Decadal scale projection of changes in Australian fisheries stocks under climate change. Canberra. Plaganyi, E., M. Haywood, B. Gorton and S. Condie (2018). Environmental drivers of variability and climate projections for Torres Strait tropical lobster Panulirus ornatus. Brisbane: 156.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
94	Physiochemical	Primary Productivity	CSIRO		Modelled	1992	2099	The modified Ocean Forecasting Australia Model version 3 (OFAM-v3) run under standard IPCC emissions scenarios to project future ocean states around Australia. These scenarios are taken from global ocean-atmosphere models (CMIP5 climate models, which set the context for the finer scale OFAMv3 model, which focuses on the Australian region in more detail. The OFAM-v3 model was originally developed for upper-ocean short-range operational forecasting (e.g. ocean forecasts of the type found at the bom.gov.au website) and was adapted for climate change studies. The downscaling simulations run with OFAM-v3 provide high-resolution (10km, 0.1º) outputs that can resolve important oceanographic features (e.g. eddies) and how these may change under future climate change. A biogeochemical model that represents nutrient flows and plankton components of the ocean food web (primary producers such as phytoplankton, some bacteria and zooplankton consumers) was coupled with OFAM-v3 to produce patterns of primary productivity, nutrient cycling and carbon fluxes that are consistent with observations. The OFAM3 outputs provide downscaled climate change projections for all common ocean state variables including currents, temperature (ºC), phytoplankton (mmol Nm-3) and primary productivity (mmol C m-2day-1). These outputs were then used as input to the ecosystem models.Data were modelled for the Torres Strait as defined by: A. Top left coordinates: 9o 08’ 24.83” S / 141o 01’ 0.00” E B. Bottom Right coordinates: 11o 10’ 0.00” S / 144o 28’ 0.00” E	on request to Richard Matear and Xuebin Zhang (CSIRO)	Fulton, E. A., A. J. Hobday, H. Pethybridge, J. Blanchard, C. Bulman, I. Butler, W. Cheung, L. X. C. Dutra, R. Gorton, T. Hutton, H. Lozano-Montes, R. Matear, G. Pecl, E. E. Plagányi, C. Villanueva and X. Zhang (2018). Decadal scale projection of changes in Australian fisheries stocks under climate change. Canberra. Plaganyi, E., M. Haywood, B. Gorton and S. Condie (2018). Environmental drivers of variability and climate projections for Torres Strait tropical lobster Panulirus ornatus. Brisbane: 156.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
95	Physiochemical	Phytoplankton	CSIRO		Modelled	1992	2099	The modified Ocean Forecasting Australia Model version 3 (OFAM-v3) run under standard IPCC emissions scenarios to project future ocean states around Australia. These scenarios are taken from global ocean-atmosphere models (CMIP5 climate models, which set the context for the finer scale OFAMv3 model, which focuses on the Australian region in more detail. The OFAM-v3 model was originally developed for upper-ocean short-range operational forecasting (e.g. ocean forecasts of the type found at the bom.gov.au website) and was adapted for climate change studies. The downscaling simulations run with OFAM-v3 provide high-resolution (10km, 0.1º) outputs that can resolve important oceanographic features (e.g. eddies) and how these may change under future climate change. A biogeochemical model that represents nutrient flows and plankton components of the ocean food web (primary producers such as phytoplankton, some bacteria and zooplankton consumers) was coupled with OFAM-v3 to produce patterns of primary productivity, nutrient cycling and carbon fluxes that are consistent with observations. The OFAM3 outputs provide downscaled climate change projections for all common ocean state variables including currents, temperature (ºC), phytoplankton (mmol Nm-3) and primary productivity (mmol C m-2day-1). These outputs were then used as input to the ecosystem models.Data were modelled for the Torres Strait as defined by: A. Top left coordinates: 9o 08’ 24.83” S / 141o 01’ 0.00” E B. Bottom Right coordinates: 11o 10’ 0.00” S / 144o 28’ 0.00” E	on request to Richard Matear and Xuebin Zhang (CSIRO)	Fulton, E. A., A. J. Hobday, H. Pethybridge, J. Blanchard, C. Bulman, I. Butler, W. Cheung, L. X. C. Dutra, R. Gorton, T. Hutton, H. Lozano-Montes, R. Matear, G. Pecl, E. E. Plagányi, C. Villanueva and X. Zhang (2018). Decadal scale projection of changes in Australian fisheries stocks under climate change. Canberra. Plaganyi, E., M. Haywood, B. Gorton and S. Condie (2018). Environmental drivers of variability and climate projections for Torres Strait tropical lobster Panulirus ornatus. Brisbane: 156.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
96	Physiochemical	Currents	CSIRO		Modelled	1992	2099	The modified Ocean Forecasting Australia Model version 3 (OFAM-v3) run under standard IPCC emissions scenarios to project future ocean states around Australia. These scenarios are taken from global ocean-atmosphere models (CMIP5 climate models, which set the context for the finer scale OFAMv3 model, which focuses on the Australian region in more detail. The OFAM-v3 model was originally developed for upper-ocean short-range operational forecasting (e.g. ocean forecasts of the type found at the bom.gov.au website) and was adapted for climate change studies. The downscaling simulations run with OFAM-v3 provide high-resolution (10km, 0.1º) outputs that can resolve important oceanographic features (e.g. eddies) and how these may change under future climate change. A biogeochemical model that represents nutrient flows and plankton components of the ocean food web (primary producers such as phytoplankton, some bacteria and zooplankton consumers) was coupled with OFAM-v3 to produce patterns of primary productivity, nutrient cycling and carbon fluxes that are consistent with observations. The OFAM3 outputs provide downscaled climate change projections for all common ocean state variables including currents, temperature (ºC), phytoplankton (mmol Nm-3) and primary productivity (mmol C m-2day-1). These outputs were then used as input to the ecosystem models.Data were modelled for the Torres Strait as defined by: A. Top left coordinates: 9o 08' 24.83" S / 141o 01' 0.00" E B. Bottom Right coordinates: 11o 10' 0.00" S / 144o 28' 0.00" E	on request to Richard Matear and Xuebin Zhang (CSIRO)	Fulton, E. A., A. J. Hobday, H. Pethybridge, J. Blanchard, C. Bulman, I. Butler, W. Cheung, L. X. C. Dutra, R. Gorton, T. Hutton, H. Lozano-Montes, R. Matear, G. Pecl, E. E. Plagányi, C. Villanueva and X. Zhang (2018). Decadal scale projection of changes in Australian fisheries stocks under climate change. Canberra. Plaganyi, E., M. Haywood, B. Gorton and S. Condie (2018). Environmental drivers of variability and climate projections for Torres Strait tropical lobster Panulirus ornatus. Brisbane: 156.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
97	Physiochemical	Currents	Geosciences Australia		Modelled	1997	2004	outputs include three-dimensional distributions of velocity, temperature, salinity, and mixing coefficients, as well as two-dimensional fields such as sea level and bottom friction	Not known	Saint-Cast, F. (2008). "Multiple time-scale modelling of the circulation in Torres Strait-Australia." Continental Shelf Research 28(16): 2214-2240.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
98	Physiochemical	Tides	QLD DSITIA	QLD storm tides monitoring sites	Observational	2011	2020	Obervations every minute of Tide actual, predicted and residuals plotted against predicted Lowest Astronomical Tide datum (LAT), and also plotted on the Australian Height Datum (AHD) is available for the following stations: 1) Boigu Island monitoring site, 2) Ugar Island monitoring site, 3) Iama Island monitoring site, 4) Moa Island (St Pauls) monitoring site, 5) Moa Island (Kubin) monitoring site, and 6) Thursday Island monitoring site. 1- Boigu Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/boigu): Installation 23 November 2013 2- Ugar Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/ugar): Installation 22 November 2013 3- Iama Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/iama): Installation 22 November 2013 4- Moa Island (St Pauls) monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/stpauls): Installation 23 November 2013, not currently recording 5- Moa Island (Kubin) monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/kubin): Installation 22 November 2013 6- Thursday Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/thursday-island): Installation 13 May 2011	Data can be obtained by contacting Daryl Metters from the Queensland Department of Science Information Technology Innovation and the Arts (DSITIA)	https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
99	Physiochemical	Tides	Geosciences Australia	Development of a bathymetric grid for the Gulf of Papua and adjacent areas	Modelled			bathymetric grid for the Gulf of Papua and northern Australia was produced for the area 140°–150°E, 6°–14°S, with a 3.6″ (~110 m) cell size.	Not known	Daniell, J. J. (2008). "Development of a bathymetric grid for the Gulf of Papua and adjacent areas: A note describing its development." Journal of Geophysical Research: Earth Surface 113(F1).
100	Physiochemical	Tides	Geosciences Australia / Partly in the report	Circulation modelling in Torres Strait	Modelled and Observational	1997	2002	The circulation model incorporated realistic atmospheric and oceanographic forcing, including winds, waves, tides, and large-scale regional circulation taken from global model outputs. Simulations covered a hindcast period of eight years, allowing the tidal, seasonal, and interannual flow characteristics to be investigated		Saint-Cast, F. and S. Condie (2006). Circulation modelling in Torres Strait: 82.
101	Physiochemical	Currents	Geosciences Australia / Partly in the report	Circulation modelling in Torres Strait	Modelled and Observational	1997	2002	The circulation model incorporated realistic atmospheric and oceanographic forcing, including winds, waves, tides, and large-scale regional circulation taken from global model outputs. Simulations covered a hindcast period of eight years, allowing the tidal, seasonal, and interannual flow characteristics to be investigated		Saint-Cast, F. and S. Condie (2006). Circulation modelling in Torres Strait: 82.
102	Physiochemical	Sea level	Geosciences Australia / Partly in the report	Circulation modelling in Torres Strait	Modelled and Observational	1997	2002	The circulation model incorporated realistic atmospheric and oceanographic forcing, including winds, waves, tides, and large-scale regional circulation taken from global model outputs. Simulations covered a hindcast period of eight years, allowing the tidal, seasonal, and interannual flow characteristics to be investigated		Saint-Cast, F. and S. Condie (2006). Circulation modelling in Torres Strait: 82.
103		Temperature	Geosciences Australia / Partly in the report	Circulation modelling in Torres Strait	Modelled and Observational	1997	2002	The circulation model incorporated realistic atmospheric and oceanographic forcing, including winds, waves, tides, and large-scale regional circulation taken from global model outputs. Simulations covered a hindcast period of eight years, allowing the tidal, seasonal, and interannual flow characteristics to be investigated		Saint-Cast, F. and S. Condie (2006). Circulation modelling in Torres Strait: 82.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
104		Salinity	Geosciences Australia / Partly in the report	Circulation modelling in Torres Strait	Modelled and Observational	1997	2002	The circulation model incorporated realistic atmospheric and oceanographic forcing, including winds, waves, tides, and large-scale regional circulation taken from global model outputs. Simulations covered a hindcast period of eight years, allowing the tidal, seasonal, and interannual flow characteristics to be investigated		Saint-Cast, F. and S. Condie (2006). Circulation modelling in Torres Strait: 82.
105	Physiochemical	Tides	Geosciences Australia		Modelled	1997	2004	outputs include three-dimensional distributions of velocity, temperature, salinity, and mixing coefficients, as well as two-dimensional fields such as sea level and bottom friction	Not known	Saint-Cast, F. (2008). "Multiple time-scale modelling of the circulation in Torres Strait-Australia." Continental Shelf Research 28(16): 2214-2240.
106	Physiochemical	Mean Sea Level	Aviso	Altimeter Mean Sea Level Data	Modelled	2015	2016	Altimetry-derived surface currents in the NCS were obtained from NOAA OSCAR. The spatial and temporal resolution of the data was 1/3 and 5 days respectively, from mid-November 2015 to mid-April 2016.	unknown	Wolanski, E., F. Andutta, E. Deleersnijder, Y. Li and C. J. Thomas (2017). "The Gulf of Carpentaria heated Torres Strait and the Northern Great Barrier Reef during the 2016 mass coral bleaching event." Estuarine Coastal and Shelf Science 194: 172-181. (http://www. aviso.altimetry.fr/
108	Physiochemical	Light penetration	CSIRO; Partly in the paper		Modelled	1997	2000	The 3-D sediment transport model was driven by a 3-D nonlinear, non-stationary hydrodynamic model, which solved Reynolds' equations with a free surface boundary condition, using the Boussinesq approximation and the hydrostatic assumption.	None mentioned	Margvelashvili, N., F. Saint-Cast and S. Condie (2008). "Numerical modelling of the suspended sediment transport in Torres Strait." Continental Shelf Research 28(16): 2241-2256.
109	Physiochemical	Salinity	Geosciences Australia		Modelled	1997	2004	outputs include three-dimensional distributions of velocity, temperature, salinity, and mixing coefficients, as well as two-dimensional fields such as sea level and bottom friction	Not known	Saint-Cast, F. (2008). "Multiple time-scale modelling of the circulation in Torres Strait-Australia." Continental Shelf Research 28(16): 2214-2240.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
110	Geological	Sediment	CSIRO; partly in the paper	Sediment mobility due to currents and waves in the Torres Strait Gulf of Papua region	Modelled and Observational	1990	1994			Hemer, M. A., P. T. Harris, D. Coleman and J. Hunter (2004). "Sediment mobility due to currents and waves in the Torres Strait Gulf of Papua region." Continental Shelf Research 24(19): 2297-2316.
111	Physiochemical	Currents	CSIRO; partly in the paper	Sediment mobility due to currents and waves in the Torres Strait Gulf of Papua region	Modelled and Observational	1990	1994			Hemer, M. A., P. T. Harris, D. Coleman and J. Hunter (2004). "Sediment mobility due to currents and waves in the Torres Strait Gulf of Papua region." Continental Shelf Research 24(19): 2297-2316.
112	Physiochemical	Tides	CSIRO; partly in the paper	Sediment mobility due to currents and waves in the Torres Strait Gulf of Papua region	Modelled and Observational	1990	1994			Hemer, M. A., P. T. Harris, D. Coleman and J. Hunter (2004). "Sediment mobility due to currents and waves in the Torres Strait Gulf of Papua region." Continental Shelf Research 24(19): 2297-2316.
113	Geological	Sediment	CSIRO; Partly in the paper	Numerical modelling of the suspended sediment transport in Torres Strait	Modelled	1997	2000	Torres trait region. The 3-D sediment transport model was driven by a 3-D nonlinear, non-stationary hydrodynamic model, which solved Reynolds' equations with a free surface boundary condition, using the Boussinesq approximation and the hydrostatic assumption.		Margvelashvili, N., F. Saint-Cast and S. Condie (2008). "Numerical modelling of the suspended sediment transport in Torres Strait." Continental Shelf Research 28(16): 2241-2256.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
114	Physiochemical	Barometric pressure	QLD storm tides monitoring sites		Observational	2011	2020	Obervations every minute for Sea barometric pressure is available for the following stations: 1) Boigu Island monitoring site, 2) Ugar Island monitoring site, 3) Iama Island monitoring site, 4) Moa Island (St Pauls) monitoring site, 5) Moa Island (Kubin) monitoring site, and 6) Thursday Island monitoring site. 1- Boigu Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/boigu): Installation 23 November 2013 2- Ugar Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/ugar): Installation 22 November 2013 3- Iama Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/iama): Installation 22 November 2013 4- Moa Island (St Pauls) monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/stpauls): Installation 23 November 2013, not currently recording 5- Moa Island (Kubin) monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/kubin): Installation 22 November 2013 6- Thursday Island monitoring site (https://www.qld.gov.au/environment/coasts-waterways/beach/storm-sites/thursday-island): Installation 13 May 2011	Data can be obtained by contacting Daryl Metters from the Queensland Department of Science Information Technology Innovation and the Arts (DSITIA)	https://www.qld.gov.au/environment/coasts-waterways/beach/storm/storm-sites/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
115	Habitat	Mangroves	ESRI grid: https://www.agriculture.gov.au/abares/forestsaustralia/forest-data-maps-and-tools/spatial-data/forest-cover	Forests of Australia 2018 dataset	Observational (Landsat Foliage cover 30x30m)	2018	2018		CC BY4.0	https://www.agriculture.gov.au/sites/default/files/abares/forestsaustralia/documents/datasets/sofr2018/Forests_of_Australia_2018_Metadata.pdf
116	Habitat	Mangroves	527 MB data download on CM's PC: Queensland Spatial Catalogue Data Request (JobID: 20200525_132500028000-67480, Date: 25/05/2020)	REDD Regional Ecosystem Database (Excel, Access)	Observational (Ecosystem (vegetation) distribution observed, multiple sources)	2019	2019		CC	https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/descriptions/download

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
117	Habitat	Mangroves	1.6 GB data download on CM's PC: Queensland Spatial Catalogue Data Request (JobID: 20200525_130636315000-30676, Date: 25/05/2020)	Remnant 2017 broad vegetation groups - Queensland	Observational (Ecosystem (vegetation) distribution observed, multiple sources)	2020	2020		CC	http://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={43A2CB31-9D83-4BB9-ACE7-05E7BD271FE3}
118	Habitat	Mangroves	http://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={F5CF90D6-5881-4D8F-9581-D8F55D25F9CE}	Remnant vegetation cover - 2017 - Queensland	Observational	2017	2017	Ecosystem mapping	CC BY 4.0	http://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={F5CF90D6-5881-4D8F-9581-D8F55D25F9CE}
119	Habitat	Mangroves	http://qldspatial.information.qld.gov.au/catalogue/custom/search.page?q=Queensland+wetland+data+series	Wetland data - version 5 - Queensland series	Observational	2019	2019	Mapping of water bodies and wetland regional ecosystems at 1:100,000 scale across Queensland	CC BY 4.0	http://qldspatial.information.qld.gov.au/catalogue/custom/search.page?q=Queensland+wetland+data+series

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
120	Habitat	Mangroves	https://wetlandinfo.des.qld.gov.au/ is another portal with wetland v5 maps. Check source and if it has more than qldspatial	Wetland data - version 5 - Queensland series	Observational	2019	2019	Mapping of water bodies and wetland regional ecosystems at 1:100,000 scale across Queensland	CC BY 4.0	https://wetlandinfo.des.qld.gov.au/
121	Habitat	Mangroves	553 MB data download on CM's PC: Queensland Spatial Catalogue Data Request (JobID: 20200525_144339773000-67480, Date: 25/05/2020)	Map of Queensland wetland environmental values		2020	2020		cc	qldspatial.information.qld.gov.au/catalogue/custom/search.page?q="Map+of+Queensland+wetland+environmental+values"

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
122	Habitat	Mangroves	Can be downloaded as xls file. Search in approximate TS area returned 137 record from approx. 15 institutions which are on CM's PC	Atlas of Living Australia	Observational	2020	2020		CC	https://www.ala.org.au/
123	Habitat	Mangroves	eAtlas. Downloaded to GIS on CM's PC	Map of research work undertaken by NERP project 2.2.	Locations and tracks of mangrove surveys	2015	2015		CC	https://eatlas.org.au/nerp-te/ts-jcu-mangrove-freshwater-status-torres-strait-islands-2-2
124	Habitat	Mangroves	Excel spreadsheet. Downloaded on CM's PC: https://eatlas.org.au/pydio/public/ts_nerp-te-2-2_jcu_mangrove-species-surveys_1981-2013-zip.php	Mangrove species in Torres Strait (list of species per island) (NERP TE 2.2, JCU)	Observational				Not clear	https://eatlas.org.au/node/1525

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
125	Habitat	Mangroves	In paper	Mangrove and Freshwater Wetland Habitat Status of the Torres Strait Islands Biodiversity, Biomass, Changing Condition of Wetlands	Observations (percentage coverage by island)	2012	2014		Not clear	https://www.researchgate.net/publication/309721863_Mangrove_and_Freshwater_Wetland_Habitat_Status_of_the_Torres_Strait_Islands_Biodiversity_Biomass_Changing_Condition_of_Wetlands
126	Habitat	Mangroves	Data source given as 'in publication'. Location of spatial layers not clear. Requires search	Distribution of Mangroves in Torres Strait	Observations (Mapping based on Landsat TM satellite imagery)	1997	1997		Not clear	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!e2d96ace-98da-76c3-e043-08114f8c0f19
127	Habitat	Mangroves	data.gov	Queensland - National Intertidal-Subtidal Benthic NISB Habitat Map (PLUS)		2007	2007		CC	http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B3C2A5C8D-8AC6-43EC-B603-8150F2B2BBD1%7D
128	Fisheries	Turtles	eAtlas	Marine turtles and dugongs of the Torres Strait - Spatial models of dugong and turtle distribution and relative density of aerial surveys from 1987 - 2013 (NERP TE 2.1, JCU)	Modelled and Observational	1987	2013	raster spatial model of the distribution and relative density of dugongs (Dugong dugong) in the Torres Strait region based on an aggregate of 27 years (1987 - 2013) of systematic aerial surveys; and (2) a raster spatial model of the distribution and relative density of marine turtles (green turtles, Chelonia mydas) in the Torres Strait based on an aerial survey conducted in 2013. https://eatlas.org.au/geonetwork/srv/eng/metadata.show?uuid=939cb936-68b9-4d9f-925e-f5ce12a3bf34&currTab=complete	CC	https://eatlas.org.au/data/uuid/939cb936-68b9-4d9f-925e-f5ce12a3bf34

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
129	Habitat	Seagrass	JCU	Torres Strait Mapping: Seagrass Consolidation, 2002 – 2014	Modelled and Observational	2002	2014		The large seagrass spatial composite is not available publically but may be obtained through special request to Dr Alex Carter, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)	Carter, A. B., H. A. Taylor and M. A. Rasheed (2014). Torres Strait Mapping: Seagrass Consolidation, 2002 – 2014. Carins, Centre for Tropical Water & Aquatic Ecosystem Research: 47pp. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+55+Torres+strait+mapping+seagrass+consolidation+(2).pdf&subfolder_nav_tracking=1
130	Habitat	Seagrass	JCU	Torres Strait Seagrass 2019 Report Card	Modelled and Observational	2018	2019	Data used in this report card was collected from mid-2018 to mid-2019 for the Torres Strait Seagrass Monitoring Program (TSSMP). The TSSMP incorporates the Torres Strait Seagrass Observers Program, Ranger Subtidal Monitoring Program, Queensland Ports Seagrass Monitoring Program, and Reef-top Monitoring Program. Twenty-seven sites/meadows were classified for the 2019 report card across four Torres Strait Island Clusters.		Carter, A. B., J. M. Mellors, C. Reason and M. A. Rasheed (2019). Torres Strait Seagrass 2019 Report Card. Cairns: 62p.. https://www.dropbox.com/s/uydzgt5jk40rirj/19%2016%20Torres%20Strait%20seagrass%202019%20report%20card.pdf?dl=0
131	Habitat	Seagrass	JCU	The effects of climate on seagrass in the Torres Strait – 2011-2014 Report	Modelled and Observational	2011	2014	An intertidal seagrass monitoring site was established at Mabuiag Island where information on seagrass biomass and species composition, and environmental data including irradiance (light), global solar exposure, daytime tidal air exposure, mean and maximum daily water temperature, rainfall, wind speed and salinity, were collected		Carter, A. B., H. A. Taylor, S. A. McKenna, P. Y. York and M. A. Rasheed (2014). The effects of climate on seagrass in the Torres Strait – 2011-2014 Report. Cairns: 36p. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+48+The+effect+of+climate+on+seagass+in+the+Torres+Strait.pdf&subfolder_nav_tracking=1

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
132	Physiochemical	Light penetration	JCU	The effects of climate on seagrass in the Torres Strait – 2011-2014 Report	Observational	2011	2014	An intertidal seagrass monitoring site was established at Mabuiag Island where information on seagrass biomass and species composition, and environmental data including irradiance (light), global solar exposure, daytime tidal air exposure, mean and maximum daily water temperature, rainfall, wind speed and salinity, were collected		Carter, A. B., H. A. Taylor, S. A. McKenna, P. Y. York and M. A. Rasheed (2014). The effects of climate on seagrass in the Torres Strait – 2011-2014 Report. Cairns: 36p. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+48+The+effect+of+climate+on+seagass+in+the+Torres+Strait.pdf&subfolder_nav_tracking=2
133	Physiochemical	Solar exposure	JCU	The effects of climate on seagrass in the Torres Strait – 2011-2014 Report	Observational	2011	2014	An intertidal seagrass monitoring site was established at Mabuiag Island where information on seagrass biomass and species composition, and environmental data including irradiance (light), global solar exposure, daytime tidal air exposure, mean and maximum daily water temperature, rainfall, wind speed and salinity, were collected		Carter, A. B., H. A. Taylor, S. A. McKenna, P. Y. York and M. A. Rasheed (2014). The effects of climate on seagrass in the Torres Strait – 2011-2014 Report. Cairns: 36p. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+48+The+effect+of+climate+on+seagass+in+the+Torres+Strait.pdf&subfolder_nav_tracking=3
134	Physiochemical	Daytime tidal air exposure	JCU	The effects of climate on seagrass in the Torres Strait – 2011-2014 Report	Observational	2011	2014	An intertidal seagrass monitoring site was established at Mabuiag Island where information on seagrass biomass and species composition, and environmental data including irradiance (light), global solar exposure, daytime tidal air exposure, mean and maximum daily water temperature, rainfall, wind speed and salinity, were collected		Carter, A. B., H. A. Taylor, S. A. McKenna, P. Y. York and M. A. Rasheed (2014). The effects of climate on seagrass in the Torres Strait – 2011-2014 Report. Cairns: 36p. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+48+The+effect+of+climate+on+seagass+in+the+Torres+Strait.pdf&subfolder_nav_tracking=4

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
135	Physiochemical	Water temperature	JCU	The effects of climate on seagrass in the Torres Strait – 2011-2014 Report	Observational	2011	2014	An intertidal seagrass monitoring site was established at Mabuiag Island where information on seagrass biomass and species composition, and environmental data including irradiance (light), global solar exposure, daytime tidal air exposure, mean and maximum daily water temperature, rainfall, wind speed and salinity, were collected		Carter, A. B., H. A. Taylor, S. A. McKenna, P. Y. York and M. A. Rasheed (2014). The effects of climate on seagrass in the Torres Strait – 2011-2014 Report. Cairns: 36p. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+48+The+effect+of+climate+on+seagass+in+the+Torres+Strait.pdf&subfolder_nav_tracking=5
136	Physiochemical	Rainfall	JCU	The effects of climate on seagrass in the Torres Strait – 2011-2014 Report	Observational	2011	2014	An intertidal seagrass monitoring site was established at Mabuiag Island where information on seagrass biomass and species composition, and environmental data including irradiance (light), global solar exposure, daytime tidal air exposure, mean and maximum daily water temperature, rainfall, wind speed and salinity, were collected		Carter, A. B., H. A. Taylor, S. A. McKenna, P. Y. York and M. A. Rasheed (2014). The effects of climate on seagrass in the Torres Strait – 2011-2014 Report. Cairns: 36p. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+48+The+effect+of+climate+on+seagass+in+the+Torres+Strait.pdf&subfolder_nav_tracking=6
137	Physiochemical	Wind speed	JCU	The effects of climate on seagrass in the Torres Strait – 2011-2014 Report	Observational	2011	2014	An intertidal seagrass monitoring site was established at Mabuiag Island where information on seagrass biomass and species composition, and environmental data including irradiance (light), global solar exposure, daytime tidal air exposure, mean and maximum daily water temperature, rainfall, wind speed and salinity, were collected		Carter, A. B., H. A. Taylor, S. A. McKenna, P. Y. York and M. A. Rasheed (2014). The effects of climate on seagrass in the Torres Strait – 2011-2014 Report. Cairns: 36p. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+48+The+effect+of+climate+on+seagass+in+the+Torres+Strait.pdf&subfolder_nav_tracking=7

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
138	Physiochemical	Salinity	JCU	The effects of climate on seagrass in the Torres Strait – 2011-2014 Report	Observational	2011	2014	An intertidal seagrass monitoring site was established at Mabuiag Island where information on seagrass biomass and species composition, and environmental data including irradiance (light), global solar exposure, daytime tidal air exposure, mean and maximum daily water temperature, rainfall, wind speed and salinity, were collected		Carter, A. B., H. A. Taylor, S. A. McKenna, P. Y. York and M. A. Rasheed (2014). The effects of climate on seagrass in the Torres Strait – 2011-2014 Report. Cairns: 36p. https://www.dropbox.com/sh/mo8dcq1322qv5c3/AACBP7wEpNeQfiI2f8RqT8MOa/2014?dl=0&preview=14+48+The+effect+of+climate+on+seagrass+in+the+Torres+Strait.pdf&subfolder_nav_tracking=8
139	Habitat	Seagrass	JCU	Seagrass Habitat in the Port of Thursday Island: Annual Monitoring Report 2019	Observational	2019	2019	Aerial and boat surveys of seagrass meadows were conducted between 26th – 30th March 2019. The surveys included a whole of port survey as well as a survey of the annual monitoring meadows		Wells, J. N., M. A. Rasheed and R. G. Coles (2019). Seagrass Habitat in the Port of Thursday Island: Annual Monitoring Report 2019. Cairns: 43p. https://www.dropbox.com/s/4jcufvc75gfs7bw/19%2027%20Seagrass%20habitat%20in%20the%20port%20of%20Thursday%20Island.pdf?dl=0
142	Physiochemical	Water temperature	AIMS	AIMS weather stations	Observational	2017	2020		Freely available on website	https://weather.aims.gov.au/#/overview
143	Physiochemical	Wind	AIMS	AIMS weather stations	Observational	2017	2020		Freely available on website	https://weather.aims.gov.au/#/overview
144	Physiochemical	Air temperature	AIMS	AIMS weather stations	Observational	2017	2020		Freely available on website	https://weather.aims.gov.au/#/overview
145	Physiochemical	Rainfall	AIMS	AIMS weather stations	Observational	2017	2020		Freely available on website	https://weather.aims.gov.au/#/overview
146	Physiochemical	Atmospheric pressure	AIMS	AIMS weather stations	Observational	2017	2020		Freely available on website	https://weather.aims.gov.au/#/overview
147	Physiochemical	Humidity	AIMS	AIMS weather stations	Observational	2017	2020		Freely available on website	https://weather.aims.gov.au/#/overview

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
148	Physiochemical	Light	AIMS	AIMS weather stations	Observational	2017	2020		Freely available on website	https://weather.aims.gov.au/#/overview
149	Physiochemical	Sea level	BoM	About ACCESS model	Modelled		3 hours to 240 hours	3-day predictions; from 12km to 24km grid resolution. ACCESS output is available in map form or as gridded data products	on request to BoM	http://www.bom.gov.au/australia/charts/about/about_access.shtml
150	Physiochemical	Wind	BoM	About ACCESS model	Modelled		3 hours to 240 hours	3-day predictions; from 12km to 24km grid resolution. ACCESS output is available in map form or as gridded data products	on request to BoM	http://www.bom.gov.au/australia/charts/about/about_access.shtml
151	Physiochemical	Rainfall	BoM	About ACCESS model	Modelled		3 hours to 240 hours	3-day predictions; from 12km to 24km grid resolution. ACCESS output is available in map form or as gridded data products	on request to BoM	http://www.bom.gov.au/australia/charts/about/about_access.shtml
152	Physiochemical	Air temperature	BoM	About ACCESS model	Modelled		3 hours to 240 hours	3-day predictions; from 12km to 24km grid resolution. ACCESS output is available in map form or as gridded data products	on request to BoM	http://www.bom.gov.au/australia/charts/about/about_access.shtml
153	Physiochemical	Humidity	BoM	About ACCESS model	Modelled		3 hours to 240 hours	3-day predictions; from 12km to 24km grid resolution. ACCESS output is available in map form or as gridded data products	on request to BoM	http://www.bom.gov.au/australia/charts/about/about_access.shtml
154	Physiochemical	Sea Surface Temperature	BoM	About the sea surface temperature timeseries graphs	Modelled and Observational	1900	2020			http://www.bom.gov.au/climate/change/about/sst_timeseries.shtml
155	Physiochemical	Sea Surface Temperature	NOAA	NOAA Extended Reconstructed Sea Surface Temperature (SST) V5	Modelled	1854	2020	A global monthly SST analysis from 1854 to the present derived from ICOADS data with missing data filled in by statistical methods	Access through website	https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html
156	Physiochemical	Air temperature	BoM	Horn Island Station ID 027058	Observational	1995	2020		Access through website	http://www.bom.gov.au/climate/averages/tables/cw_027058.shtml
157	Physiochemical	Rainfall	BoM	Horn Island Station ID 027058	Observational	1995	2020		Access through website	http://www.bom.gov.au/climate/averages/tables/cw_027058.shtml

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
158	Physiochemical	Wind speed	BoM	Horn Island Station ID 027058	Observational	1995	2020		Access through website	http://www.bom.gov.au/climate/averages/tables/cw_027058.shtml
159	Physiochemical	Atmospheric pressure	BoM	Horn Island Station ID 027058	Observational	1995	2020		Access through website	http://www.bom.gov.au/climate/averages/tables/cw_027058.shtml
160	Physiochemical	Air temperature	BoM	Thursday Island Station ID 200892	Observational		?			http://www.bom.gov.au/products/IDQ60801/IDQ60801.94181.shtml
161	Physiochemical	Wind speed	BoM	Thursday Island Station ID 200892	Observational		?			http://www.bom.gov.au/products/IDQ60801/IDQ60801.94181.shtml
162	Physiochemical	Atmospheric pressure	BoM	Thursday Island Station ID 200892	Observational		?			http://www.bom.gov.au/products/IDQ60801/IDQ60801.94181.shtml
163	Physiochemical	Air temperature	BoM	Coconut Island Station ID 027054	Observational	1995	2020			http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=027054
164	Physiochemical	Atmospheric pressure	BoM	Coconut Island Station ID 027055	Observational	1995	2020			http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=027054
165	Physiochemical	Rainfall	BoM	Coconut Island Station ID 027056	Observational	1995	2020			http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=027054
166	Physiochemical	Sea Surface Temperature	BoM	OceanMaps	Modelled		7-day forecasts	OceanMAPS produces 7-day forecasts of the ocean circulation around Australia (900-180E, south of 20N) every day.	Site registration	http://www.bom.gov.au/oceanography/forecasts/index.shtml
167	Physiochemical	Currents	BoM	OceanMaps	Modelled		7-day forecasts	OceanMAPS produces 7-day forecasts of the ocean circulation around Australia (900-180E, south of 20N) every day.	Site registration	http://www.bom.gov.au/oceanography/forecasts/index.shtml
168	Physiochemical	Sea level	BoM	OceanMaps	Modelled		7-day forecasts	OceanMAPS produces 7-day forecasts of the ocean circulation around Australia (900-180E, south of 20N) every day.	Site registration	http://www.bom.gov.au/oceanography/forecasts/index.shtml

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
169	Physiochemical	Salinity	BoM	OceanMaps	Modelled		7-day forecasts	OceanMAPS produces 7-day forecasts of the ocean circulation around Australia (900-180E, south of 20N) every day.	Site registration	http://www.bom.gov.au/oceanography/forecasts/index.shtml
170	Physiochemical	Sea level	CSIRO / BoM	Climate Change in Australia	Modelled and Observational	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/
171	Physiochemical	Sea Surface Temperature	CSIRO / BoM	Climate Change in Australia	Modelled and Observational	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/
172	Physiochemical	Aragonite Saturation	CSIRO / BoM	Climate Change in Australia	Modelled and Observational	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/
173	Physiochemical	Rainfall	CSIRO / BoM	Climate Change in Australia	Modelled and Observational	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/
174	Physiochemical	Air temperature	CSIRO / BoM	Climate Change in Australia	Modelled and Observational	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/
175	Physiochemical	Ocean pH	CSIRO / BoM	Climate Change in Australia	Modelled	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
176	Physiochemical	Wind Speed	CSIRO / BoM	Climate Change in Australia	Modelled and Observational	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/
177	Physiochemical	Humidity	CSIRO / BoM	Climate Change in Australia	Modelled and Observational	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/
178	Physiochemical	Solar radiation	CSIRO / BoM	Climate Change in Australia	Modelled and Observational	1900	2020	Climate change projections show how Australia's climate may change in the future. Using up to 40 global climate models, the projections found here represent the most comprehensive analysis of Australia's future climate ever undertaken	Mostly freely accessible with areas that require registration	https://www.climatechangeinaustralia.gov.au/
179	Physiochemical	Air temperature	WorldClim	WorldClim	Modelled	1970	2000	This is WorldClim version 2.1 climate data for 1970-2000. This version was released in January 2020. There are monthly climate data for minimum, mean, and maximum temperature, precipitation, solar radiation, wind speed, water vapor pressure, and for total precipitation. There are also 19 "bioclimatic" variables. The data is available at the four spatial resolutions, between 30 seconds (~1 km2) to 10 minutes (~340 km2). Each download is a "zip" file containing 12 GeoTiff (.tif) files, one for each month of the year (January is 1; December is 12).	Free download	https://worldclim.org/data/worldclim21.html

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
180	Physiochemical	Rainfall	WorldClim	WorldClim	Modelled	1970	2000	This is WorldClim version 2.1 climate data for 1970-2000. This version was released in January 2020. There are monthly climate data for minimum, mean, and maximum temperature, precipitation, solar radiation, wind speed, water vapor pressure, and for total precipitation. There are also 19 "bioclimatic" variables. The data is available at the four spatial resolutions, between 30 seconds (~1 km2) to 10 minutes (~340 km2). Each download is a "zip" file containing 12 GeoTiff (.tif) files, one for each month of the year (January is 1; December is 12).	Free download	https://worldclim.org/data/worldclim21.html
181	Physiochemical	Solar radiation	WorldClim	WorldClim	Modelled	1970	2000	This is WorldClim version 2.1 climate data for 1970-2000. This version was released in January 2020. There are monthly climate data for minimum, mean, and maximum temperature, precipitation, solar radiation, wind speed, water vapor pressure, and for total precipitation. There are also 19 "bioclimatic" variables. The data is available at the four spatial resolutions, between 30 seconds (~1 km2) to 10 minutes (~340 km2). Each download is a "zip" file containing 12 GeoTiff (.tif) files, one for each month of the year (January is 1; December is 12).	Free download	https://worldclim.org/data/worldclim21.html

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
182	Physiochemical	Wind speed	WorldClim	WorldClim	Modelled	1970	2000	This is WorldClim version 2.1 climate data for 1970-2000. This version was released in January 2020. There are monthly climate data for minimum, mean, and maximum temperature, precipitation, solar radiation, wind speed, water vapor pressure, and for total precipitation. There are also 19 “bioclimatic” variables. The data is available at the four spatial resolutions, between 30 seconds (~1 km2) to 10 minutes (~340 km2). Each download is a “zip” file containing 12 GeoTiff (.tif) files, one for each month of the year (January is 1; December is 12).	Free download	https://worldclim.org/data/worldclim21.html
183	Physiochemical	Air temperature	WorldClim	WorldClim	Modelled		2021-2100	The data available here are CMIP6 downscaled future climate projections. The downscaling and calibration (bias correction) was done with WorldClim v2.1 as baseline climate. Monthly values of minimum temperature, maximum temperature, and precipitation were processed for nine global climate models (GCMs): BCC-CSM2-MR, CNRM-CM6-1, CNRM-ESM2-1, CanESM5, GFDL-ESM4, IPSL-CM6A-LR, MIROC-ES2L, MIROC6, MRI-ESM2-0, and for four Shared Socio-economic Pathways (SSPs): 126, 245, 370 and 585. The monthly values were averages over 20 year periods (2021-2040, 241-2060, 2061-2080, 2081-2100). The following spatial resolutions are available (expressed as minutes of a degree of longitude and latitude): 10 minutes, 5 minutes, 2.5 minutes. Data at 30-seconds spatial resolution is expected to be available by the end of March, 2020. CMIP6 terms of use and citation information.	Free download	https://worldclim.org/data/cmip6/cmip6climate.html

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
184	Physiochemical	Rainfall	WorldClim	WorldClim	Modelled	2021	2100	The data available here are CMIP6 downscaled future climate projections. The downscaling and calibration (bias correction) was done with WorldClim v2.1 as baseline climate. Monthly values of minimum temperature, maximum temperature, and precipitation were processed for nine global climate models (GCMs): BCC-CSM2-MR, CNRM-CM6-1, CNRM-ESM2-1, CanESM5, GFDL-ESM4, IPSL-CM6A-LR, MIROC-ES2L, MIROC6, MRI-ESM2-0, and for four Shared Socio-economic Pathways (SSPs): 126, 245, 370 and 585. The monthly values were averages over 20 year periods (2021-2040, 241-2060, 2061-2080, 2081-2100). The following spatial resolutions are available (expressed as minutes of a degree of longitude and latitude): 10 minutes, 5 minutes, 2.5 minutes. Data at 30-seconds spatial resolution is expected to be available by the end of March, 2020. CMIP6 terms of use and citation information.	Free download	https://worldclim.org/data/cmip6/cmip6climate.html
185	Ecological	fish	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia	Observational	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.
186	Ecological	Seagrass	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia	Observational	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
187	Ecological	Live coral cover	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia	Observation al	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.
188	Ecological	Algae	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia	Observation al	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.
189	Geological	Sand	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia	Observation al	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.
190	Geological	Rubble	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia	Observation al	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.
191	Geological	Boulders	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia	Observation al	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.
192	Geological	Consolidate d rubble	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia	Observation al	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.
193	Geological	Pavement	CSIRO	Influence of coastal processes on large scale patterns in reef fish communities of	Observation al	1995	1996	Underwater visual transects at 276 sites on 41 reefs. Data stored in excel /shared drive	Contact CSIRO	Milton, D. A. and B. G. Long (1997). Influence of coastal processes on large scale patterns in reef fish communities of Torres Strait, Australia. Cleveland.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
				Torres Strait, Australia						
194	Fisheries	Finfish - Spanish Mackerel	AFMA	Spanish Mackerel Catch data	Observational	1989	2019	Data on Torres Strait Spanish mackerel harvests were from two sources: 1) AFMA compulsory logbook (Log) database and 2)AFMA docket (Doc) book records. The docket (Doc) book records are important information for harvest reporting through community processor/freezer establishments. At the time of this report, the Doc data recorded mostly harvests from Islander commercial fishers. Historically, docket book reporting was noncompulsory and database maintenance was not frequent	Contact AFMA	O'Neill, M. F. (2019). Appendix B - Torres Strait Spanish mackerel stock assessment. In: Harvest Strategies for the Torres Strait Finfish fishery, T. Hutton, M. O'Neill, G. Leigh et al. Brisbane, AFMA
195	Fisheries	Finfish - Spanish Mackerel	AFMA	Spanish Mackerel CPUE data	Observational	2013	2019	Data on Torres Strait Spanish mackerel harvests were from two sources: 1) AFMA compulsory logbook (Log) database and 2)AFMA docket (Doc) book records. The docket (Doc) book records are important information for harvest reporting through community processor/freezer establishments. At the time of this report, the Doc data recorded mostly harvests from Islander commercial fishers. Historically, docket book reporting was noncompulsory and database maintenance was not frequent	Contact AFMA	O'Neill, M. F. (2019). Appendix B - Torres Strait Spanish mackerel stock assessment. In: Harvest Strategies for the Torres Strait Finfish fishery, T. Hutton, M. O'Neill, G. Leigh et al. Brisbane, AFMA

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
196	Fisheries	Finfish - Spanish Mackerel	AFMA	Spanish Mackerel Length data	Observational	2000	2002	Data on Torres Strait Spanish mackerel harvests were from two sources: 1) AFMA compulsory logbook (Log) database and 2)AFMA docket (Doc) book records. The docket (Doc) book records are important information for harvest reporting through community processor / freezer establishments. At the time of this report, the Doc data recorded mostly harvests from Islander commercial fishers. Historically, docket book reporting was noncompulsory and database maintenance was not frequent	Contact AFMA	O'Neill, M. F. (2019). Appendix B - Torres Strait Spanish mackerel stock assessment. In: Harvest Strategies for the Torres Strait Finfish fishery, T. Hutton, M. O'Neill, G. Leigh et al. Brisbane, AFMA
197	Fisheries	Finfish - Coral Trout	AFMA	Coral Trout Catch Data	Observational	1992	2019		Contact AFMA	Holden, M. H. and G. M. Leigh (2019). Appendix E - Preliminary Stock Assessment for Coral Trout in Torres Strait - Project No. 2016/0824. In: Harvest Strategies for the Torres Strait Finfish fishery, T. Hutton, M. O'Neill, G. Leigh et al. Brisbane, AFMA.
198	Fisheries	Finfish - Coral Trout	AFMA	Coral Trout CPUE Data	Observational	1992	2019		Contact AFMA	Holden, M. H. and G. M. Leigh (2019). Appendix E - Preliminary Stock Assessment for Coral Trout in Torres Strait - Project No. 2016/0824. In: Harvest Strategies for the Torres Strait Finfish fishery, T. Hutton, M. O'Neill, G. Leigh et al. Brisbane, AFMA.
199	Physiochemical	Sea level	AIMS	Water circulation in the Gulf of Papua	Observational	1990	1992	Aanderaa water level recorders were bottom mounted at Tirere at the mouth of the Fly River estuary, as well as at the mouth of the two other channels of the estuary. Temperature and salinity profiles were obtained using a Seabird profiler.	unknown	Wolanski, E., A. Norro and B. King (1995). "Water circulation in the Gulf of Papua." Continental Shelf Research 15(2): 185-212.
200	Physiochemical	Currents	AIMS	Water circulation in the Gulf of Papua	Observational	1990	1992	two current meters were deployed, at least some of the time, to measure the current velocity both in and below the river plume. At site F, three meters were deployed, two above and one below the thermocline.	unknown	Wolanski, E., A. Norro and B. King (1995). "Water circulation in the Gulf of Papua." Continental Shelf Research 15(2): 185-212.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
201	Physiochemical	Water temperature	AIMS	Water circulation in the Gulf of Papua	Observational	1990	1992	Temperature profiles were obtained using a Seabird profiler.	unknown	Wolanski, E., A. Norro and B. King (1995). "Water circulation in the Gulf of Papua." Continental Shelf Research 15(2): 185-212.
202	Physiochemical	Salinity	AIMS	Water circulation in the Gulf of Papua	Observational	1990	1992	Salinity profiles were obtained using a Seabird profiler.	unknown	Wolanski, E., A. Norro and B. King (1995). "Water circulation in the Gulf of Papua." Continental Shelf Research 15(2): 185-212.
203	Physiochemical	Currents	AIMS	Water Circulation and Shelf Waves in the Northern Great Barrier Reef Lagoon	Observational	1979	1979	Currents and sea levels were measured at a number of locations in the Great Barrier Reef (GBR) lagoon from about 10 to 13°S., during the period October-December 1979.	unknown	Wolanski, E. and B. Ruddick (1981). "Water Circulation and Shelf Waves in the Northern Great Barrier Reef Lagoon." Marine and Freshwater Research 32(5): 721-740.
204	Physiochemical	Sea level	AIMS	Water Circulation and Shelf Waves in the Northern Great Barrier Reef Lagoon	Observational	1979	1979	Currents and sea levels were measured at a number of locations in the Great Barrier Reef (GBR) lagoon from about 10 to 13°S., during the period October-December 1979.	unknown	Wolanski, E. and B. Ruddick (1981). "Water Circulation and Shelf Waves in the Northern Great Barrier Reef Lagoon." Marine and Freshwater Research 32(5): 721-740.
205	Physiochemical	Currents	AIMS	Tidal Period Upwelling within Raine Island Entrance Great Barrier-Reef	Observational	1981	1982	Temperature and current measurements collected from November 1981 to May 1982 at the head of Raine Island Entrance	unknown	Thomson, R. E. and E. J. Wolanski (1984). "Tidal Period Upwelling within Raine Island Entrance Great Barrier-Reef." Journal of Marine Research 42(4): 787-808.
206	Physiochemical	Water temperature	AIMS	Tidal Period Upwelling within Raine Island Entrance Great Barrier-Reef	Observational	1981	1982	Temperature and current measurements collected from November 1981 to May 1982 at the head of Raine Island Entrance	unknown	Thomson, R. E. and E. J. Wolanski (1984). "Tidal Period Upwelling within Raine Island Entrance Great Barrier-Reef." Journal of Marine Research 42(4): 787-808.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
207	Physiochemical	Salinity	AIMS	River plumes, Coral Reefs and mixing in the Gulf of Papua and the northern Great Barrier Reef	Observational	1979	1982	Oceanographic cruises were completed in the area in November 1981, April-May 1982 and October 1982. Salinity, temperature and silicate concentration were measured from water samples (Mitchell et al., 1982) and, for salinity and temperature, also with a profiler and a thermosalinograph.	unknown	Wolanski, E., G. L. Pickard and D. L. B. Jupp (1984). "River plumes, Coral Reefs and mixing in the Gulf of Papua and the northern Great Barrier Reef." Estuarine, Coastal and Shelf Science 18(3): 291-314.
208	Physiochemical	Water temperature	AIMS	River plumes, Coral Reefs and mixing in the Gulf of Papua and the northern Great Barrier Reef	Observational	1979	1982	Oceanographic cruises were completed in the area in November 1981, April-May 1982 and October 1982. Salinity, temperature and silicate concentration were measured from water samples (Mitchell et al., 1982) and, for salinity and temperature, also with a profiler and a thermosalinograph.	unknown	Wolanski, E., G. L. Pickard and D. L. B. Jupp (1984). "River plumes, Coral Reefs and mixing in the Gulf of Papua and the northern Great Barrier Reef." Estuarine, Coastal and Shelf Science 18(3): 291-314.
209	Physiochemical	Silicate	AIMS	River plumes, Coral Reefs and mixing in the Gulf of Papua and the northern Great Barrier Reef	Observational	1979	1982	Oceanographic cruises were completed in the area in November 1981, April-May 1982 and October 1982. Salinity, temperature and silicate concentration were measured from water samples (Mitchell et al., 1982) and, for salinity and temperature, also with a profiler and a thermosalinograph.	unknown	Wolanski, E., G. L. Pickard and D. L. B. Jupp (1984). "River plumes, Coral Reefs and mixing in the Gulf of Papua and the northern Great Barrier Reef." Estuarine, Coastal and Shelf Science 18(3): 291-314.
210	Physiochemical	Currents	AIMS	Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea	Observational	1992	1992	Oceanographic moorings were maintained over 8 weeks in 1992 in the southeast trade wind season a number of stations in the Fly River mouth. Each mooring comprised one or two vector-averaging current meters.	unknown	Wolanski, E., R. J. Gibbs, S. Spagnol, B. King and G. Burnskill (1998). "Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea." Mangroves and Salt Marshes 2(2): 85-98.
211	Physiochemical	Salinity	AIMS	Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea	Observational	1992	1992	Oceanographic moorings were maintained over 8 weeks in 1992 in the southeast trade wind season a number of stations in the Fly River mouth. Each mooring comprised a Dataflow self-logging salinometer	unknown	Wolanski, E., R. J. Gibbs, S. Spagnol, B. King and G. Burnskill (1998). "Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea." Mangroves and Salt Marshes 2(2): 85-98.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
212	Physiochemical	Turbidity	AIMS	Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea	Observational	1992	1992	Oceanographic moorings were maintained over 8 weeks in 1992 in the southeast trade wind season a number of stations in the Fly River mouth. Each mooring comprised three nephelometers spread from 0.2 to 2.2 m above the bottom.	unknown	Wolanski, E., R. J. Gibbs, S. Spagnol, B. King and G. Burnskill (1998). "Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea." Mangroves and Salt Marshes 2(2): 85-98.
213	Physiochemical	Currents	AIMS	Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea	Observational	1995	1995	Oceanographic moorings were maintained over 8 weeks in 1992 in the southeast trade wind season a number of stations in the Fly River mouth. Each mooring comprised three nephelometers spread from 0.2 to 2.2 m above the bottom.	unknown	Wolanski, E., R. J. Gibbs, S. Spagnol, B. King and G. Burnskill (1998). "Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea." Mangroves and Salt Marshes 2(2): 85-98.
214	Physiochemical	Salinity	AIMS	Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea	Observational	1995	1995	Oceanographic moorings were maintained over 8 weeks in 1992 in the southeast trade wind season a number of stations in the Fly River mouth. Each mooring comprised three nephelometers spread from 0.2 to 2.2 m above the bottom.	unknown	Wolanski, E., R. J. Gibbs, S. Spagnol, B. King and G. Burnskill (1998). "Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea." Mangroves and Salt Marshes 2(2): 85-98.
215	Physiochemical	Turbidity	AIMS	Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea	Observational	1995	1995	Oceanographic moorings were maintained over 8 weeks in 1992 in the southeast trade wind season a number of stations in the Fly River mouth. Each mooring comprised three nephelometers spread from 0.2 to 2.2 m above the bottom.	unknown	Wolanski, E., R. J. Gibbs, S. Spagnol, B. King and G. Burnskill (1998). "Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea." Mangroves and Salt Marshes 2(2): 85-98.
216	Physiochemical	Water depth	AIMS	Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea	Observational	1995	1995	Oceanographic moorings were maintained over 8 weeks in 1992 in the southeast trade wind season a number of stations in the Fly River mouth. Each mooring comprised three nephelometers spread from 0.2 to 2.2 m above the bottom.	unknown	Wolanski, E., R. J. Gibbs, S. Spagnol, B. King and G. Burnskill (1998). "Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea." Mangroves and Salt Marshes 2(2): 85-98.
217	Physiochemical	Water depth	AIMS	Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea	Observational	1992	1992	Oceanographic moorings were maintained over 8 weeks in 1992 in the southeast trade wind season a number of stations in the Fly River mouth. Each mooring comprised three nephelometers spread from 0.2 to 2.2 m above the bottom.	unknown	Wolanski, E., R. J. Gibbs, S. Spagnol, B. King and G. Burnskill (1998). "Inorganic sediment budget in the mangrove-fringed Fly River Delta, Papua New Guinea." Mangroves and Salt Marshes 2(2): 85-98.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
218	Physiochemical	Salinity	AIMS	Patchiness in the Fly River plume in Torres Strait	Observational	1994	1995	Four oceanographic cruises were completed, each about 12 days long, in August 1994, September 1994, January–February 1995 and February-March 1995. On each mooring a vector-averaging current meter, three optical-fibre backscattering nephelometers and one Dataflow salinometer were deployed.	unknown	Wolanski, E., S. Spagnol, B. King and T. Ayukai (1999). "Patchiness in the Fly River plume in Torres Strait." Journal of Marine Systems 18(4): 369-381.
219	Physiochemical	Currents	AIMS	Patchiness in the Fly River plume in Torres Strait	Observational	1994	1995	Four oceanographic cruises were completed, each about 12 days long, in August 1994, September 1994, January–February 1995 and February-March 1995. On each mooring a vector-averaging current meter, three optical-fibre backscattering nephelometers and one Dataflow salinometer were deployed.	unknown	Wolanski, E., S. Spagnol, B. King and T. Ayukai (1999). "Patchiness in the Fly River plume in Torres Strait." Journal of Marine Systems 18(4): 369-381.
220	Physiochemical	Turbidity	AIMS	Patchiness in the Fly River plume in Torres Strait	Observational	1994	1995	Four oceanographic cruises were completed, each about 12 days long, in August 1994, September 1994, January–February 1995 and February-March 1995. On each mooring a vector-averaging current meter, three optical-fibre backscattering nephelometers and one Dataflow salinometer were deployed.	unknown	Wolanski, E., S. Spagnol, B. King and T. Ayukai (1999). "Patchiness in the Fly River plume in Torres Strait." Journal of Marine Systems 18(4): 369-381.
221	Physiochemical	Sea level	AIMS	Patchiness in the Fly River plume in Torres Strait	Observational	1994	1995	Four oceanographic cruises were completed, each about 12 days long, in August 1994, September 1994, January–February 1995 and February-March 1995. On each mooring a vector-averaging current meter, three optical-fibre backscattering nephelometers and one Dataflow salinometer were deployed.	unknown	Wolanski, E., S. Spagnol, B. King and T. Ayukai (1999). "Patchiness in the Fly River plume in Torres Strait." Journal of Marine Systems 18(4): 369-381.
222	Physiochemical	Water temperature	AIMS	Patchiness in the Fly River plume in Torres Strait	Observational	1994	1995	Four oceanographic cruises were completed, each about 12 days long, in August 1994, September 1994, January–February 1995 and February-March 1995. On each mooring a vector-averaging current meter, three optical-fibre backscattering nephelometers and one Dataflow salinometer were deployed.	unknown	Wolanski, E., S. Spagnol, B. King and T. Ayukai (1999). "Patchiness in the Fly River plume in Torres Strait." Journal of Marine Systems 18(4): 369-381.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
223	Habitat	*Coral reefs*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2019	Torres Strait		Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
224	Habitat	*Seagrass*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2020			Pitcher, C. R., T. D. Skewes, D. M. Dennis and J. H. Prescott (1992). "Distribution of Seagrasses, Substratum Types and Epibenthic Macrobiota in Torres Strait, with Notes on Pearl Oyster Abundance." Australian Journal of Marine and Freshwater Research 43(2): 409-419.
225	Physiochemical	Alkalinity	IMOS	IMOS ARGOS Profile	Modelled	1990	2020		Free download	https://portal.aodn.org.au/search
226	Physiochemical	Nutrient	IMOS	IMOS ARGOS Profile	Modelled	1990	2020		Free download	https://portal.aodn.org.au/search
227	Physiochemical	Oxygen	IMOS	IMOS ARGOS Profile	Modelled	1990	2020		Free download	https://portal.aodn.org.au/search
228	Physiochemical	Salinity	IMOS	IMOS ARGOS Profile	Modelled	1990	2020		Free download	https://portal.aodn.org.au/search
229	Physiochemical	Temperature	IMOS	IMOS ARGOS Profile	Modelled	1990	2020		Free download	https://portal.aodn.org.au/search
230	Physiochemical	Water Pressure	IMOS	IMOS ARGOS Profile	Modelled	1990	2020		Free download	https://portal.aodn.org.au/search
231	Physiochemical	Acoustics	IMOS	IMOS - Australian National Mooring Network (ANMN) Facility - Current velocity time-series	Modelled	2007	2020		Free download	https://portal.aodn.org.au/search
232	Physiochemical	Currents	IMOS	IMOS - Australian National Mooring Network (ANMN) Facility - Current velocity time-series	Modelled	2007	2020		Free download	https://portal.aodn.org.au/search
233	Physiochemical	Water Pressure	IMOS	IMOS - Australian National Mooring Network (ANMN)	Modelled	2007	2020		Free download	https://portal.aodn.org.au/search

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
				Facility - Current velocity time-series						
234	Ecological	Phytoplankton	IMOS	IMOS - AusCPR: Phytoplankton Abundance	Observational	2008	2020	Vessel	Free download	https://portal.aodn.org.au/search
235	Physiochemical	Sea Surface Temperature	IMOS	IMOS - SRS - SST - L3S - Single Sensor - 6 day - day and night time - Australia	Modelled	2002	2020		Free download	https://portal.aodn.org.au/search
236	Physiochemical	Chlorophyl a	IMOS	IMOS - SRS - MODIS - 01 day - Chlorophyll-a concentration (OC3 model)	Modelled	2002	2020		Free download	https://portal.aodn.org.au/search
237	Physiochemical	Alkalinity	IMOS	Ocean acidification historical reconstruction	Modelled	1870	2013		Free download	https://portal.aodn.org.au/search
238	Physiochemical	Salinity	IMOS	Ocean acidification historical reconstruction	Modelled	1870	2013		Free download	https://portal.aodn.org.au/search
239	Physiochemical	Carbon	IMOS	Ocean acidification historical reconstruction	Modelled	1870	2013		Free download	https://portal.aodn.org.au/search
240	Physiochemical	Sea Surface Temperature	IMOS	Ocean acidification historical reconstruction	Modelled	1870	2013		Free download	https://portal.aodn.org.au/search
241	Physiochemical	Currents	IMOS	IMOS - OceanCurrent - Gridded sea level anomaly - Near real time	Modelled	2011	2020		Free download	https://portal.aodn.org.au/search
242	Physiochemical	Sea Surface Height	IMOS	IMOS - OceanCurrent - Gridded sea level anomaly - Near real time	Modelled	2011	2020		Free download	https://portal.aodn.org.au/search
243	Physiochemical	Sea Surface Temperature	IMOS	SST Atlas of Australian Regional Seas (SSTAARS) - Daily climatology fit	Modelled	1992	2016		Free download	https://portal.aodn.org.au/search
244	Physiochemical	Sea Surface Temperature	IMOS	IMOS - SRS - SST - L3S - Single Sensor - 1 day - night time - Australia	Modelled	1992	2020		Free download	https://portal.aodn.org.au/search

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
245	Ecological	Phytoplankton	IMOS	The Australian Phytoplankton Database (1844 - ongoing) - abundance and biovolume	Modelled	1844	2020		Free download	https://portal.aodn.org.au/search
246	Physiochemical	Chlorophyl a	IMOS	IMOS - SRS - MODIS - 01 day - Net Primary Productivity (OC3 model and Eppley-VGPM algorithm)	Modelled	2002	2020		Free download	https://portal.aodn.org.au/search
247	Physiochemical	Density	IMOS	CARS 2009 - CSIRO Atlas of Regional Seas - Australian weekly	Modelled	1985	2009		Free download	https://portal.aodn.org.au/search
248	Physiochemical	Nutrient	IMOS	CARS 2009 - CSIRO Atlas of Regional Seas - Australian weekly	Modelled	1985	2009		Free download	https://portal.aodn.org.au/search
249	Physiochemical	Oxygen	IMOS	CARS 2009 - CSIRO Atlas of Regional Seas - Australian weekly	Modelled	1985	2009		Free download	https://portal.aodn.org.au/search
250	Physiochemical	Salinity	IMOS	CARS 2009 - CSIRO Atlas of Regional Seas - Australian weekly	Modelled	1985	2009		Free download	https://portal.aodn.org.au/search
251	Physiochemical	Sea Surface Temperature	IMOS	CARS 2009 - CSIRO Atlas of Regional Seas - Australian weekly	Modelled	1985	2009		Free download	https://portal.aodn.org.au/search
252	Physiochemical	Air Pressure	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - delayed mode data	Observational	2008	2020	Vessels	Free download	https://portal.aodn.org.au/search
253	Physiochemical	Carbon	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - delayed mode data	Observational	2008	2020	Vessels	Free download	https://portal.aodn.org.au/search
254	Physiochemical	Salinity	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - delayed mode data	Observational	2008	2020	Vessels	Free download	https://portal.aodn.org.au/search

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
255	Physiochemical	Sea Surface Temperature	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - delayed mode data	Observational	2008	2020	Vessels	Free download	https://portal.aodn.org.au/search
256	Physiochemical	Wind	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - delayed mode data	Observational	2008	2020	Vessels	Free download	https://portal.aodn.org.au/search
257	Physiochemical	Sea Surface Temperature	IMOS	IMOS - SRS - SST - L3S - Single Sensor - 1 month - day and night time - Australia	Modelled	1992	2020	Satellite	Free download	https://portal.aodn.org.au/search
258	Physiochemical	Chlorophyl a	IMOS	IMOS - SRS - MODIS - 01 day - Chlorophyll-a concentration (GSM model)	Modelled	2002	2020		Free download	https://portal.aodn.org.au/search
259	Physiochemical	Wind	IMOS	IMOS - SRS Surface Waves Sub-Facility - scatterometer wind	Modelled	1992	2020		Free download	https://portal.aodn.org.au/search
260	Physiochemical	Sea Surface Temperature	IMOS	AIMS Sea Water Temperature Observing System (AIMS Temperature Logger Program)	Modelled	1991	2020		Free download	https://portal.aodn.org.au/search
261	Physiochemical	Sea Surface Temperature	IMOS	MARVL3 - Australian shelf temperature data atlas	Modelled	1994	2015		Free download	https://portal.aodn.org.au/search
262	Physiochemical	Air Pressure	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - Near real-time raw data	Observational	2017	2020	Vessel	Free download	https://portal.aodn.org.au/search
263	Physiochemical	Carbon	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - Near real-time raw data	Observational	2017	2020	Vessel	Free download	https://portal.aodn.org.au/search
264	Physiochemical	Salinity	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group -	Observational	2017	2020	Vessel	Free download	https://portal.aodn.org.au/search

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
				Near real-time raw data						
265	Physiochemical	Sea Surface Temperature	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - Near real-time raw data	Observational	2017	2020	Vessel	Free download	https://portal.aodn.org.au/search
266	Physiochemical	Wind	IMOS	IMOS - SOOP Underway CO2 Measurements Research Group - Near real-time raw data	Observational	2017	2020	Vessel	Free download	https://portal.aodn.org.au/search
267	Physiochemical	Air Pressure	IMOS	Northern Australia Automated Marine Weather and Oceanographic Stations	Observational	1980	2020	Automated weather and oceanographic stations	Free download	https://portal.aodn.org.au/search
268	Physiochemical	Air temperature	IMOS	Northern Australia Automated Marine Weather and Oceanographic Stations	Observational	1980	2020	Automated weather and oceanographic stations	Free download	https://portal.aodn.org.au/search
269	Physiochemical	Humidity	IMOS	Northern Australia Automated Marine Weather and Oceanographic Stations	Observational	1980	2020	Automated weather and oceanographic stations	Free download	https://portal.aodn.org.au/search
270	Physiochemical	Optical Properties	IMOS	Northern Australia Automated Marine Weather and Oceanographic Stations	Observational	1980	2020	Automated weather and oceanographic stations	Free download	https://portal.aodn.org.au/search
271	Physiochemical	Precipitation	IMOS	Northern Australia Automated Marine Weather and Oceanographic Stations	Observational	1980	2020	Automated weather and oceanographic stations	Free download	https://portal.aodn.org.au/search
272	Physiochemical	Evaporation	IMOS	Northern Australia Automated Marine Weather and Oceanographic Stations	Observational	1980	2020	Automated weather and oceanographic stations	Free download	https://portal.aodn.org.au/search

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
273	Physiochemical	Sea Surface Temperature	IMOS	Northern Australia Automated Marine Weather and Oceanographic Stations	Observational	1980	2020	Automated weather and oceanographic stations	Free download	https://portal.aodn.org.au/search
274	Physiochemical	Wind	IMOS	Northern Australia Automated Marine Weather and Oceanographic Stations	Observational	1980	2020	Automated weather and oceanographic stations	Free download	https://portal.aodn.org.au/search
275	Physiochemical	Salinity	IMOS	Royal Australian Navy (RAN) - CTD profiles	Observational	2004	2016	Vessel	Free download	https://portal.aodn.org.au/search
276	Physiochemical	Water temperature	IMOS	Royal Australian Navy (RAN) - CTD profiles	Observational	2004	2016	Vessel	Free download	https://portal.aodn.org.au/search
277	Physiochemical	Water Pressure	IMOS	Royal Australian Navy (RAN) - CTD profiles	Observational	2004	2016	Vessel	Free download	https://portal.aodn.org.au/search
278	Physiochemical	Wave	IMOS	IMOS - SRS Surface Waves Sub-Facility - SAR wave - Near real-time data	Modelled	2019	2020	Satellite	Free download	https://portal.aodn.org.au/search
279	Physiochemical	Pigment	IMOS	The Australian Chlorophyll a Database (1965 - 2017)	Modelled	1965	2017		Free download	https://portal.aodn.org.au/search
280	Physiochemical	Salinity	IMOS	MARVL3 - Australian shelf salinity data atlas	Modelled	1994	2015		Free download	https://portal.aodn.org.au/search
281	Physiochemical	Chlorophyl a	IMOS	Marine Plastic Pollution in Waters around Australia	Modelled	2013	2013		Free download	https://portal.aodn.org.au/search
282	Physiochemical	Salinity	IMOS	Marine Plastic Pollution in Waters around Australia	Modelled	2013	2013		Free download	https://portal.aodn.org.au/search
283	Physiochemical	Sea Surface Temperature	IMOS	Marine Plastic Pollution in Waters around Australia	Modelled	2013	2013		Free download	https://portal.aodn.org.au/search
284	Physiochemical	Turbidity	IMOS	Marine Plastic Pollution in Waters around Australia	Modelled	2013	2013		Free download	https://portal.aodn.org.au/search
285	Ecological	Ocean Biota	IMOS	Redmap - Sightings of range shifting marine species	Observational	2010	2020		Free download	https://portal.aodn.org.au/search

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
286	Ecological	Ocean Biota	IMOS	Seamap Australia - a national seafloor habitat classification scheme	Observational	1966	2017		Free download	https://portal.aodn.org.au/search
287	Habitat	Seagrass	IMOS	Seagrass Presence Absence Australia (ACEAS)	Modelled	1983	2012	Presence / Absence	Free download	https://portal.aodn.org.au/search
288	Habitat	Seagrass	IMOS	Torres Strait Seagrass Mapping Consolidation	Modelled	1983	2012		Free download	https://portal.aodn.org.au/search
289	Fisheries	Tropical Rock Lobster	AFMA	Torres Strait Tropical Rock Lobster Fishery Daily Fishing Log (transferrable vessel holder; TVH)	Observational	1994	2019	catch and effort data to be recorded for individual fishing operations related to each vessel tender	on request to AFMA	Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
290	Fisheries	Tropical Rock Lobster	AFMA	TIB Docket-Book Data	Observational	2004	2017	used in the TIB sector of the Torres Strait rock lobster fishery to record the catch sold by fishers (known as sellers on the Docket-Book) at the end of a fishing trip. It was replaced on 1 December 2017 by the mandatory Torres Strait Catch Disposal Record.	on request to AFMA	Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
291	Fisheries	Tropical Rock Lobster	AFMA	Torres Strait Catch Disposal Record	Observational	2017	2019	require only aggregate catch and effort data to be recorded at the end of each trip.	on request to AFMA	Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
292	Habitat	*Seagrass*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2019	Torres Strait		Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
293	Physiochemical	*Salinity*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2019	Torres Strait		Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
294	Physiochemical	*Visibility*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2019	CSIRO has been engaged, for the past 30 years, by AFMA to undertake annual diving surveys to determine the relative abundance of Tropical Rock Lobsters (TRL) (Panulirus ornatus). Divers complete a census of lobster along transects at pre-determined sampling sites, with a subset of lobster collected for additional measurements. Data collected: The number and age-class of lobsters observed, but not collected; The number of lobsters collected per age-class; The size (tail width in mm), sex and moult stage of the collected lobsters	Contact CSIRO	Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
295	Physiochemical	*Water depth*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2019	CSIRO has been engaged, for the past 30 years, by AFMA to undertake annual diving surveys to determine the relative abundance of Tropical Rock Lobsters (TRL) (Panulirus ornatus). Divers complete a census of lobster along transects at pre-determined sampling sites, with a subset of lobster collected for additional measurements. Data collected: The number and age-class of lobsters observed, but not collected; The number of lobsters collected per age-class; The size (tail width in mm), sex and moult stage of the collected lobsters	Contact CSIRO	Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
296	Physiochemical	*Water temperature*	CSIRO	Torres Strait Tropical Rock Lobster Mid- and Pre-season surveys and commercial catch samples	Observational	1989	2019	Torres Strait		Plagányi, É., M. Tonks, N. Murphy, R. Campbell, R. Deng, S. Edgar, K. Salee and J. Upston (2020). Torres Strait Tropical Rock Lobster (TRL) Milestone Report 2020 on fishery surveys, CPUE, stock assessment and harvest strategy: AFMA Project R2019/0825 - Draft Final Report 2020. Cleveland: 183.
297	Health	*Diseases*	Centre for Tropical Environmental and Sustainability Studies	Detecting Emerging Infectious Diseases in the Torres Strait: a review of mosquito-borne disease studies	Modelled and Observational	1995	2011	Review on mosquitoe borne diseases with insights into risks of dispersal from PNG into Australia from other organisms	Not known	Laurance, S. G. W., D. Meyer-Steiger and S. Ritchie (2014). Detecting Emerging Infectious Diseases in the Torres Strait: a review of mosquito-borne disease studies. Report to the National Environmental Research Program. Cairns: 17.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
298	Physiochemical	rainfall	Queensland Government	Queensland Future Climate	Modelled	2030	2050	downscaled models from CMIP5 from RCP8.5 and 4.5 for a range of different metrics: queensland futureclimatedashboard. Website: Resolution is 10km x 10km grid regionalised at council scale. But also time series base on information on grid-based scale for TERN. Products have been developed to provide information for the land (not water), but they have capability to link with ocean information. Differs from climate change in Australia because the areas of interest are based on council areas so better regionalised outputs. SLR and SST are expected to be developed in the future and Ralph and Jacqui are keen to collaborate on this. Problem is time commitment and availability to do this. By late November another person from the group will be back from leave and can provide better information on this. Working with this group will have the advantage of using already made products with a better resolution than Climate in Australia website. Need to consider the need of a dedicated data person to extract downscaled model outputs if not available in the portal.	none: data can be accessed via login on website	https://www.longpaddock.qld.gov.au/qld-future-climate/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
299	Physiochemical	evaporation	Queensland Government	Queensland Future Climate	Modelled	2030	2050	downscaled models from CMIP5 from RCP8.5 and 4.5 for a range of different metrics: queensland futureclimatedashboard. Website: Resolution is 10km x 10km grid regionalised at council scale. But also time series base on information on grid-based scale for TERN. Products have been developed to provide information for the land (not water), but they have capability to link with ocean information. Differs from climate change in Australia because the areas of interest are based on council areas so better regionalised outputs. SLR and SST are expected to be developed in the future and Ralph and Jacqui are keen to collaborate on this. Problem is time commitment and availability to do this. By late November another person from the group will be back from leave and can provide better information on this. Working with this group will have the advantage of using already made products with a better resolution than Climate in Australia website. Need to consider the need of a dedicated data person to extract downscaled model outputs if not available in the portal.	none: data can be accessed via login on website	https://www.longpaddock.qld.gov.au/qld-future-climate/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
300	Physiochemical	temperature	Queensland Government	Queensland Future Climate	Modelled	2030	2050	downscaled models from CMIP5 from RCP8.5 and 4.5 for a range of different metrics: queensland futureclimatedashboard. Website: Resolution is 10km x 10km grid regionalised at council scale. But also time series base on information on grid-based scale for TERN. Products have been developed to provide information for the land (not water), but they have capability to link with ocean information. Differs from climate change in Australia because the areas of interest are based on council areas so better regionalised outputs. SLR and SST are expected to be developed in the future and Ralph and Jacqui are keen to collaborate on this. Problem is time commitment and availability to do this. By late November another person from the group will be back from leave and can provide better information on this. Working with this group will have the advantage of using already made products with a better resolution than Climate in Australia website. Need to consider the need of a dedicated data person to extract downscaled model outputs if not available in the portal.	none: data can be accessed via login on website	https://www.longpaddock.qld.gov.au/qld-future-climate/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
301	Physiochemica l	solar radiation	Queensland Government	Queensland Future Climate	Modelled	2030	2050	downscaled models from CMIP5 from RCP8.5 and 4.5 for a range of different metrics: queensland futureclimatedashboard. Website: Resolution is 10km x 10km grid regionalised at council scale. But also time series base on information on grid-based scale for TERN. Products have been developed to provide information for the land (not water), but they have capability to link with ocean information. Differs from climate change in Australia because the areas of interest are based on council areas so better regionalised outputs. SLR and SST are expected to be developed in the future and Ralph and Jacqui are keen to collaborate on this. Problem is time commitment and availability to do this. By late November another person from the group will be back from leave and can provide better information on this. Working with this group will have the advantage of using already made products with a better resolution than Climate in Australia website. Need to consider the need of a dedicated data person to extract downscaled model outputs if not available in the portal.	none: data can be accessed via login on website	https://www.longpaddock.qld.gov.au/qld-future-climate/

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
302	Physiochemical	vapour pressure deficit	Queensland Government	Queensland Future Climate	Modelled	2030	2050	downscaled models from CMIP5 from RCP8.5 and 4.5 for a range of different metrics: queensland futureclimatedashboard. Website: Resolution is 10km x 10km grid regionalised at council scale. But also time series base on information on grid-based scale for TERN. Products have been developed to provide information for the land (not water), but they have capability to link with ocean information. Differs from climate change in Australia because the areas of interest are based on council areas so better regionalised outputs. SLR and SST are expected to be developed in the future and Ralph and Jacqui are keen to collaborate on this. Problem is time commitment and availability to do this. By late November another person from the group will be back from leave and can provide better information on this. Working with this group will have the advantage of using already made products with a better resolution than Climate in Australia website. Need to consider the need of a dedicated data person to extract downscaled model outputs if not available in the portal.	none: data can be accessed via login on website	https://www.longpaddock.qld.gov.au/qld-future-climate/

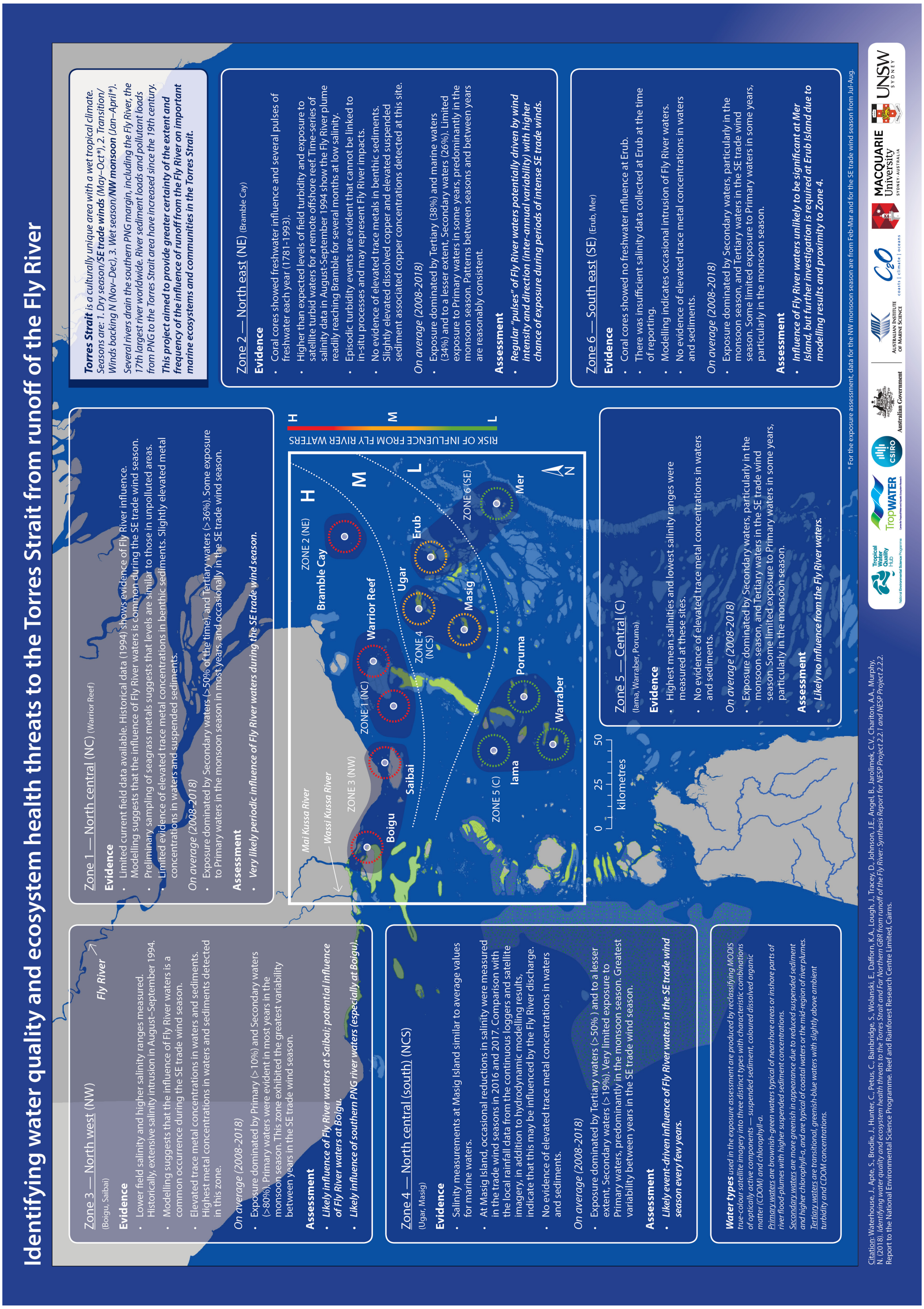
#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
303	Physiochemical	Trace metals	NESP	Identifying water quality and ecosystem health threats to the Torres Strait from runoff arising from mine-derived pollution of the Fly River	Observational	2018	2018	habitats located in the northeast corner of the Torres Strait Protection Zone, north of Masig Island and northwest as far as Boigu Island, are located in a higher potential risk area of exposure to brackish and turbid waters from or derived from the Fly River, as well as from/or derived from local PNG river discharges. While this movement of water from the Fly River is a historic pattern, the estimated 40% increase in sediment discharge associated with the operation of Ok Tedi mine is likely to have changed the characteristics of sediment and contaminant concentrations in this region. Despite the increased load, water and sediment quality is generally excellent across the region. Increased metal concentrations in waters and sediments were only observed around Boigu and Saibai islands.	contact authors	Waterhouse, J., et al. (2018). Identifying water quality and ecosystem health threats to the Torres Strait from runoff arising from mine-derived pollution of the Fly River: Synthesis Report for NESP Project 2.2.1 and NESP Project 2.2.2. Report to the National Environmental Science Programme. Cairns: 25p.
304	Physiochemical	Turbidity	NESP	Identifying water quality and ecosystem health threats to the Torres Strait from runoff arising from mine-derived pollution of the Fly River	Observational	2018	2018	habitats located in the northeast corner of the Torres Strait Protection Zone, north of Masig Island and northwest as far as Boigu Island, are located in a higher potential risk area of exposure to brackish and turbid waters from or derived from the Fly River, as well as from/or derived from local PNG river discharges. While this movement of water from the Fly River is a historic pattern, the estimated 40% increase in sediment discharge associated with the operation of Ok Tedi mine is likely to have changed the characteristics of sediment and contaminant concentrations in this region. Despite the increased load, water and sediment quality is generally excellent across the region. Increased metal concentrations in waters and sediments were only observed around Boigu and Saibai islands.	contact authors	Waterhouse, J., et al. (2018). Identifying water quality and ecosystem health threats to the Torres Strait from runoff arising from mine-derived pollution of the Fly River: Synthesis Report for NESP Project 2.2.1 and NESP Project 2.2.2. Report to the National Environmental Science Programme. Cairns: 25p.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
305	Physiochemical	Mean Surface Temperature	CSIRO	Downscaled Climate Projections for the Torres Strait Region: 8 km results for 2055 and 2090	Modelled	2055	2090	Three global models (GFDL-CM2.1, UKMO-HadCM3 and ECHAM5 60 km CCAM global simulations) were selected for further downscaling to 8 km resolution. Of the six host models, these show a low, middle and high amount of global warming into the future, respectively. Due to the very high demand for computer resources when downscaling at 8 km resolution, the temporal and spatial extent of the simulations was limited. Only the 1980-1999, 2046-2065 and 2080-2099 time periods were simulated for seven 1000 km x 1000 km regions, including Papua New Guinea, East Timor, Fiji, Solomon Islands, Vanuatu, Samoa and the Federated States of Micronesia. The results from the PNG simulation were used in this study because they also cover the Torres Strait region.	Contact Authors	Katzfey, J. and W. Rochester (2012). Downscaled Climate Projections for the Torres Strait Region: 8 km results for 2055 and 2090. Thursday Island.
306	Physiochemical	Rainfall	CSIRO	Downscaled Climate Projections for the Torres Strait Region: 8 km results for 2055 and 2091	Modelled	2055	2090	Three global models (GFDL-CM2.1, UKMO-HadCM3 and ECHAM5 60 km CCAM global simulations) were selected for further downscaling to 8 km resolution. Of the six host models, these show a low, middle and high amount of global warming into the future, respectively. Due to the very high demand for computer resources when downscaling at 8 km resolution, the temporal and spatial extent of the simulations was limited. Only the 1980-1999, 2046-2065 and 2080-2099 time periods were simulated for seven 1000 km x 1000 km regions, including Papua New Guinea, East Timor, Fiji, Solomon Islands, Vanuatu, Samoa and the Federated States of Micronesia. The results from the PNG simulation were used in this study because they also cover the Torres Strait region.	Contact Authors	Katzfey, J. and W. Rochester (2012). Downscaled Climate Projections for the Torres Strait Region: 8 km results for 2055 and 2090. Thursday Island.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
307	Physiochemical	Relative humidity	CSIRO	Downscaled Climate Projections for the Torres Strait Region: 8 km results for 2055 and 2092	Modelled	2055	2090	Three global models (GFDL-CM2.1, UKMO-HadCM3 and ECHAM5 60 km CCAM global simulations) were selected for further downscaling to 8 km resolution. Of the six host models, these show a low, middle and high amount of global warming into the future, respectively. Due to the very high demand for computer resources when downscaling at 8 km resolution, the temporal and spatial extent of the simulations was limited. Only the 1980-1999, 2046-2065 and 2080-2099 time periods were simulated for seven 1000 km x 1000 km regions, including Papua New Guinea, East Timor, Fiji, Solomon Islands, Vanuatu, Samoa and the Federated States of Micronesia. The results from the PNG simulation were used in this study because they also cover the Torres Strait region.	Contact Authors	Katzfey, J. and W. Rochester (2012). Downscaled Climate Projections for the Torres Strait Region: 8 km results for 2055 and 2090. Thursday Island.
308	Physiochemical	Wind Speed	CSIRO	Downscaled Climate Projections for the Torres Strait Region: 8 km results for 2055 and 2093	Modelled	2055	2090	Three global models (GFDL-CM2.1, UKMO-HadCM3 and ECHAM5 60 km CCAM global simulations) were selected for further downscaling to 8 km resolution. Of the six host models, these show a low, middle and high amount of global warming into the future, respectively. Due to the very high demand for computer resources when downscaling at 8 km resolution, the temporal and spatial extent of the simulations was limited. Only the 1980-1999, 2046-2065 and 2080-2099 time periods were simulated for seven 1000 km x 1000 km regions, including Papua New Guinea, East Timor, Fiji, Solomon Islands, Vanuatu, Samoa and the Federated States of Micronesia. The results from the PNG simulation were used in this study because they also cover the Torres Strait region.	Contact Authors	Katzfey, J. and W. Rochester (2012). Downscaled Climate Projections for the Torres Strait Region: 8 km results for 2055 and 2090. Thursday Island.

#	Domain	Parameter / species / habitat	Where is the data	Title	Obervation / Model	Date start	Date end	Metadata (e.g. Scale / Location)	Licence use	Source/ reference
309	Ecological	Growth: Panulirus ornatus	CSIRO	Long-Term Variation of Tropical Rock Lobster Panulirus Ornatus (Decapoda, Palinuridae) Growth in Torres Strait, Australia	Modelled and Observational	1989	2009	In the past two decades, growth rates have fluctuated inter-annually without displaying any distinctive trend. Associated uncertainties are large, suggesting that sampling will need to be intensified in order to detect an effect of climate change	Contact authors	Kienzle, M., et al. (2012). "Long-Term Variation of Tropical Rock Lobster Panulirus Ornatus (Decapoda, Palinuridae) Growth in Torres Strait, Australia." Crustaceana 85(2): 189-204.
310	Ecological	*Growth: Brown tiger prawn*	on paper	Migration and growth of two tropical penaeid shrimps within Torres Strait, northern Australia	Observational	1986	1988		Contact authors	Watson, R. A. and C. T. Turnbull (1993). "Migration and growth of two tropical penaeid shrimps within Torres Strait, northern Australia." Fisheries Research 17(3): 353-368.
311	Ecological	*Growth: Spanish mackerel*	on paper	Stock assessment of the Torres Strait Spanish mackerel fishery	Modelled and Observational	1988	2003	Stock assessment report that used published growth rates specific for Torres Strait in models.	Contact authors	Begg, G. A., et al. (2006). Stock assessment of the Torres Strait Spanish mackerel fishery. CRC Reef Research Centre Technical Report No. 66. Townsville.
312	Ecological	Reproduction: sea cucumbers	On Book	Torres Strait Beche-de-mer (Sea cucumber) species ID guide	Observational			Data on age at maturity, spawning season for species found in Torres Strait	Contact authors	Murphy, N., et al. (2019). Torres Strait Beche-de-mer (Sea cucumber) species ID guide. Brisbane, Commonwealth Scientific and Industrial Research Organisation
313	Ecological	Reproduction: Panulirus ornatus	on paper	Reproductive cues in Panulirus ornatus	Observational	2002	2003	Experimental work which reviews Panulirus ornatus reproductive behaviour for application in aquaculture	Contact authors	Sachlikidis, N. G., et al. (2005). "Reproductive cues in Panulirus ornatus." New Zealand Journal of Marine and Freshwater Research 39(2): 305-310.
314	Ecological	Finfish - Spanish Mackerel	on paper	Stock assessment of the Torres Strait Spanish mackerel fishery	Modelled and Observational	2000	2004	Summary of data for growth, sex ratios, maturity, reproduction, and age structure	Contact authors	Begg, G. A., et al. (2006). Stock assessment of the Torres Strait Spanish mackerel fishery. CRC Reef Research Centre Technical Report No. 66. Townsville.

Appendix B Water quality and ecosystem health threats to the Torres Strait from runoff of the Fly River (Waterhouse et al. 2018)



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